GPS Civilian Economic Value to the U.S., Interim Report

Irv Leveson

Prepared for the National Executive Committee for Space-Based Positioning, Navigation and Timing

ASRC Federal Research and Technology Solutions, Inc.

version 3, revised August 31, 2015

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Preface

It is widely accepted in the GPS user community that GPS capabilities have been incorporated into industries, technologies and sectors of the economy at a breadth that was wholly unimagined when civilian signal availability was in its infancy. Today the large civilian benefits of GPS are not well-recognized by broader audiences. Moreover, the expansion of applications and associated technologies, along with continuing advances in the GPS system and the evolution of other Global Navigation Satellite Systems (GNSSs) offers the promise of many improvements in existing applications and rewarding new applications and benefits.

Efforts to demonstrate the economic value of the civilian contribution of GPS have been scattered and incomplete. More current and comprehensive information is needed along with analysis and presentation in ways that can have wide appeal. This report is a step toward that goal.

The National Executive Committee for Space-Based Positioning Navigation and Timing (PNT EXCOM) requested a study of GPS economic value and tasked the Commerce Department with responsibility for overseeing the effort. Interest in the value of GPS has increased because the system faces growing policy challenges. Assessing the economic implications of actions such as preventing or disallowing interference, spectrum sharing or reallocation, developing supplementary or backup systems and/or toughening receivers can be informed by value estimates and the data used to derive them. This is not an academic exercise, but while the study is meant to inform policy it is not is a policy analysis.

The effort was conducted under the auspices of the National Coordination Office for Space-Based Positioning, Navigation and Timing (PNT Coordination Office) in cooperation with the National Space-Based Positioning, Navigation and Timing Advisory Board (PNT Board). An inter-agency Economic Advisory Team consisting of two dozen economists in agencies represented on the PNT EXCOM along with several engineers and subject matter experts in federal agencies met monthly to review materials and advise the study. Several agencies contributed valuable information.

This analysis is intended to be the first stage of an effort to more fully estimate and disseminate information about the benefits of GPS and the costs of disruption. The initial focus is on current U.S. economic benefits. Follow-on analyses are intended to extend the assessment of economic benefits, including consideration of future benefits, examine noneconomic benefits such as those to safety-of-life and the environment, assess international benefits and selectively consider the costs of long term signal disruption.

Many people provided valuable guidance and content to the effort. Special thanks go to the PNT Advisory Board and Governor Jim Geringer, liaison from the Board to the study, Jason Kim of the Department of Commerce who oversaw the project, Jim Miller of NASA who is responsible for administration for the PNT Board, and the members of the Economic Advisory Team who devoted considerable time and expertise. Numerous additional people in and out of government provided information and assistance. The contributions of all are greatly appreciated. Responsibility for the substance and findings rests with the author.

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Executive Summary

Context, Tasking and Objectives

Context

Far-reaching changes are taking place in space-based positioning, navigation and timing with development of new signals and satellites, ground support systems, augmentations and complementary technologies. These and previous initiatives are spawning market growth and new production processes and applications and bringing numerous benefits to businesses, governments and consumers. Moreover, GPS provides standards and leadership to other Global Navigation Satellite Systems (GNSSs) and augmentations.[1]

Information on the value of benefits and associated analyses enhance understanding of applications, constituents, markets and returns on investment for effective planning. Moreover, usage of GPS faces potential threats from a variety of sources. Information on the importance of GPS can encourage action.

Of particular concern are:

- Competition for spectrum and associated long term signal interference, along with mitigation costs and their impacts.
- Jamming, spoofing, space weather, cyber-attacks, and other intentional and unintentional temporary sources of interference.
- Vulnerability of infrastructure and application systems.
- Increasing reliance of some users on foreign positioning, navigation and timing (PNT) systems.
- Lack of adequate backup systems.
- Production delays in modernization of GPS to implement new signals and capabilities.
- Budget austerity affecting the pace of modernization and innovation and the size of the constellation.

[1] GNSS, the Global Navigation System of Systems, includes the positioning, navigation and timing systems of other countries that are in various stages of development and operation: the Russian GLONASS system, the soon to be operating European Galileo system, the regional Japanese QZSS system, the Chinese BeiDou system which is regional and will become global, the Indian IRNSS regional system which is in development, and augmentation systems for aviation and other purposes such as the U.S. Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay System (EGNOS).

Assessing the economic implications of actions such as preventing or disallowing interference, spectrum sharing or reallocation, developing supplementary or backup systems and/or toughening receivers can be informed by value estimates and the data used to derive them.

The focus of this study is on estimating the current civilian economic benefits of the Global Positioning System to the United States. Direct economic benefits to commercial sectors, consumers and government are included to the extent data and resources have permitted. Benefits of sectors using GPS to other parts of the economy are not addressed at this stage. Existing estimates are synthesized and/or new estimates made, taking account of market size and adoption of GPS. New data collection and extensive interviewing was not possible.

Advantages over previous efforts include more current information, added coverage of sectors and applications, examination of additional sources and greater attention to communication and documentation. The current study is an initial effort and is not meant to be comprehensive. GPS benefit estimates will be "ballpark" no matter how sophisticated the methodology because of limits to the availability of information, but in many cases information on orders of magnitude is essential in choosing courses of action.

PNT EXCOM Tasking and Study Arrangements

GPS was intended from the beginning to be for both civilian and military use.[2] Open access signals are provided by the U.S. free to all. The National Executive Committee for Space-Based Positioning, Navigation, and Timing (PNT EXCOM), chaired jointly by the Deputy Secretaries of Defense and Transportation with members from nine federal agencies, provides guidance on GPS and related issues. It is supported by working groups and the National Space-Based Positioning, Navigation and Timing Coordination Office (PNT Coordination Office). The PNT EXCOM is advised by the independent National Space-Based Positioning, Navigation and Timing Advisory Board (PNT Board) which is made up of experts from the private sector.

The PNT EXCOM issued the following action item:

> "DOC to lead interagency team in consultation with the National Space-Based PNT Advisory Board to develop a way forward for an updated, authoritative GPS economic benefit assessment."

The purpose is to inform the public, federal decision-makers and critical infrastructure owners/operators of the importance of GPS and the need to protect it from disruption.

[2] "Contrary to some versions of GPS history, from the very beginning, GPS was configured to be a dual-use system. Civilian users were to be given free access to the signal specification and were expected to use the so-called clear acquisition signal for navigation and other purposes." Bradford W. Parkinson and Stephen T. Powers, "The Origins of GPS, and the Pioneers Who Launched the System," *GPS World* (May 2010), p.41 http://gpsworld.com/origins-gps-part-1/

The study was directed to be administered by the U.S. Department of Commerce. To assist in the study, the Department of Commerce set up an inter-agency Economic Advisory Team composed of two dozen economists from agencies represented on the EXCOM along with several engineers and subject matter experts to provide guidance on best practices and lessons learned based on experience evaluating other public goods and information technologies.. The group held monthly meetings to review and comment on study presentations and research notes, contribute information, and suggest resources. Several government agencies contributed content.

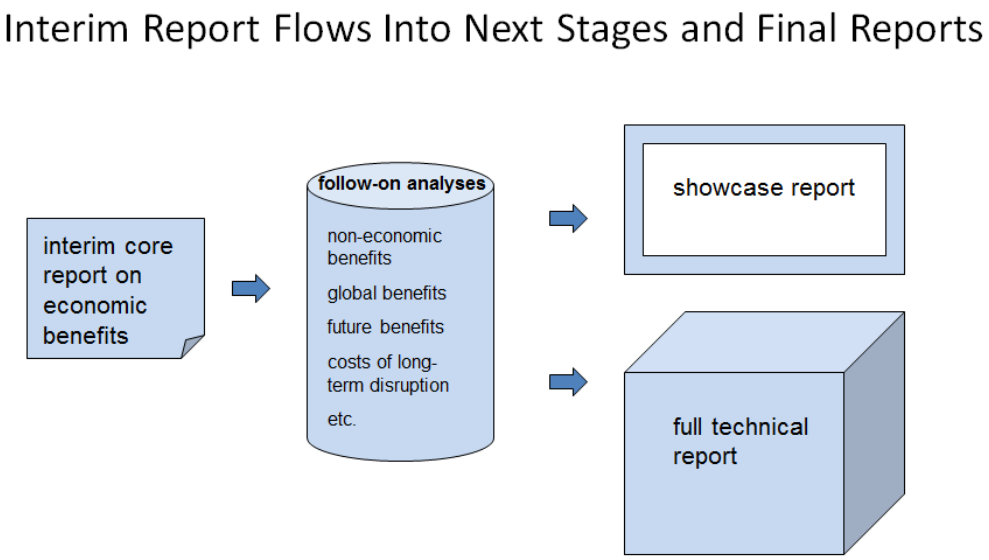
Discussions also have been held with subject matter experts in and out of government. The author has conferred with and briefed the National Space-Based Positioning, Navigation and Timing Advisory Board which maintained a liaison to the study and the Economic Advisory Team.

Objectives

The objectives of this interim report are to provide updated, more complete and methodologically sound estimates of current civilian economic benefits of GPS to the U.S. Current economic benefits are estimated for application sectors comprised largely of those for which the most robust estimates or basis for estimation was available.

This document is intended to serve as a core for subsequent analysis. Follow-on analysis is intended to include further examination of economic benefits both in sectors covered and additional sectors, estimation of values of safety-of-life and other non-economic benefits, international benefits, future benefits under alternative scenarios, and selective estimation of economic costs resulting from long-term denial of GPS. Results of the combined analyses are intended to be presented in a "showcase report" on GPS benefits designed for a broad audience, with benefits elucidated through examples, and a full analytic report documenting sources and methods (Figure S1).

Figure S1



The GPS Value Chain

GPS provides positioning, navigation and timing (PNT) information to all parts of the economy.[3] The system consists of satellites, ground stations which control the satellites, and user equipment – devices with antennas that receive the signals. Signals are enhanced by a variety of techniques and by public and private satellite-based and ground-based systems to increase reliability and precision.[4]

The U.S. Department of Homeland Security (DHS) counts GPS as an enabling technology because of its crucial role in 14 of the 16 industries that are classified as part of the nation's critical infrastructure. GPS timing provides a standard to which other timing systems requiring high precision are calibrated. GPS is especially important in industries that support the rest of the economy and are at the forefront of economic growth. The most notable of these are transportation, communications and the Internet, power and financial services. Hence GPS is referred to here as "enabling the enablers."

The number of GPS applications is large and growing rapidly. Out of these many applications come increases in productivity and savings in costs and time, innovation in production processes, development of new products and markets, facilitation of commerce, increased buyer choice and opportunity, improved safety and environmental progress and advances in science. Civilian innovation contributes to military capabilities as well.

GPS provides like benefits to the rest of the world. It serves as a time and frequency standard and is an example and source of technologies and industrial base for other nations developing their own PNT and related systems. Applications developed in or building on work in the U.S. power a growing volume of global economic activity. U.S. leadership encourages compatibility and interoperability among PNT systems, which has become essential now that other nations are upgrading, developing and expanding their own regional and global systems and augmentations.

Relationships among the GPS system, applications and domestic and global benefits are illustrated in the value chain diagram Figure S2.

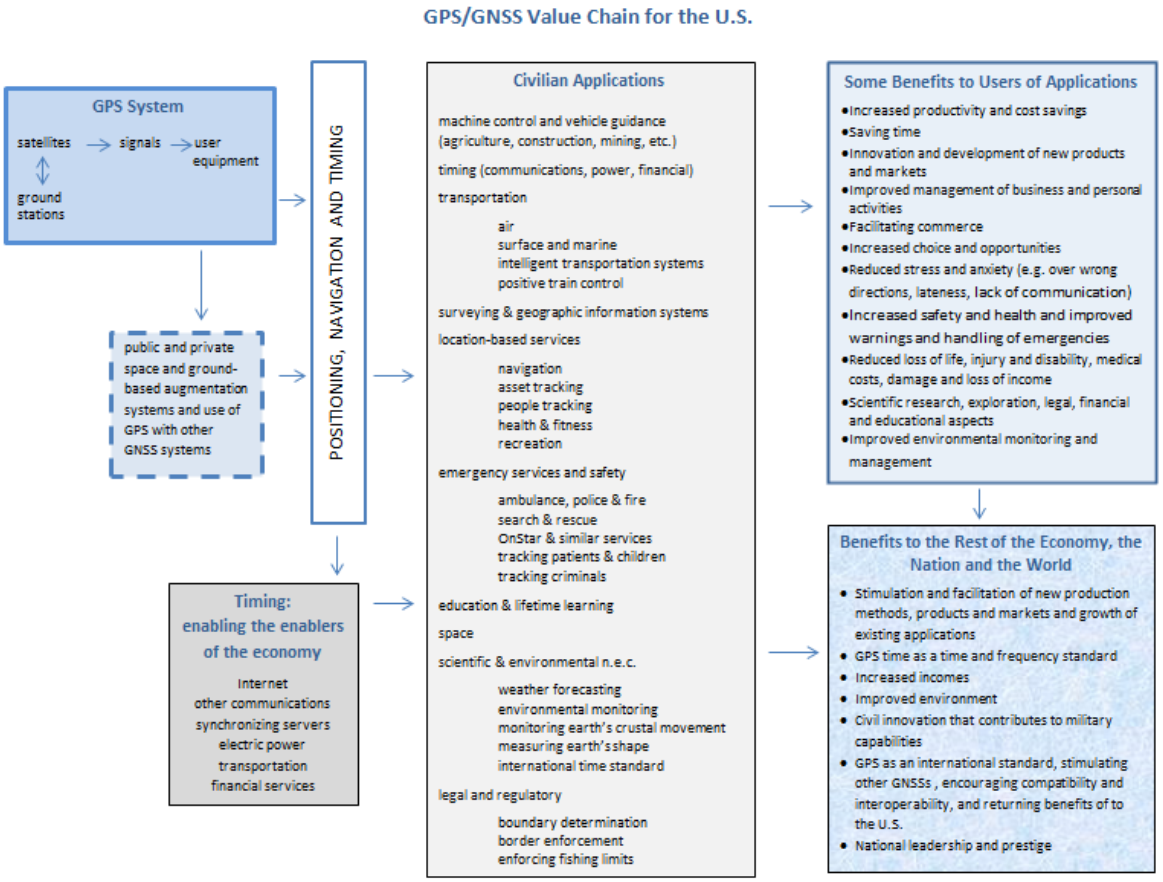
Markets and Applications

The many uses and benefits of GPS-enabled technologies and systems are evident in the contributions of across economic sectors which are described in the report. The unmistakable theme is that GPS is everywhere.

The unmistakable theme is that GPS is everywhere.

[3] Positioning refers to location, navigation to direction and movement, and timing to measurement of time and frequency of timing signals.
[4] For additional information see http://www.gps.gov/systems/gps/

Figure S2



GPS and services that rely on it play critical roles in cell phone communications, the Internet and many Internet applications. The pervasiveness of GPS is illustrated by the following examples:

- The European GNSS Agency known as GSA found in its 2015 market report[5] that 3.6 billion GNSS devices were in use globally in 2014 of which 3.08 billion were smart phones and .26 billion were for road applications. North America had about 450 million devices installed [about 80% U.S.].
- 900 million mobile phones that incorporated GPS were sold globally in 2012.[6]
- The U.S. had 188 million smart phone subscribers and 263 million Internet users in 2013.[7] 20% of U.S. mobile phone users get up-to-the-minute traffic or transit information.[8]

[5] European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

[6] Van Diggelen, Frank, "Who's Your Daddy: Why GPS Will Continue to Dominate Consumer GNSS," *Inside GNSS*, March/April 2014 http://www.insidegnss.com/node/3746

[7] Meeker, Mary, *KPCB Internet Trends 2014* www.kpcb.com/InternetTrends based on several sources.

- The new industry category in the 2012 North American Industrial Classification System: "Internet publishing and broadcasting and web search portals" (NAICS 519130) which includes social media along with location-based and mapping services had revenue of $87 billion and 181,000 employees in 2012.[9]

- Google estimated that its search and advertising tools provided $111 billion in economic activity in 2013.[10] Deloitte estimated that Facebook enabled $104 billion of economic impact and 1.2 million jobs in North America in 2014.[11]

- Google Play and the Apple App Store each had more than 1.2 million apps in 2014, including various aps that utilize GPS location and navigation information.[12]

Measuring Economic Benefits

The concept of benefits for this study is gross economic value. Economic value is the *addition* to the value of the economy from the provision of a good or service or the introduction of a technology. Gross value is value before subtracting the costs of use. The focus is on productivity gains and saving in costs and time.

Benefits are measured by the extent of gains relative to what would have been expected if there had been no GPS

Text Box S1. Scope of Benefit Estimates

- Only economic benefits are included. Health and safety and environmental benefits are to be considered later.
- Benefits include payments for services plus the value to users above their costs.
- Estimates are gross. They are not reduced by the costs of achieving the benefits.
- Contributions of augmentations are included since a quantitative basis for separating them is not available.
- Benefits are compared with alternatives without GPS or an application using it (counterfactuals).
- Estimates are primarily for direct benefits. Impacts on suppliers are included where they involve documented cost savings. Benefits to the rest of the economy are not included.
- Illustrative allowances are made for the contributions of other technologies and systems to the outcomes examined.

[8] U.S. Department of Transportation, *Beyond Traffic: Trends and Choices*, draft, 2015 http://www.dot.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf
[9] U.S. Census Bureau, *2012 Economic Census* U.S. Census Bureau, *2012 Economic Census* http://www.census.gov/econ/census/schedule/whats_been_released.html
[10] Google, *Economic Impact, United States, 2013*, http://www.google.com/economicimpact/
[11] Deloitte, *Facebook's Global Economic Impact*, January 2015 http://www2.deloitte.com/content/dam/Deloitte/uk/Documents/technology-media-telecommunications/deloitte-uk-global-economic-impact-of-facebook.pdf
[12] European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

(counterfactuals). This usually involves comparison between traditional and new technologies or comparisons of current technologies with those in use when they became available. In some cases it is useful to consider ways markets could have evolved to the present without the current technology.

Much of the benefits of GPS come not from the use of GPS alone, but rather from its use with other technologies and systems. Therefore the benefits of these associated systems must be considered for the contribution of GPS to the outcomes to be assessed. Judgments are necessary about the contribution of both other technologies and other GNSSs.

Estimates of the economic value of GPS to the U.S. are derived by building on information on market sizes, adoption of GPS and effects on productivity and cost savings for a range of applications and sectors. While emphasis is placed on the most robust information, benefit estimates are "ball park," no matter how sophisticated the methodology because the data do not exist to support more than that. Nevertheless, it is possible to demonstrate the orders of magnitude of many specific applications as well as an important number of economic benefits in total and to document the widespread nature of the benefits and beneficiaries.

U.S. Civilian Economic Benefits of GPS in 2013

Table S1 summarizes the estimates of economic benefits of GPS to users in the United States. Sectors were chosen based on availability of information to make relatively robust estimates and/or importance of sectors to the economy or policy issues. Methods used were determined based on the nature of available studies and varied among sectors. Only economic benefits are included. Health and safety and environmental benefits are expected to be considered later.

Estimates of benefits are gross. They are not reduced by the costs of achieving the benefits.

Contributions of augmentations are included in the absence of a basis for separating them. Estimates are primarily for direct benefits. Illustrative allowances are made for the contributions of other technologies and systems to the outcomes examined.

The individual estimates are displayed with a letter indicating the degree of confidence in the values.

In deriving the total, the values for two alternative estimates for timing were averaged and two alternative estimates for the category of consumer and other non-fleet vehicle were averaged.

The sum of the benefit estimates ranges from 37.1-$74.5 billion, with a midpoint of $55.8 billion (Table S1). This is about 0.3% of GDP for the aspects measured thus far. If all of the excluded sources of benefits were quantified the benefits would be much larger.

The largest benefits are in the agriculture, surveying and vehicle categories.

Table S1. Preliminary 2013 U.S. GPS Economic Benefit Estimates			
	Application Category	**Range of Benefits** ($billions)	**Mid-range Benefits** ($billions)
A	Precision Agriculture – grain*	10.0-17.7	13.7
A	Construction – earthmoving with machine guidance*	2.2-7.7	5.0
A	Surveying – independent and in sectors	9.8-13.4	11.6
A	Timing – average of eLoran and GEOs estimates	.025-.063	0.044
A	Air Transportation	.119 -.168	0.144
C	Rail Transportation – Positive Train Control	.010-.100	0.055
C	Maritime Transportation – private sector use of nautical charts and related marine information*	.106-.263	0.185
A	Fleet Vehicle Connected Telematics*	7.6-16.3	11.9
B	Consumer and other non-fleet Vehicle – average of estimates based on willingness-to-pay and value of time*	7.3-18.9	13.1
	TOTAL	**37.1-74.5**	**55.7**

A=confident, B=indicative and C=notional.
*Includes benefits from purchase input cost savings.
Note: Numbers may not add to totals due to rounding.

The estimate for consumer and other non-fleet vehicle is $13.1 billion. Combining this with the $11.9 billion for fleet vehicles gives a total vehicle benefit of $25.0 billion.

Government use of GPS is included in construction, surveying, vehicle and timing estimates. Households are in the consumer Location-Based Services (LBS) vehicle category. Inadequate information was available on the size of the overall LBS market and its benefits to make a benefit estimate. The same was true for Geographic Information Systems (GIS). Indirect benefits resulting from cost savings in supplying sectors are included for some categories, as noted in Table S1.

The overall values are judged to be an underestimate of economic benefits because some application categories and portions of other categories are not included. Neither are increases since 2013, which in some applications have been very rapid. Only some indirect economic benefits are counted and induced benefits to the rest of the economy are not included. Moreover, benefits to safety-of life and the environment and international benefits are not addressed at this stage. Possibilities of overestimation are judged to be smaller than the sources of underestimation.

Data and Research Needs

Large gaps exist in estimates of productivity and cost savings for individual sectors and there is no systematic effort at data collection or research on GPS or GNSS benefits. Existing studies often predate major technological advances while use of GNSS is increasing rapidly. More benefit information is needed for aviation and other transportation areas. There is an especially great dearth of information about the extent of GPS timing use and the quantitative benefits of timing applications at the industry level.

More generally, information is required on benefits of applications that is much more detailed with regard to particular combinations of technologies and their frequency of use. Studies are needed that take into account specific functions in which GNSS is used (e.g. plowing, seeding, fertilizing, harvesting), the GNSS and non-GNSS technologies used in each function and site, and the extent of their use and outcomes.

Ongoing research on costs of short and long term signal interference and costs and benefits of alternative measures for supplementation, backup and mitigation is essential because of the potentially high costs interference with GPS signals could impose and the related policy decisions that are to be addressed.

Information on market size, adoption and growth from market research firms, which tends to capture recent developments, is based on greatly varying sources and methods. This results in major gaps and greatly divergent estimates, especially in new areas like Location-Based Services and Geographic Information Systems. Often definitions and descriptions of methods in available documents are insufficient and information is largely proprietary. More complete and current information on adoption of applications may be needed from government where it is not expected to be available from private firms.

The Technology and Policy Environment

An Age of Rapid Technological Change

The evolution of GPS is taking place in and interacting with an environment of rapid technological change. The march of information technology from the mainframe to the PC, laptop, smart phone and tablet ushered in the era of distributed computing amid persistent reductions in cost and size. The power of the Internet has exploded with advances in search, instant communication, interactivity, and other capabilities to produce the phenomena of online social networking and mobile connectivity.

> "The radio, the telephone, the movies that we know, may all be passing fancies and in time may go."
>
> Lyrics from the song: *Our Love Is Here to Stay* by George and Ira Gershwin, 1938

Capabilities such as cable, wireless, the Internet, search, artificial intelligence, big data, cloud computing and security can be viewed as facilitators. Social and mobile are among the more powerful resulting phenomena, spurred by network effects through which benefits increase more rapidly than users and attract even more users. Underneath it all is an ever-widening set of platforms that accommodate these capabilities.

With connectivity ubiquitous, cross-platform applications abound. Use of GPS signals in conjunction with other technologies is transforming navigation, precision agriculture and construction, surveying, location-based services, geographic information systems, shopping, entertainment, health and fitness and intelligent vehicle systems that communicate with their surroundings, to name a few.

The widespread availability of platforms to house or support applications and growing integration with other technologies is accelerating opportunities for GPS and GNSS to provide widespread benefits.

GPS and GNSS Are Changing Rapidly

The Global Positioning System consists of satellites, ground stations that control the satellites and user equipment – devices with antennas to receive and process the signals. Signals are enhanced by a variety of techniques and by public and private satellite based and ground-based systems to increase reliability and precision. Changes taking place in GPS and GNSS include:

- Evolving Satellite Systems and Associated Augmentation Systems.
    - Introduction of the European Galileo system.
    - Upgrading of the Russian GLONASS system.

- China moving from a regional system to the global BeiDou system.
- Regional systems in Japan and India.
- Satellite augmentation systems recently developed or evolving in Europe, Russia, China, Japan and India

Signals

- New GPS L5 and L2C signals and later L1C, and the transition to dual frequency operation away from codeless and semi-codeless techniques of signal enhancement that depend on older U.S. signals.
- Galileo signals compatible with L1C and L5 E6 Commercial Service and a Public Regulated Service.
- Implementation of a Russian GLONASS CDMA signal which will use the same type signal structure as GPS and Galileo.
- Global open service signals from the Chinese Beidou GNSS system.

- Services
  - Increasing scope and more widespread adoption of services.
  - Growth of products and markets and expanding product and process innovation facilitated by added GNSS capabilities.

Increasing integration of technologies and systems and the expanded use of satellite systems from other nations increase the importance of establishing a baseline as before doing so becomes even more difficult.

The Policy Environment

Threats of Signal Interference

Growth in demand has intensified competition for spectrum. The spectrum occupied by GPS is highly desirable for wireless services. GPS signals are low power as they are received from space, which makes them vulnerable to interference.

Concerns include high power signals in adjacent radio bands, sharing spectrum with other services and reallocating services to other spectrum to avoid interference. Further issues arise with interference from use of inexpensive devices for jamming and spoofing and pseudolites and other signal repeaters. Responses being considered include addressing spectrum allocation policies, developing supplementary or backup systems and toughening receivers to increase resilience to adjacent band signals.

Adapting to Multi-GNSS

The expectation of widespread use of the Russian GLONASS system, the European Galileo System and the Chinese Beidou system raise the importance of signal compatibility and interoperability. They also raise issues of licensing the use of those signals in the U.S. and GPS use elsewhere, and of the extent to which the U.S. is willing to rely on other nations' signals for critical infrastructure.

At present high end receivers can process any combination of available signals, GLONASS is used in some domestic precision applications, and cell phones are already using signals from other GNSSs for navigation. Nevertheless, GPS is the overwhelming source of benefits to the U.S.

The globalization of positioning, navigation and timing raises important policy issues in keeping GPS as the predominant system. These include:

- Sustaining the pace of modernization to maintain leadership.
- Maintaining a robust private user equipment manufacturing, research and development sector.
- Compatibility and interoperability with systems operated by other countries.
- Protecting the GPS infrastructure and signals.
- Toughening GPS against threats.

Competing Demands for Public Resources

Maintaining planned modernization is constrained by rising costs and delays as well as the overall federal budget environment. This situation is not unique to GPS, but difficulties even in other civilian and military capital intensive programs can further slow progress in GPS modernization – through both influences such as launch schedules and through budget impacts. Moreover the availability of other GNSSs has caused some to question appropriate numbers of satellites in the GPS constellation at the same time as others have concerns about increased dependence on foreign systems.

The GPS Value Chain

GPS timing provides a standard to which other timing systems requiring high precision are calibrated. GPS is especially important in industries that support the rest of the economy and are at the forefront of economic growth. The most notable of these are transportation, communications and the Internet, power and financial services. Hence GPS is referred to here as "enabling the enablers" (Figure 1).

The number of GPS applications is large and growing rapidly. From these many applications come increases in productivity improvements and savings in costs and time, innovation in production processes, development of new products and markets, facilitation of commerce and increased buyer choice and opportunity, improved safety and environmental progress and advances in science. Civilian innovation contributes to military capabilities as well.

GPS provides similar benefits to the rest of the world. It serves as a time and frequency standard[13] and is an example and source of technologies and industrial base for other nations developing PNT and related systems. U.S. leadership is used to encourage compatibility and interoperability among PNT systems which has become essential now that other nations are upgrading, developing and expanding their own regional and global systems and augmentations.[14]

Relationships among the GPS system, applications and domestic and global benefits are illustrated in the value chain diagram in Figure 1.

Figure 1

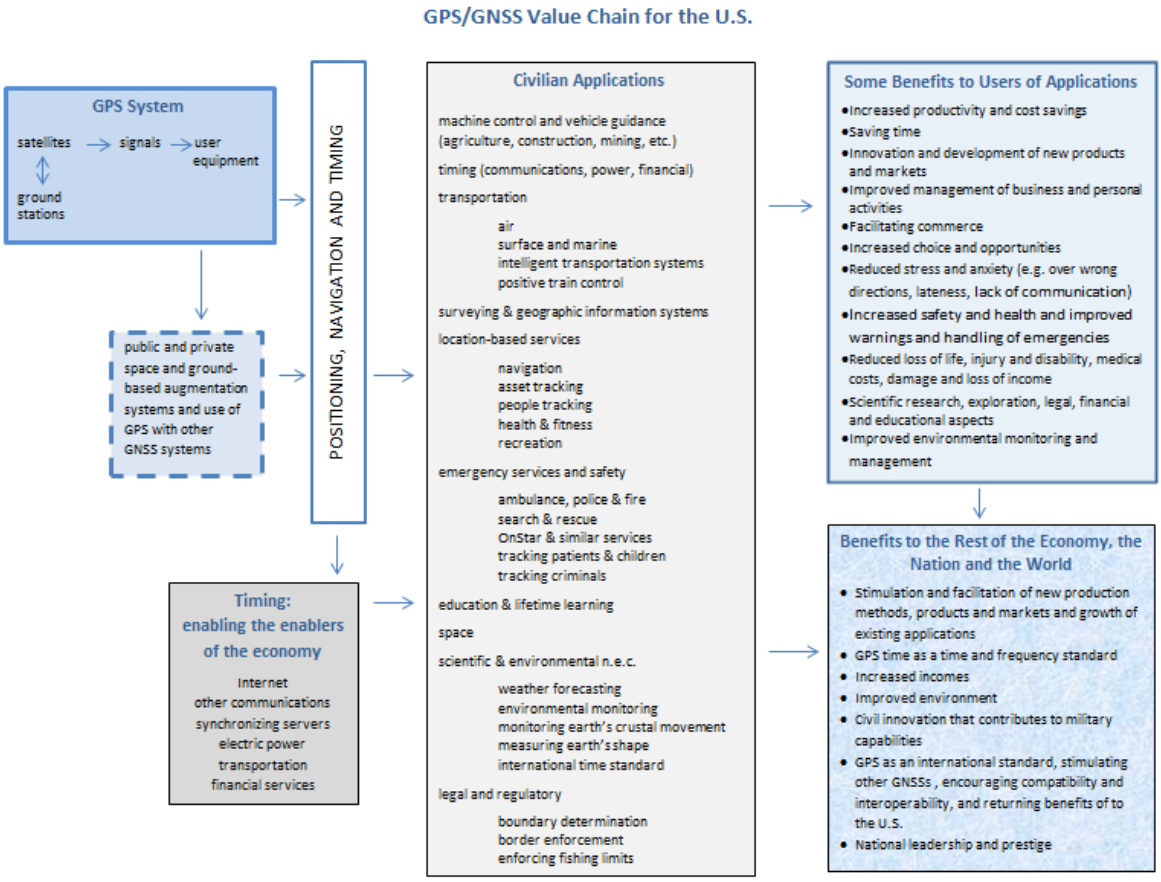


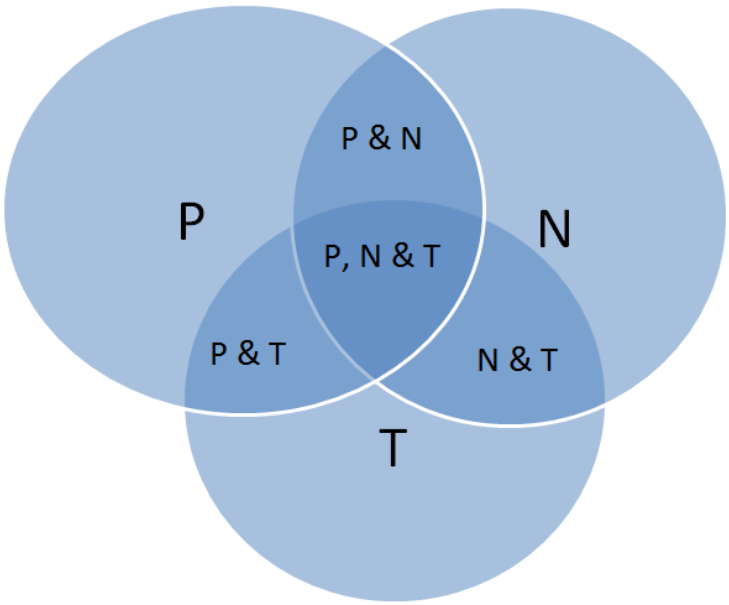
Figure 2 indicates the use of combinations of positioning, navigation and timing capabilities in a number of applications.

[13] Navigation and survey receivers use GPS time in computation of position solutions. Time and frequency receivers use GPS satellite transmissions to control timing signals and oscillators.

[14] The term GNSS is used for any satellite navigation system that has global coverage. It also has been used for the set of systems from multiple countries to mean The Global Navigation Satellite System of Systems or The Global Navigation Satellite System.

Figure 2

Uses of Positioning, Navigation and Timing



P: surveying, mapping, measuring the earth's crustal movement, measuring the earth's shape

N

T: broadcasting, electricity generation and transmission, time stamping financial transactions and synchronizing servers and receivers via GPS time as a stable frequency standard and an international time standard

P&N: aviation, marine and vehicle navigation, precision agriculture, earth moving, paving, virtual staking, first responder dispatching, search and rescue, environmental monitoring

P&T: cell phone, radio occultation

N&T

P,N,&T: people tracking, asset tracking, positive train control

Concepts and Measures of Economic Value and Economic Impact

Economic Value vs. Economic Impact

Economic Value

Economic value is the *addition* to the value of the economy from the provision of a good or service or the introduction of a technology. Benefits are measured relative to what would have been expected if there were no GPS.

Direct economic value is the increase in value in using sectors. Total economic value includes increases in value to suppliers and value induced in the rest of the economy.

Economic Impact

Direct economic impact on the other hand, refers to measures of the *importance* of sectors that are using GPS. It is measured by revenue, expenditures or value added. Value added subtracts the costs of purchased inputs from a sector's revenue to provide a measure of the resources used from that sector. It avoids double counting due to purchases of one sector from another when the values for multiple sectors are to be combined. Since GPS use is so pervasive, direct economic impact covers a large part of the economy.

Total economic impact is the importance of sectors affected by GPS, whether they are using it or not. Total economic impact also is measured by revenue, expenditures or value added. When one considers the scope of GPS applications, total economic impact approaches the size of the whole economy, so it is not very meaningful.

Measures of GPS/GNSS economic impact that have been used include the sizes of the user equipment sector[15] and addressable (potential) markets for GPS/GNSS applications. Addressable markets are not a measure of *current* economic impact and need not accurately reflect the size of future markets because many things can change before complete market penetration occurs.

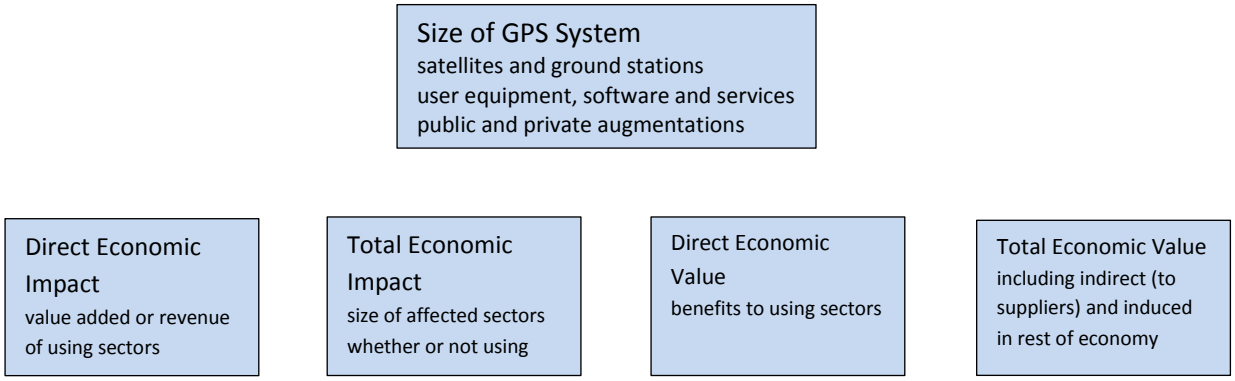
[15] Determining the size of the GPS/GNSS user equipment, software and services sector has become more difficult because of the rapid integration of technologies at levels ranging from systems-on-a-chip (SOC) to use of multiple technologies in farm and construction equipment, trains and ships. Firms that were standalone providers of hardware, software, maps, etc. have been acquired by companies making mobile phones, industrial measuring equipment and other products and their technologies have increasingly been integrated into the acquirers' products and systems. Scattered information is still available and some market research firms continue to update their estimates from less complicated times.

None of the measures of sector size measures the added contribution of GPS to the economy. Revenue or value added in current markets provide at most a minimum estimate of benefits since many users are willing to pay more than the market price for equipment or services, resources may be shifted from productive e uses in other sectors and developments in a sector using GPS can affect other parts of the economy.

The distinction between economic value and economic impact is critical in clarifying the added benefit of an activity. Even if economic impact is measured by value added rather than revenue, the value is not the *net addition* to the economy from the use of the product or technology. It is only a measure of the size of the using sector because it does not take into account the contribution to the economy if the resources employed in the sector had been used in other ways.

Figure 3

Measuring GPS Economic Value and Economic Impact



Forms of Economic Value

Economic value of GPS can take many forms:

- Savings in the cost of the method (e.g. lower cost of surveying or fleet vehicle use).
- Productivity and cost savings in a sector using the method.
- Benefits such as product quality and availability in the using sector. For example:
    - In surveying, benefits can come in construction and other sectors from improvements in precision, accuracy, timeliness of the input, time saved in completing an activity and in coordination of activities.
    - In agriculture, yield improvements can come from improved plant health with better distribution of seed, fertilizer and pesticides.

- In communications, use of GPS as a time standard provides coordination among systems and locations.

- Impacts on the rest of the economy.
  - Supplying industries can benefit from increased demand when a sector using GPS becomes more efficient or improves or adds services and grows.
  - Use of GPS as an enabler of other services (e.g. in improved transportation), can have large economy-wide benefits in addition to benefits to sectors directly using it.

Most available studies concentrate on productivity or cost savings in applications that make use of GPS.

Gauging Economic Value

The concept of benefits for this study is the gross addition to economic value. Gross economic value is value before subtracting the costs of use. Separate costs of GPS are not always readily be determined when GPS is used along with other technologies. Moreover, typically there are too few studies that measure costs for an application to allow them to be taken into account.

The size of the user equipment, software and services industry is a basic measure of the importance of GPS/GNSS. However, user equipment is a cost to users and not a benefit.

The primary focus in the present analysis is on estimating benefits in the form of productivity improvements, cost savings, and cost avoidance. Costs include the value of users' time. These outcomes allow more to be produced with the same amount of resources in the sectors utilizing the technology or allow resources to be freed up for other uses. In that sense productivity improvements and cost reductions are equivalent.

The primary focus in the present analysis is on benefits in the form of productivity improvements, cost savings, and cost avoidance.

Price reductions can lead to greater demand from sectors using the services. The extent of expansion depends on both the price change and the responsiveness of supply. Observed use already takes price effects into account.[16]

Economic value is measured by comparing the observed value contributed by an application with the value that would have existed in the absence of the newer technology (counterfactuals).[17] In some cases

[16] Productivity increases and cost savings shift supply to the right. Unless demand is constant the marginal benefit is lower. The benefit to previous buyers, including consumer surplus, is not affected. The lower value to added buyers is not taken into account in the benefit estimates because of complexities in estimation.

[17] Quantitatively comparing economic benefits to situations without a technology has a long and honored history in economics. For example, in his classic work on hybrid corn in 1958, Zvi Griliches assessed that: "The value of this increase to 'society' will be measured by the loss in total corn production that would have resulted if there were no hybrid corn." Griliches took into account the market value of the corn, valued at prices that would have occurred after adjustment to the difference in production, and the difference in consumer surplus. This involved

this is possible because both old and new technologies are in operation at the same time or the potential effect of introducing the new technology is being tested. In other situations the present technology is compared with the technology that was in use previously.

When other technologies and markets would have been expected to have developed differently in the absence of the technologies being studied, it is necessary to compare benefits with those that would have been expected to have come into use when an alternative technology or system evolved. Defining alternative situations for comparison can require considering multiple scenarios with varying likelihood.

For individuals and households, value is often measured by surveys of willingness-to-pay (WTP). This has been especially useful in assessing non-economic benefits such as those to safety-of-life and the environment.

Some measures are obtained from surveys measuring consumer choices among groups of attributes, a process called contingent valuation. Values for individual attributes are derived by statistical methods from the patterns of choices made. Information from previous contingent valuation efforts can be useful but new studies are costly and have encountered long delays in obtaining and refining results, which has limited use of the approach.

Estimating willingness to pay for businesses and governments has very rarely been tried since it is difficult to get responses from a person or group that truly represents the decision-making behavior of the organization. However, interviews can have the same limitation.

Most of the benefits of GPS come not from the use of GPS alone, but rather from its use together with other technologies and systems. Therefore the combined benefits of jointly used technologies and systems must be adjusted to reflect the contribution of GPS to the joint outcomes. This issue arises both with other technologies and with use of other GNSSs.

Gauging Broader Economic Impacts

"Direct benefits" refers to benefits to the sector using the technology. "Indirect benefits" refers to changes in inputs purchased by a sector. "Induced benefits" are the effects on the rest of the economy.

Induced benefits are typically added to direct and indirect benefits in a multiplier analysis, often using a model based on inter-industry purchasing (Input-Output) relationships, to provide a more complete measure of economic impacts. The best known Input-Output model for the U.S. is RIMS II, the Regional

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sensitivity testing and making assumptions about the elasticity of supply, and using an estimate of elasticity of demand. The work pioneered by demonstrating a way of computing the rate of return to investments in research and development. Z. Griliches, "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy*, October 1958, pp.419-431. A revised version that corrects some of the formulas was published as: Z. Griliches, "Research Costs and Social Returns: Hybrid Corn and Related innovations," in *The Economic of Technological Change*, edited by Nathan Rosenberg, Middlesex, England, Penguin Books, 1971, pp.182-202.

Input-Output Model of the U.S. Department of Commerce.[18] Another widely used but more complex and detailed model for regional analysis is IMPLAN.[19]

Unfortunately, the inter-industry tables on which such models rely lag by many years and are several years apart. That means the Input-Output tables either provide a snapshot of relationships from an earlier time or depict changes between earlier periods with even more lag. While models based on Input-Output tables have been useful in regional analysis where data is limited, their usefulness for economy-wide estimates can be limited or the results misleading when the structure of the economy is undergoing extensive change.

The effects of new technologies, products and markets on the rest of the economy can be pervasive and far-reaching. New technologies can stimulate other technological developments, applications and markets, sometimes resulting in restructuring of whole industries or markets. Innovation can come from producers, suppliers, customers, cooperation among participants at different stages of production and distribution, and/or simultaneous developments in multiple sectors. Multiplier analysis, on the other hand, has largely been limited by the fixed inter-industry relationships of Input-Output analysis even when performed within a sophisticated model.

Multipliers from Computable General Equilibrium models (CGE) attempt to address the limitations by placing the Input-Output table in a more sophisticated model of the economy. CGE models take into account the drawing of resources from one part of the economy to another, so they generate a net economic value along with measures of economic impact. They also take into account economy-wide international trade. However, they also rely on past behaviors with lagging Input-Output data and may not capture important, rapidly changing economic and technological relationships.

Some recent studies have entered productivity changes in dozens of specific sectors into a CGE model as the starting point for tracing benefits and impacts. This goes part way toward overcoming the limitations of fixed inter-industry relationships. However, in the studies that have done this the estimates of productivity outcomes have not been obtainable for many of the industries included so extensive assumptions about have been required.

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[18] U.S. Department of Commerce, Bureau of Economic Analysis, *RIMS II: An Essential Tool for Regional Developers and Planners*, Washington, DC, December 2013 http://www.bea.gov/regional/pdf/rims/RIMSII_User_Guide.pdf

[19] RESI of Towson University, "What is IMPPLAN," June 15, 2006 http://cier.umd.edu/RGGI/documants?IMPLAN.pdf

GPS Applications, Markets and Benefits

Some Market Magnitudes

The most comprehensive estimates of global GNSS market size come from the European GNSS Agency known as GSA which has released four market reports from 2010 through 2015.[20] The data are measures of economic impact and not economic value. GSA found in its 2015 market report[21] that:

- 3.6 billion GNSS devices were in use globally in 2014 of which 3.08 billion were smart phones and .26 billion were for road.
- North America had about 450 million devices installed [about 80% U.S.].
- North America had 1.4 devices per capita in 2014.
- North American shipments were 250-300 million devices in 2013 (read from chart).

Global core revenue was estimated at roughly €62 billion and enabled revenue at €227 billion in 2014 (read from chart). Core revenue includes GNSS devices, software and services while enabled revenue relates to applications.

Location-Based Services (LBS) was projected to account for 53.2% of 2013-2023 core revenue and road applications 38% of core revenue.

North American-based companies had sizeable shares of the global GNSS core market in 2012, particularly among component manufacturers. Their market share among system integrators was highest in aviation (Table 1).

Table 1. North America-Based Company Shares of Global GNSS Core Market, 2012

Sector	Component Manufacturers	System Integrators
LBS	80%	31%
Road	25%	21%
Aviation	63%	65%
Rail	41%	17%
Marine	13%	35%
Agriculture	63%	46%
Surveying	62%	48%

Source: GSA *GNSS Market Report 2015*.

North American-based companies had a 44% market share of value-added services revenue in 2012.

[20] European GNSS Agency, *GNSS Market Report—Issue* 1, October 2010 http://www.gsa.europa.eu/system/files/sdk_files/GSA%20GNSS%20Market%20report%202010_0.pdf European GNSS Agency (GSA), *GNSS Market Report – Issue 2*, GSA, May 2012 http://www.gsa.europa.eu/sites/default/files/MarketReportMEP72012WEB.PDF European GNSS Agency (GSA), *GNSS Market Report – Issue 3*, GSA, October 2013 http://www.gsa.europa.eu/market/market-report European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

[21] European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

GPS and services that rely on it play critical roles in cell phone communications, the Internet and many Internet and mobile applications. The pervasiveness of GPS-enabled applications is illustrated by the following examples:

- 900 million mobile phones that incorporated GPS were sold globally in 2012.[22]
- The U.S. had 188 million smart phone subscribers and 263 million Internet users in 2013.[23]
- 20% of U.S. mobile phone users get up-to-the-minute traffic or transit information.[24]
- The new industry category in the 2012 North American Industrial Classification System: "Internet publishing and broadcasting and web search portals" (NAICS 519130) which includes social media along with location-based and mapping services had revenue of $87 billion and 181,000 employees in 2012.[25]
- Google estimated that its search and advertising tools provided $111 billion in economic activity in 2013.[26]
- Deloitte estimated that Facebook enabled $104 billion of economic impact and 1.2 million jobs in North America in 2014.[27]
- Google Play and the Apple App Store each had more than 1.2 million apps in 2014, including various apps that utilize location and navigation information.[28]

The many uses and benefits of GPS-enabled technologies and systems are evident in the contributions of across economic sectors which are discussed below. The unmistakable theme is that GPS is everywhere.

The unmistakable theme is that GPS is everywhere.

Agriculture

GPS is used in auto-steering for tractors, combines and sprayers to enable precise operation and allow operation in fog and at night. It also is used to coordinate movements of multiple tractors or other equipment.

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[22] Van Diggelen, Frank, "Who's Your Daddy: Why GPS Will Continue to Dominate Consumer GNSS," *Inside GNSS*, March/April 2014 http://www.insidegnss.com/node/3746

[23] Meeker, Mary, *KPCB Internet Trends 2014* www.kpcb.com/InternetTrends based on several sources.

[24] U.S. Department of Transportation, *Beyond Traffic: Trends and Choices*, draft, 2015 http://www.dot.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf

[25] U.S. Census Bureau, *2012 Economic Census* U.S. Census Bureau, *2012 Economic Census* http://www.census.gov/econ/census/schedule/whats_been_released.html

[26] Google, *Economic Impact, United States, 2013*, http://www.google.com/economicimpact/

[27] Deloitte, *Facebook's Global Economic Impact*, January 2015 http://www2.deloitte.com/content/dam/Deloitte/uk/Documents/technology-media-telecommunications/deloitte-uk-global-economic-impact-of-facebook.pdf

[28] European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

Variable rate technology allows placement of seed, fertilizer and pesticides in precise locations according to soil conditions and temperature.

Yield monitoring allows for more precise planting and watering. Savings in inputs occur because seed, fertilizers and pesticides are no longer placed doubly in some spots while other spots are missed. These processes also can improve plant health.

Yield improvements from better health of plants are in addition to input cost savings. Along with more precise placement of seed, fertilizer and pesticides, GPS-enabled technologies contribute through improved timeliness of operations, e.g. earlier sowing after rain and more timely application of herbicides, insecticides and fertilizer due to better traction, increased soil water holding capacity resulting in better water and root penetration, and less crop damage when machines are used to apply sprays and fertilizer in mid-season.

Agriculture makes extensive use of mapping and other Geographic Information Systems and of private and public space-based augmentation systems such as OmniSTAR and ground-based augmentation systems such as Real Time Kinematic (RTK).

Forestry and Fisheries

GPS is employed for monitoring and managing forest health, ecological restoration and reducing fire and other hazards. It is used in equipment to harvest and load forest products and for road building in forests.

GPS use on fishing vessels goes beyond safe and reliable vessel navigation to helping reduce the duration of fishing operations, lowering operation cost and energy use, increasing income and productivity, and providing improved safety and security. GPS helps fishers locate the best legal fishing spots not only to catch the designated species, but to reduce bycatch and avoid sites that may cause nets or gear to snag or tear.

GPS is also used by state and federal fishery managers in pre-season and in-season site sampling and in-vessel observation to control fishing and ensure sustainable species populations.

Construction

GPS-enabled machine control in construction is used to directs the movement of dozers, excavators, pavers, scrapers, compactors and other heavy equipment and the placement of blades to give precise results. It can improve the process or loading earth into trucks and contribute to

better utilization of equipment through monitoring equipment location and use. Virtual staking allows the operator to view points on a screen instead of physical stakes being inserted into the ground.

The role of the surveyor is in setting up the geodetic control that defines the location, creating the 3D model for the machine control system, and monitoring the machine control operation for quality control and assurance.

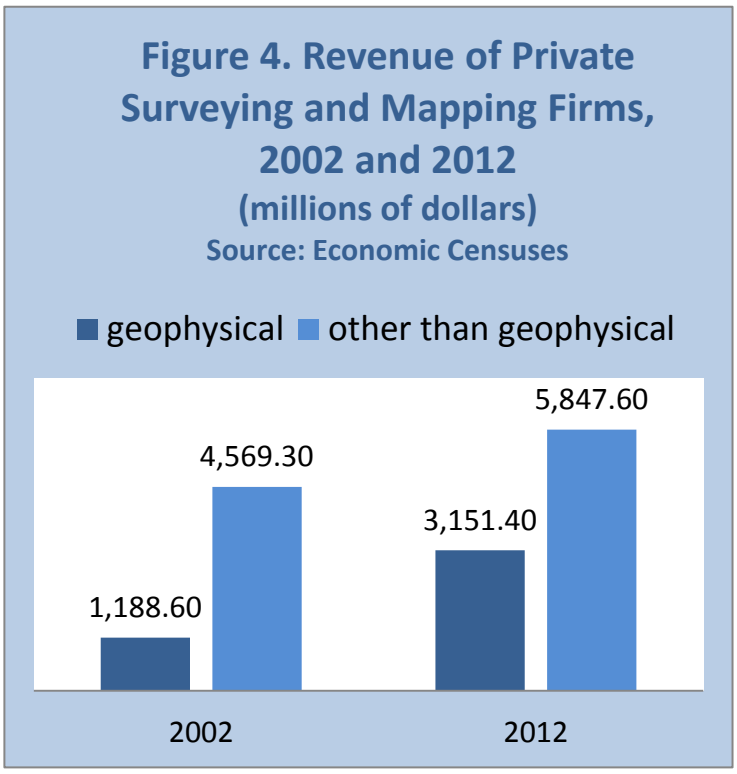
Benefits of GPS-enabled automated machine control in construction include saving time that otherwise would be spent in traditional surveying and inspecting and speeding up work which results in saving operator labor, fuel and use of machines. Automated machine control results in obtaining benefits of the project sooner, coordinating equipment availability among jobs, improving accuracy which can lead to less rework, products lasting longer and performing better, and improving billing and saving office staff time through automated information flow.

Mining

GPS-enabled machine control is used in open pit mining where the equipment can receive the signals above ground. It can guide loaders, dozers, drills and draglines to within centimeters, ensuring precise cuts and minimal waste. The operator in a cab can be provided with information on ore types and waste, mined out areas, elevation of the machine and hole patterns. Private space-based augmentation systems enhance the GPS signals.

Energy Exploration and Development

GPS extensive role in offshore energy exploration and development includes drilling, surface and subsea installations, pipe laying, diving operations, pipe inspection, repair and maintenance and abandonment. Remotely operated vehicles (ROVs) guided by GPS monitor construction and facilities above the sea. Marine navigation systems guide ships and drilling rigs. Aviation navigation systems guide helicopters. Private satellite-based augmentation systems are used along with GPS to provide precise positioning.



Surveying

Surveying is defined here to include all surveying, whether in private survey firms or in business or government organizations. The sector comprises both persons in surveying and mapping firms and self-employed and activities in organizations that collect and make use of the information for their own purposes. Thus, it includes surveying done in agriculture, construction, mining, state and local transportation and public works departments, etc. Both horizontal and elevation measurement and geophysical and non-geophysical surveying are included (see Text Box 1 for definitions).

Revenue of private firms went up and down with the construction cycle after 2002 and partly recovered by 2012. Growth since 2002 has been particularly rapid in geophysical surveying (Figure 4).[29] Surveying and mapping revenue data are not separated from each other in the Economic Censuses or other federal data collection of private sector information.

In addition to lowering cost, GPS-enabled surveying can increase accuracy and raise productivity and/or product quality in using sectors. Examples of quality impacts include better maps, more efficient farming, faster construction, more scientific uses and fuller resolution of legal disputes.

Use of the Continuously Operating Reference Station (CORS) system which shares and distributes observations among users affords greater accuracy and reliability and makes it possible to use the survey results of others. Sharing GPS observations on physical bench marks for which precise locations have been determined improves GPS

Text Box 1. Surveying and Mapping Industry Definitions from the 2012 NAICS

Geophysical Surveying and Mapping Services (541360)

"This industry comprises establishments primarily engaged in gathering, interpreting, and mapping geophysical data. Establishments in this industry often specialize in locating and measuring the extent of subsurface resources, such as oil, gas, and minerals, but they may also conduct surveys for engineering purposes. Establishments in this industry use a variety of surveying techniques depending on the purpose of the survey, including magnetic surveys, gravity surveys, seismic surveys, or electrical and electromagnetic surveys."

Surveying and Mapping (except Geophysical) Services (541370)

"This industry comprises establishments primarily engaged in performing surveying and mapping services of the surface of the Earth, including the sea floor. These services may include surveying and mapping of areas above or below the surface of the Earth, such as the creation of view easements or segregating rights in parcels of land by creating underground utility easements."

Examples include cadastral surveying services [determining property boundaries], mapping (except geophysical) services, cartographic surveying services, topographic surveying services and geodetic surveying services.

[29] Adjustment has not been made for changes in definitions between 2002 and 2002. The trends are not likely to be affected.

orthometric heights. CORS had 2.4 million FTP (file transfer protocol) data downloads in February 2015 alone.

Mapping is included in the discussion of Geographic information Systems.

Air Transportation

GPS is used in aviation for navigation and monitoring aircraft positions. "For navigation, GPS is the principal position source for those aircraft equipped with Area Navigation (RNAV) or Required Navigation Performance (RNP), and is the only position source for satellite-based augmentation system (SBAS, or WAAS)."[30]

Systems for which GPS is sometimes or always used in flights in the National Airspace System include:

- Area Navigation (RNAV) provides flight procedures for properly equipped aircraft.
- Required Navigation Performance (RNP) defines the level of performance required for a specific block of airspace.
- The Wide Area Augmentation System (WAAS) is a satellite-based augmentation system that augments the GPS signal to improve accuracy and integrity during all phases of flight.
    - Performance-Based Navigation (PBN) includes RNAV, RNP and WAAS.

- Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance system using GPS at very early stages of implementation that enables an aircraft to determine its position in relation to a satellite and broadcast the position so the aircraft can be tracked. It can be an alternative to radar. ADS-B Out broadcasts the position of the aircraft for surveillance. ADS-B In lets the aircraft determine the positions of nearby aircraft.
- A Ground-Based Augmentation System (GBAS) augments GPS by providing corrections to aircraft in the vicinity of an airport in order to improve accuracy and provide integrity for GPS navigational positions.

The next generation air traffic control system (NextGen) will rely on GPS in the airplane, allowing planes to share positions and direction with each other. Benefits will include increased safety and spacing planes closer together for more efficient use of facilities and airspace. NextGen is expected to save operations and passenger time, equipment use and fuel and reduce impacts on the environment. The elements of NextGen are ADS-B, Next Generation Data Communications, Next Generation Network Enabled Weather and the single National Airspace System Voice Switch.

[30] FAA NextGen Systems Analysis unit, communication with the author, May 21, 2015.

GPS was used in 2011 by 5,800-7,250 passenger cargo and regional U.S. operated aircraft, 2,800-4,000 international operators' aircraft, 61,000 instrument flight rule-approved GPS navigation and general aviation and air taxi aircraft, and 310,000 pilots without instrument ratings.[31]

Rail Transportation

Railroads use GPS include for train pacing systems, Positive Train Control (PTC), track defect location, locating trucks with rail workers (high limit compliance), readers in freight cars to track them (still experimental), and using track geometry to find defects.

Train pacing systems provide intelligent, fuel-saving cruise control for locomotive that optimizes fuel consumption based on a specific train's make up and the route traveled. The systems calculate the most efficient operation by considering such factors as train length, weight, grade, track conditions, weather and locomotive performance. The trip's profile is updated continuously through a complex network of on-board computers, GPS systems and advanced algorithms that make adjustments, enabling the train to use less fuel while maintaining smooth train. Sustainable fuel savings of 3-17% (depending on train weight, configuration, terrain, etc.) and corresponding emissions reductions are obtained along with reduced maintenance costs associated with better train handling.[32]

Positive Train Control is a family of technologies that often include radio frequency (RF) communications and GPS positioning to keep track of train locations and movement authorities. The Federal Railroad Administration (FRA) 1999 PTC Working Group defined the core functions of PTC to include:

- Prevention of train-to-train collisions (positive train separation).
- Enforcement of speed restrictions, including civil engineering restrictions (curves, bridges, etc.) and temporary slow orders.
- Protection of roadway workers and their equipment.

The Rail Safety Improvement Act of 2008 expanded the core functions of PTC to include prevention of movement through misaligned switches and seamless interoperability between different rail carriers.

Implementation on Class I railroads and intercity passenger railroads is required by December 31, 2015 but the industry is far behind schedule and implementation will not be completed before 2017.

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[31] Molly Smith, "Estimated Benefits of GPS for U.S. Civil Aviation," presentation to the National Space-Based Positioning, Navigation and Timing Advisory Board, August 14, 2012 http://www.gps.gov/governance/advisory/meetings/2012-08/smith1.pdf

[32] Federal Railroad Administration, communication with the author.

Marine Transportation

Many vessel systems incorporate GPS for navigation collision avoidance, communications and situational awareness and for monitoring by on-shore authorities in addition to vessel personnel. These include integrated ship systems that tie together many of the critical vessel systems for navigation, communication and equipment operation, some of which are listed below.

- GPS receivers that display constant latitude and longitude position of the vessel.
- Global Maritime Distress and Safety System (GMDSS) for vessel to shore and vessel to vessel communications and data transfer.
- Electronic Chart Display and Information System (ECDIS) and electronic charting systems (ECS).
- Radar/ARPA displays for navigation and collision avoidance.
- Autopilots and Track Control units for vessel steering systems utilizing GPS Waypoints.
- Ship Security Alert System (SSAS) to communicate vessel is under attack.
- Emergency Position Indicating Radio Beacon (EPIRB).[33]
- Automatic Identification System (AIS).
- INMARSTAT or Fleet Broadband Terminals.

Many pilot organizations in the U.S. also use differential GPS (DGPS)[34] pilot laptop systems that have electronic charts with enhanced features to promote safer transits than the vessel's equipment alone is capable of providing.[35]

Within the GMDSS, shipboard equipment relies on GPS to facilitate U.S. Coast Guard messages for identification and tracking, vessel traffic services, weather and safety broadcasts, and distress and rescue assistance.

For example, Automatic Identification System (AIS) transmits and receives vessel to vessel location information. A screen lists each nearby vessel and details about it (Figure 5). This is essential for harbor safety and security.

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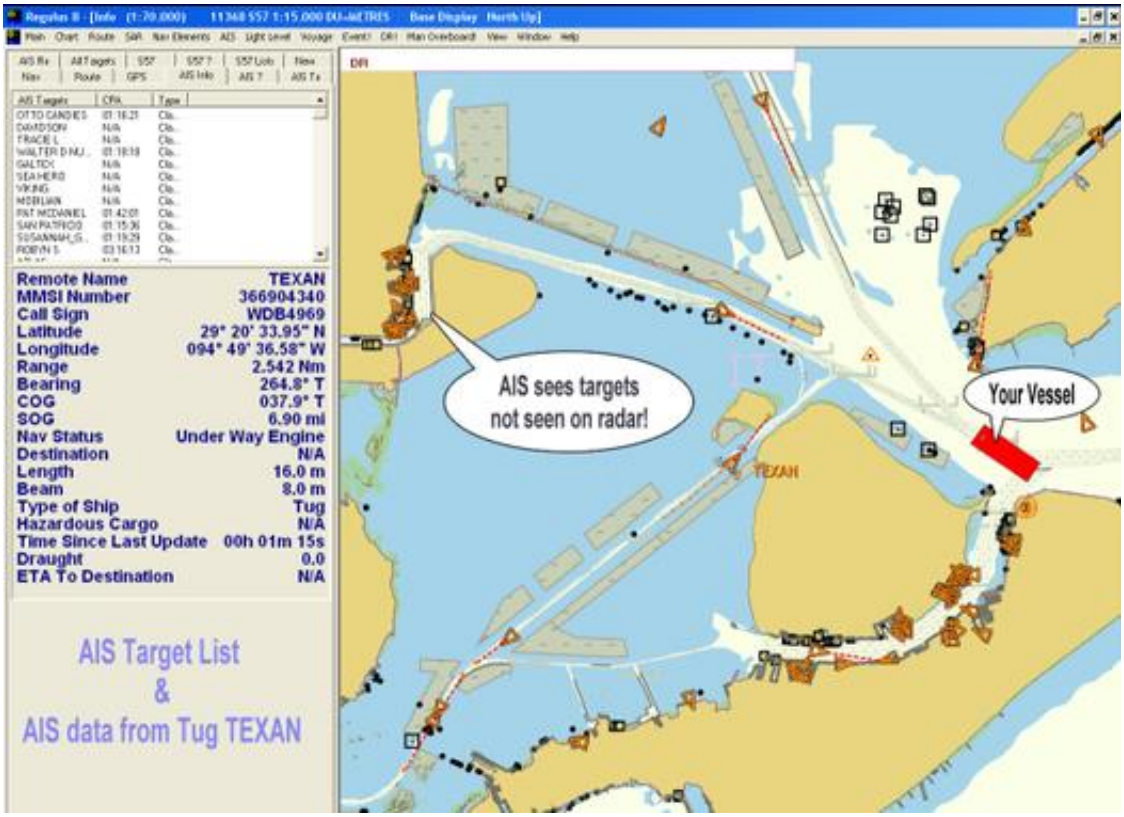
[33] Not all EPIRB use GPS.

[34] DGPS is a system of ground-based reference stations that increase the accuracy of GPS signals.

[35] Joel Szabat, "Letter to Karl B. Nebbia, Associate Administrator, National Telecommunications and Information Administration, on the impact of the LightSquared Concept of Operations, and Appendices," U.S. Department of Transportation, Office of the Secretary, July 21, 2011, p.C1 http://science.house.gov/sites/republicans.science.house.gov/files/documents/Letters/2011%2007%2021%20DOT%20LSQ%20Impact%20Assessment.pdf

Figure 5. Automatic Identification System Screen



Commercial fishing fleets use GPS to navigate to optimum fishing locations and track fish migrations. Recreational boaters and fishing boats use electronic nautical charts for navigation and recreational fishing boats use GPS to return to areas where they have been able to find fish.

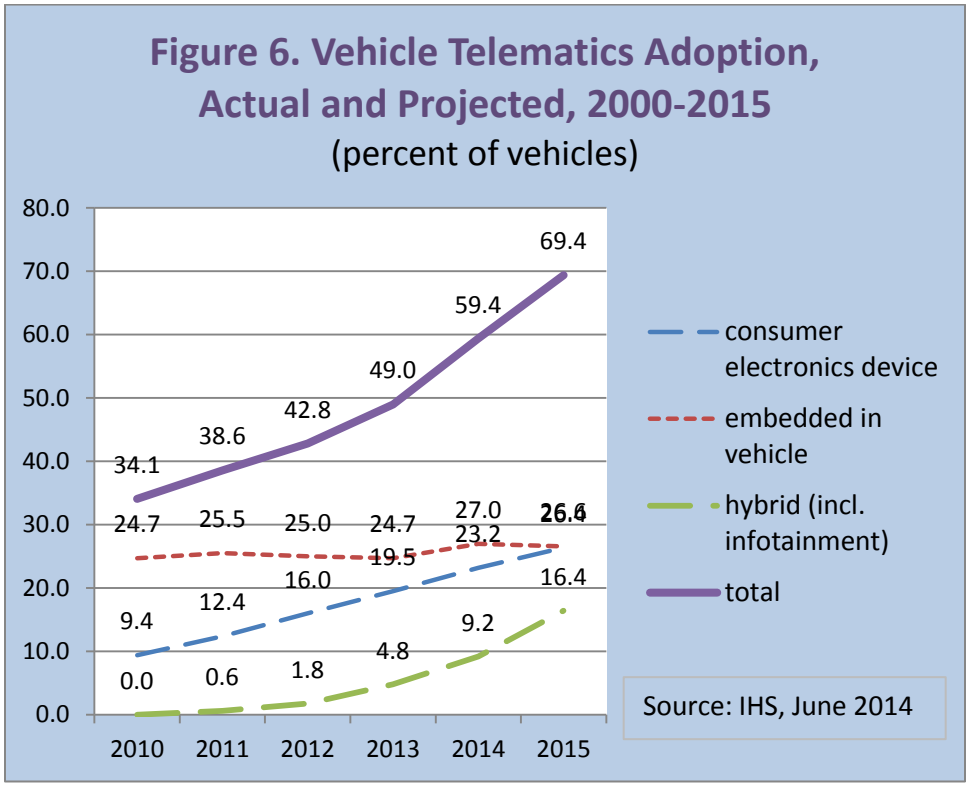
Marine navigation tools are also used in the offshore energy industry.

Some marine system use is driven by government requirements. The principal factors that will impact future marine positioning, navigation and timing requirements are safety, economics, environment, and energy conservation.

Vehicle Transportation

Telematics is generally defined to include the combination of computer and mobile communications systems. Vehicle telematics also relies on GPS and on maps and other databases.

Vehicle telematics adoption has been growing rapidly Figure 6).[36] The category encompasses mobile phones, personal navigation devices and systems embedded in vehicles for navigation or as combinations with other services (infotainment). Systems that are purchased in new vehicles or installed afterward are included. Vehicle telematics results in fewer and shorter trips and less idle time, saving vehicle purchases and fuel and other operating costs.



The U.S. Department of Transportation has been working with industry and public sector stakeholders to develop and evaluate connected vehicle technologies which include those that operate vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-devices or other points of connection. The safety-critical alerts and crash avoidance warnings enabled by these cooperative technologies require GPS/GNSS for the common timing and positioning functions without which the technology would not work.[37]

Timing

GPS timing is provided by signals from precise atomic clocks on the GPS satellites. GPS is used for timing and for time frequency synchronization in many industries, most notably broadcasting and communications, electric power generation and transmission and financial services. While other sources

[36] IHS, "Telematics Market Status," June 2014 https://www.ihs.com/newsletter/automotive/june-2014/telematics-market-status-html

[37] Communication with the U.S. Department of Transportation Intelligent Transportation Systems Joint Program Office.

of timing are in use, GPS time provides an authoritative standard against which other measurements are calibrated. GPS timing is currently being used as a reference by the European Galileo, the Russian GLONASS and the Chinese BeiDou system.

GPS is used in communications network synchronization for both cell phone and traditional telephone applications. Power companies use it to locate line faults and to maintain phase relationships along and among transmission lines and facilities. Financial trading exchanges require precise real time stamping to ascribe transactions to market participants and meet requirements of financial regulators. Regulators are expected to require synchronization among trading locations, which will greatly increase the use of GPS time in financial trading. GPS is used to synchronize servers in many settings. Other industries using GPS time include transportation and emergency services.

While significant work has been done on the points in processes at which GPS timing can be used, data on the extent of actual use is largely unavailable.

Timing applications have varying user requirements. The next table shows the latest requirements for the various timing applications as identified by the U.S. Government in its Federal Radionavigation Plan (Figure 7).[38] There are major gaps, including in knowledge of how extensively GPS timing and syntonization (frequency synchronization) is used within various systems.

Figure 7

Timing User Requirements

REQUIREMENTS	MEASURES OF MINIMUM PERFORMANCE CRITERIA TO MEET REQUIREMENTS					
	ACCURACY (Time with respect to UTC)	AVAILABILITY	CONTINUITY	INTEGRITY	TIME TO ALERT	COVERAGE
Financial transaction timestamp	1 s	TBD	TBD	TBD	TBD	Worldwide
Electric power transmission	1 μs	TBD	TBD	TBD	TBD	North America
Cellular telephony	1 μs	Outages not to exceed 8 hr	TBD	TBD	TBD	North America
Inter-carrier telephone and data networks	1 μs	TBD	TBD	TBD	TBD	North America
Scientific community	nanoseconds	TBD	TBD	TBD	TBD	Worldwide
Traffic Signal Timing	TBD	TBD	TBD	TBD	TBD	Nation Wide/Intersections

The largest application of GPS time and synchronization in the power industry is in synchrophasors (Phasor Measurement Units or PMUs) to precisely measure time so that when or where problems occurred can be determined. Use is not extensive but is growing. In addition to devices, PMUs require applications and a high speed communications network. More information on synchrophasors is in Appendix D.

[38] U.S. Departments of Defense, Homeland Security and Transportation, *2014 Federal Radionavigation Plan* http://www.navcen.uscg.gov/pdf/FederalRadionavigationPlan2014.pdf

Location-Based Services

Rapid growth is taking place in Location-Based Services (LBS) which include everything from indoor location to many aspects of the Internet of Things and the "sharing economy."

The Pew Survey of Internet and American Life[39] found that:

> "Mobile is now a behavior, not a device."
>
> Omid Kordestani, Google Chief Business Officer, January 29, 2015

- 30% say that at least one of their social media accounts is set up to include their location in their posts.
- 12% use a geosocial service to "check in" to certain locations or share their location with friends.

Another Pew Research Center survey found that 49% of *all* cell phone owners in the U.S. use their cell phone to get directions, recommendations, or other location-based information in 2013.[40] A Pew survey for 2013 reported that 74% of *adult* smart phone owners ages 18 and older say they use their phone to get directions or other information based on their current location.[41]

Smart phone adoption was 56% in 2013 vs. 35% for other mobile phones and 9% with no cell phone.[42] 20% of U.S. mobile phone users get up-to-the-minute traffic or transit information, according to Pew.[43] The U.S had 188 million smart phone subscribers in 2013.[44]

Smart phones now have as many as 12 sensors, including but not limited to gyros, accelerometers, fingerprint, proximity, ambient light, Near Field Communications, a payment system sensor, barometer, compass, hall (recognizes whether cover is open or closed) and heart rate. Several of these are employed in applications that involve GPS.

WAZE, a Google company, provides real time traffic information based on crowdsourcing.

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[39] Kathryn Zickuhr, *Location-Based Services*, Pew Research Center, September 12, 2013 http://www.pewinternet.org/2013/09/12/location-based-services/

[40] Maeve Duggan, *Cell Phone Activities in 2013*, Pew Research Center, 2013 http://www.pewinternet.org/2013/09/19/cell-phone-activities-2013/

[41] Zickuhr, *op.cit*.

[42] Aaron Smith, *Smartphone Ownership in 2013*, Pew Research Center, 2013 http://www.pewinternet.org/2013/06/05/smartphone-ownership-2013/

[43] Pew Research Center, "Mobile Technology Fact Sheet," October 2014 http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet/

[44] Mary Meeker, *KPCB Internet Trends 2014* www.kpcb.com/InternetTrends based on several sources.

GPS is used for tracking and inventorying assets including heavy machinery on farms, construction sites and mines, pipe and other materials, shipping containers in trucking sites and ports, and the location of utilities in the ground. Uses in logistics include planning of product flow and transport.

Security uses of location information have become ubiquitous. Cameras are widely used to locate and investigate incidents in streets, stores, buildings and at ATMs and to monitor traffic flow and speeding. Locations of criminals are monitored with ankle bracelets. This may have been the first use of wearables to get widely noticed.

The growth of wearables will provide even more location information. It will be spurred by the expanded use of Internet Protocol version 6 (IPv6)), a standard for interconnection used on packet-switched communications networks which will allow a nearly unlimited number of objects to each have their own IP address. Adoption may occur more rapidly now that Internet Protocol version 4 (IPv4) has had to deny requests for large numbers of addresses.

Location, navigation and communication services are crucial to police, fire, ambulance and search and rescue operations. The many emergency, scientific and environmental applications of GPS include structural monitoring of bridges and damns, earthquake monitoring by measuring the movement of tectonic plates, studying drought in the Western U.S., keeping track of floods, monitoring and predicting space weather, issuing tsunami warnings, determining evacuation routes when roads are flooded or congested, assessing damage, monitoring vegetation growth, monitoring sea level change, and studying the size of the Arctic and Antarctic ice sheets.

Geographic Information Systems

Geographic Information Systems include not only databases and mapping but also and sophisticated systems for information management, analysis and display. According to leading GIS firm ESRI: "A geographic information system (GIS) lets us visualize, question, analyze, and interpret data to understand relationships, patterns, and trends".[45] GIS application includes integration of technologies, information and analytics and modeling tied to location references. Its many uses include business intelligence, supply chain tracking, asset management, reinsurance, environmental monitoring and disaster response.

Mapping is used extensively in agriculture, construction, mining, energy exploration and development, marine, air and ground transportation and other industries. Hydrographic surveys enable ships to avoid obstructions and channels to be cleared while supporting on-shore development and environmental management.

> The growth of same day delivery, which takes advantage of Internet, cell phone and navigation technologies enabled by GPS, is a continuation of the growth in just-in-time delivery that has been a phenomenon in manufacturing for several decades. Now it is having a more profound effect on wholesale trade, retail trade and transportation.

[45] ESRI, "What Is GIS?" hsttp://www.esri.com/what-is-gis

Geodesy, the measurement of the earth's geometric shape, orientation in space, and gravity field, is used to map the U.S. shoreline, determine land boundaries, and improve transportation and navigation safety.

Remote sensing from space has become increasingly important as a means of mapping the earth. It is used extensively for land and coastal mapping and recently in measuring depths of water.

Applications of geographic information systems abound. The growth of same day delivery, which takes advantage of Internet, cell phone and navigation technologies enabled by GPS, is a continuation of the growth in just-in-time delivery that has been a phenomenon in manufacturing for several decades. Now it is having a more profound effect on wholesale trade, retail trade and transportation.

Estimates of the size of the LBS and GIS markets vary greatly in definition and magnitude (Text Box 2). Along with the number and diversity of applications, the lack of reliable revenue data makes it difficult to develop even a rough estimate of overall benefits.

Text Box 2. A Wide Range of LBS and GIS Market Size Estimates

For LBS and GIS, definitions and measures can vary greatly and often are not explicit.

Location-Based Services Market Size Estimates

- Frost & Sullivan estimated the *global* LBS market at €$22.8 billion in 2012 and forecast €32.0 billion in 2015
- Market and Markets estimated *global* LBS revenue at $8.1 billion in 2014
- Berg Insight estimated *North American* LBS revenue at $835 million in 2012

The US can be assumed to spend 20%-25% of the world value and about 80% of the North American value.

Geographic information Systems Market Size Estimates

- BCG estimated the revenue of the U.S. GIS industry at $73 billion in 2011
- The global GIS market will reach $10.6 billion in 2015 according to a report of Global Industry Analysts in 2013
- The Canadian Geomatics study found private sector spending of $2.3 billion in 2013. If U.S private spending was the same percentage of GDP it would be $23.6 billion

The Sharing Economy

GPS supports the "sharing economy" through its role in the Internet, cell phones and other communications, positioning, navigation and payment systems. The sharing economy, with its extensive use of location-based and geographic information systems and exemplified by ride and home sharing companies UBER, LYFT, airbnb and Home Away is the application of long-standing trends toward mass customization along with just-in-time production applied to service businesses.

The "sharing economy," with its extensive use of location-based and geographic information systems…, is the application of long-standing trends toward mass customization along with just-in-time production applied to service businesses.

A 2015 PWC study emphasized five new sectors: peer-to-peer finance, online staffing, peer-to-peer accommodation, car sharing and music and video rental.[46] PWC found that:

- Global revenue of the five sectors is $15 billion, 5% of traditional sharing sectors: car, book, DVD, and equipment rental and B&B and hostels. However, by 2025 the five together could be equal to the traditional sectors and have revenue of $335 billion.
- Airbnb averages over 20% more guests per night than Hilton Worldwide.
- 19% of U.S. adults have engaged in a sharing economy transaction.
- 7% of the U.S. population is providers in the sharing economy.

There is a debate over whether the potential of the sharing economy has been over-hyped, not only because it is in some ways an extension of long-standing trends, but also because of difficulties that can arise with quality control, opposition to competitive losses of jobs and conflicts with regulations. For example, rules for peer-to-peer finance have been tightened to assure the money is used as promised and intense battles with municipalities are taking place over ride-sharing.

Emergency Services

Location, navigation and communication services are crucial to police, fire, ambulance and search and rescue operations. The recent FCC auction of spectrum for advanced wireless services which closed in January 2015 will fund FirstNet with $7 billion to establish a nationwide interoperable wireless broadband public safety network to enable greater communication among first responders.

911, the telephone-based emergency calling system, is to be replaced by systems that will meet the enhanced 911 requirement for Commercial Mobile Radio Service providers to deliver horizontal information within 50 meters of callers within two years. Services are to provide vertical information within 3 meters for 67% of 911 calls placed from indoor environments within two years and 80% within five years. Recently, 911 has been required to support text messages.

Cospas-Sarsat satellites have been used for 33 years to receive distress signals and inform search and rescue teams. The Distress Alerting Satellite System (DASS), its replacement, will provide location information and have worldwide coverage. SPOT LLC, a Globalstar company, has been providing location information for rescues since 2007.

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[46] PWC, *The Sharing Economy*, 2015 http://www.pwc.com/en_US/us/technology/publications/assets/pwc-consumer-intelligence-series-the-sharing-economy.pdf and PWC, "The Sharing Economy – Sizing the Revenue Opportunity," 2015 http://www.pwc.co.uk/issues/megatrends/collisions/sharingeconomy/the-sharing-economy-sizing-the-revenue-opportunity.jhtml

After the Amtrak train crash near Philadelphia, the Federal Railroad Administration partnered with Google to add the locations of all grade crossings to Google Maps. Audio and visual alerts will be added to the navigation feature as well and other mobile map makers have been approached. There are about 130,000 public and 85,000 private grade or level crossings across the country.[47]

Unmanned Aerial Systems (UASs) will take on increasing importance in dealing with natural and other disasters. A team from the FAA test site for drones assisted search and rescue efforts in Texas after deadly floods in May 2015. Drones have been used to deliver medicine to remote areas.

Medical personnel are increasingly using cell phones to locate staff and patients both during emergencies and regular activities and to record, view and share medical records across locations.

Structural Monitoring

GPS supports structural monitoring to determine deformation in bridges, dams, tunnels, buildings, offshore energy platforms, vessels and wellheads, and other facilities. The information contributes to actions involving intensity of use, remediation, replacement and insurance. While most events may be rare, their costs can be high in lives lost and injury, delays in travel and transportation of goods, lost production and property and infrastructure damage.

Weather

GPS is a fundamental component of weather forecasting. It has been used traditionally in weather satellites for weather and climate information, to track the positions of dropsondes which monitor sea state, radiosondes (on weather balloons) which monitor water vapor, and to monitor storms. Radio Occultation is used to examine the amount of bending in the GPS beam as it passes through the atmosphere. This provides temperature information that is incorporated in forecasts. GPS echoes have been used to measure the thickness of snow packs. Weather information is collected from thousands of GPS-located weather stations around and the country and distributed through many apps that provide local information, current updates and warnings. A large private weather services industry has evolved.

Numerous apps have been developed to provide weather information, flood, wind, hurricane and tornado warnings, and to assist in preparing and responding to weather and other disasters. Some apps enable locating shelters and medical services and finding people and pets. The FEMA app includes a photo-sharing system that can help disaster workers understand what is happening on the ground.

[47] Jad Mouawad, "Agency Taps Mapping Technology to Curb Rail Crossing Accidents," nytimes.com, June 29, 2015 http://www.nytimes.com/2015/06/29/technology/agency-taps-mapping-technology-to-curb-rail-crossing-accidents.html?_r=0 and insideGNSS.com, "Federal Rain Agency, Google Partner on Rail Crossing Safety with GNSS/Mapping Apps" http://www.insidegnss.com/node/4552

Scientific ad Environmental Applications

GPS is fundamental to a great deal of scientific data collection that takes place outdoors. Scientific applications include many environmental purposes. Some examples are:

- Earthquake monitoring.
- Ground subsidence monitoring.
- Measuring tides and other coastal and inland water levels.
- Studies of coastal margins and shore erosion.
- Watershed assessment, wetlands, and water quality assessment.
- Land use, vegetation, forestry health and soil studies.
- Measuring glacial melt and snow depth.
- Geological research.
- Fisheries research – sampling with location for fish and crustaceans.
- Tracking endangered species.
- Wildlife and avian research – tagging and locating mammals and birds in the wild.
- Archaeology.

Space

GPS is an important component of the space services sector. GPS is used to track the location of spacecraft and satellites near the earth. GNSS receivers have been developed with NASA involvement that reduces the need for ground-based satellite tracking. NASA has identified nearly 80 launched or planned missions that utilize GNSS receivers. New Navigator receivers can be used at the highest altitudes to determine the locations of satellites.

The evolving TDRSS Augmentation Service for Satellites (TASS) provides GNSS integrity information and other parameters.

GPS is used to track the position of satellites in space. The Space Foundation has estimated the global total of public and private space activity at $314 billion in

Table 2. Some Nascent and Emerging Applications	
Mobile payment systems	Autonomous vehicles
Wearables and prosthetics	NextGen and other aviation systems
Internet of things	Global improvements in aircraft tracking
Augmented and virtual reality	Electronic tolling and insurance rate-setting
UAVs and robotics	Next Generation (NG) 911
Infotainment and other connected vehicle systems	Improvements in environmental monitoring
Intelligent Transportation Systems	

2013.[48]

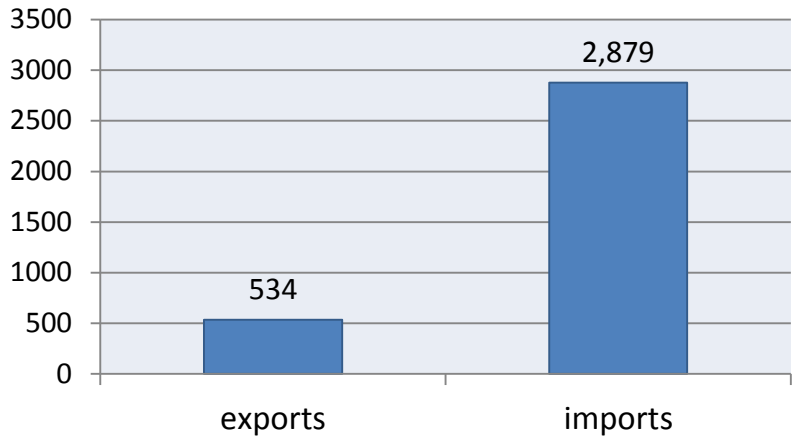
While NASA satellites are primarily for research rather than operational purposes, they have played an important role in weather, environmental and climate forecasting along with scientific activities.

The many nascent applications will have a huge impact on future markets and benefits (Table 2).

International Trade

Data from the U.S. International Trade Commission show a $2.3 billion U.S. deficit in trade in GPS equipment in 2013 (Figure 9). This gives an incomplete and misleading picture of the role of the U.S. and the benefits that result.

Figure 8. U.S. Trade in GPS Equipment, 2013
(millions of dollars)



The trade numbers for GPS equipment do not include revenue for licensing, international payments to social media and e-commerce companies or other Internet-based revenue for which the U.S may have a net trade surplus. These are an important source of revenue and profits for U.S.-based companies.

Imports of GPS equipment software and services enable the U.S. to gain more efficient production in applications at home and enable the U.S. to export more of products that use GPS.

Exports of GPS components and equipment come back to the U.S. in products that benefit U.S. businesses and consumers with more capabilities and/or lower prices. Exports of GPS equipment enable other countries to build on the technologies and contribute to innovation, while imports enable the U.S. to share in foreign innovations.

Exports of GPS equipment and associated knowledge also raise incomes in other countries, creating larger markets for U.S. goods and services.

[48] Space Foundation, *The Space Report, 2014*, 2014 http://www.spacefoundation.org/programs/research-and-analysis/space-report

Broad Studies of Economic Benefits

Overview

This section examines ten studies of overall benefits of GPS and/or GNSS or substantial portions of it that have been performed in the U.S., Europe and Australia over the last several years (Table 3). Studies

Table 3. Coverage of Broad Economic Benefit Studies

Study	Geography	Date	Date of Data	Coverage	Measures	Documents Benefit Sources and Methods*
GSA	world and some for regions	2015, 2013, 2012, 2010	various, including projections	core and enabled markets 9 sectors and their components	revenue and shipments	B
Oxera	world	2013	various	Geo services, overall and 4 use cases	revenue, gross value added, time and fuel saved, lives saved, income from education, competition	A
BCG	U.S.	2012	not specified	overall geospatial services and 3 components, including some projections	revenue, jobs, cost savings, projections of efficiency gains, value of services to households	C
NDP 2011	U.S	2011	various 2005-2010	GPS equipment industry, agriculture, construction, incl. surveying and mapping, surface transportation	value added, indirect economic benefits, productivity and cost savings, costs of denial of GPS	A
NDP 2013	U.S	2013	various	benefit information from other studies	revenue, value added and cost savings	C
Leveson 2010	U.S.	2010	2008	18 sectors	productivity and cost savings	B
Canadian Geomatics	Canada	2015	2013	location-based services in private firms	productivity	B
ACIL Allen	Australia	2013	2012	Augmented GPS/precise positioning	productivity	B
ACIL-Tasman	Australia	2008	2006-2007	spatial information in detailed sectors and economy	productivity	B
Allen Consulting	Australia	2008	2008	High resolution positioning services	productivity	B

*A, B and C are grades representing judgements of the sufficiency of documentation.

of benefits of geospatial data are included because of their frequent dependence on GPS location information.

Because of earlier publication dates and lags in data, much of the recent explosion in the breadth and depth of GPS use and benefits that go with that use is not reflected in the studies. Also, until very recently when other systems were introduced into cell phones, U.S. use of positioning, navigation and timing (PNT) satellite systems from other nations has been limited to some precision users accessing GLONASS.

Available studies differ widely in definitions and methods. Some examine affected markets and others potential market size or market size of using sectors. Some cover GPS and others explicitly include additional GNSSs. Some gauge economic benefits by productivity gains, cost savings and cost avoidance, and in some cases by willingness to pay and time saved.

Revenues from user equipment and related software and services, as in some of the data reported by GSA, are costs to the user.

Analyses differ according to which economic sectors are included and in level of detail and completeness. Measures of indirect benefits – purchases of the using sector from other industries, and benefits induced in the rest of the economy, are included in a few studies. Some also explore non-economic benefits.

Sufficient information about sources and methods of benefit estimates is not always provided. Examples of this are the BCG study which has an insufficient description of its methodology, the Oxera study in its reliance on the BCG U.S. benefit to extrapolate its upper limit global estimate, and the 2013 NDP Analytics study which utilizes the BCG estimate as its value for location-based services.

GSA Market Reports

The European Global Navigation Satellite Systems Agency, known as the European GNSS Agency or GSA, published four reports examining the GNSS market in 2010, 2012, 2013 and 2015.[49] The reports include extensive estimates and projections of GNSS global market size and growth and some estimates for Europe, North American and the rest of world. Estimates and projections are for revenue and not net additions to

> The reports are of great interest because of their comprehensive look at markets and because revenue can be indicative of benefits in the absence of other information. The reports also are of interest because market information and projections often are proprietary and there can be great inconsistency across market research studies.

[49] European GNSS Agency, *GNSS Market Report—Issue* 1, October 2010 http://www.gsa.europa.eu/system/files/sdk_files/GSA%20GNSS%20Market%20report%202010_0.pdf European GNSS Agency (GSA), *GNSS Market Report – Issue 2*, GSA, May 2012 http://www.gsa.europa.eu/sites/default/files/MarketReportMEP72012WEB.PDF European GNSS Agency (GSA), *GNSS Market Report – Issue 3*, GSA, October 2013 http://www.gsa.europa.eu/market/market-report European GNSS Agency (GSA), *GNSS Market Report—Issue 4*, GSA, March 2015 http://www.gsa.europa.eu/2015-gnss-market-report

economic value.

The estimates include revenue of the European space-based augmentation system EGNOS which provides augmentation of the Galileo signal for aviation, shipping and other applications.

The reports are of great interest for this review because of their comprehensive look at market sizes and because revenue can be somewhat indicative of benefits in the absence of other information. The reports also are of interest because market information and projections often are proprietary and there can be great inconsistency across market research studies. GSA makes use of many confidential studies without revealing which sources contributed to each estimate. It apparently has been allowed to use proprietary information from many market research firms because it is subsumed in GSA's own estimates and because most of the data GSA presents is in the form of graphs for which the underlying data is not provided – from which it is often difficult to even roughly extract the numbers.

The 2010 and 2012 reports stated the methodology as: "The underlying forecasting model is based on advanced econometric techniques. An extensive set of variables is used to model scenarios based on key assumptions."[50] Results were checked against opinions of market segment experts and market research reports. However, these analyses are not provided in the reports and have not been made available. Specific bases of aggregate and sector projections are not provided.

A distinction is made between the core market which includes the value of components that provide GNSS functionality in devices, and enabled markets which "represent the services and devices enabled by GNSS." The 2015 report provides global data on both core and enabled market and goes into more detail on core markets for application sectors. In addition to providing sector information that did not appear previously, the 2015 report presents results of a survey of GNSS constellations supported by receivers being offered by suppliers.

While Galileo is on a fast implementation schedule, it has encountered long delays in the past, and projections may be overstated by overestimating how soon Galileo will become available. Delays can have a more significant effect on the projections than might appear because only some of the data is updated in each report. Optimism about Galileo availability would be expected to affect both the model assumptions and the sources against which the model assumptions were cross-checked, and would apply to varying degrees to all of the reports.

[50] *Ibid*., p.3.

Economic Impact of GEO Services, Oxera, 2013

The Oxera study of geospatial services[51] is one of two studies commissioned by Google to demonstrate its economic impact. The other is by the Boston Consulting Group BCG, a discussion of which follows. The BCG study deals with the U.S. and the Oxera study is global.

Geospatial services are defined by Oxera as: "all interactive digital mapping and location-based services. These include providers of satellite imagery, digital maps, satellite positioning signals and navigation devices. Digital maps are defined to include both online maps and locally-stored digital maps such as satellite navigation systems used in cars," but not traditional hard-copy maps.

The study considers global revenues, quantitative and qualitative benefits of services to households, businesses and governments, and effects beyond using sectors. Revenues were obtained by a "bottom up" method using data from companies in related activities and a "top down" approach that extrapolates international revenues from those in the U.S. taken from the BCG study. Extrapolation from the U.S. to the rest of the world is based on GDP per capita of countries thought to have significant use of geospatial services, allowing for differences in purchasing power of currencies.

The geospatial sector was estimated to generate $150-$270 billion in annual revenues globally, with the difference resulting from the two methods. The lower estimate which is from the bottom up approach is thought by the authors to be an understatement because some companies were too diverse to be included. However, unrelated parts of the companies included are counted too. As noted, the higher estimate is based on the BCG study for the U.S. which is insufficiently documented.

The geospatial sector was estimated to account for about $113 billion of gross value added, a measure which deducts the costs of inputs obtained from other sectors. Both military and civilian uses are included.

U.S. revenue from BCG for the "top down" method is described in the BCG materials as the location-based geospatial data sector of the geospatial services industry that: "Collects, manages, and distributes spatial information and imagery" and "provides navigation aides [sic] and other location-finding services."[52]

The Oxera report states that "in some cases" it is appropriate to measure benefits by the difference in productivity when using resources in the geospatial sector vs. using them other parts of the economy,[53] but that approach was not implemented.

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[51] Oxera Consulting, Ltd., *What Is the Economic Impact Of GEO Services?*, Prepared for Google, 2013 http://www.oxera.com/Oxera/media/Oxera/downloads/reports/What-is-the-economic-impact-of-Geo-services---summary_2.pdf

[52] The Boston Consulting Group, "Putting the U.S. Geospatial Services Industry On the Map," slides, BCG, December 2012, p.3 http://www.ncge.org/files/documents/US-FullReport.pdf

[53] *Op. cit.*, p.7.

In addition to the main estimates, rough benefit magnitudes were quantified for four cases: 1) fuel and time savings from use of navigation devices in motor vehicles, 2) the value of lives saved from increased emergency response times for cardiac arrest, 3) illustrative effects of use of GIS in secondary education on future earnings, and 4) implications of alternative assumptions about the effects of increased competition and search on savings.

The authors note that the effects of use of GIS in education on future income, which they apply to the work force, would only apply to the future work force because most of those presently working have not had the advantages of GIS in their education. In the emergency response analysis much lower magnitudes for the value of a life saved are applied than have typically been used in U.S. studies, reflecting the practice in the UK.

Geospatial Services in the U.S. Economy, Boston Consulting Group, 2012

The Boston Consulting Group (BCG) study was conducted for Google with the objectives of assessing the size of the U.S. geospatial services sector, establishing the benefits that U.S businesses and consumers derive from the sector, and identifying trends, including interdependencies with public policy and public and private investment. Information is available from a three page report issued in June 2012 and a set of nine slides released in December 2012.[54] These provide only very limited information on sources and methods. This discussion draws on both documents.

Geospatial services are defined as those that let decisions be made based on geographic data. The geospatial services industry is defined as: "Groups of companies and organizations providing the tools and technologies for end users to benefit from location-based information."

Uses of geospatial services are discussed and estimates are provided for the size of the industry, the size of affected industries and some benefits. Since sources and methods for the magnitudes of cost savings/efficiency gains and value to consumers are not well documented their validity cannot be determined.

Since sources and methods for the magnitudes of cost savings/efficiency gains and value to consumers are not well documented their validity cannot be determined.

Quantitative findings include:

- The geospatial services industry generated annual revenues of almost $75 billion in 2011 and provided 500,000 high wage jobs. The industry will approach $100 billion in revenue in the next five years (2016).
- Three primary sectors of the industry have the following revenues:
    - Geo-expert industries $2.6 billion.

[54] The Boston Consulting Group, "Geospatial Services: A $1.6 Trillion Growth Engine for the U.S. Economy, BCG, June 2012 http://www.bcg.com/documents/file109372.pdf and The Boston Consulting Group, "Putting the U.S. Geospatial Services Industry On the Map," slides, BCG, December 2012 http://education.nationalgeographic.com/media/file/BostonConsultingGroup_US_FullReport.pdf

- Geo-applications and devices $54 billion.
- Location-based geo-data $17 billion (which is for imaging satellite manufacturing and launch, imaging programming and platform providers).[55]

- Geospatial services are used on a daily basis by roughly 5.3 million workers.
- Geospatial services companies drove $1.6 trillion in revenues throughout the U.S. economy. The $1.6 trillion figure includes all spending by companies on logistics and marketing. The economic impact of three key business functions of geospatial services: logistics, marketing and strategic decision-making will grow over 10% per year over the next five years.
- The industry contributes $1.4 trillion in cost savings to the economy. Continuing technological innovations will lead to efficiency gains that add $2.6 trillion to broader economic activity in the next five years. The impact of geospatial services on the economy is 15-20 times the size of the geospatial industry.
- Consumers (households) believe they receive $37 billion per year in value above what they pay for devices, applications and access. (This is what economists call consumer surplus.)

The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption, NDP Consulting, 2011

This report[56] was prepared for the Coalition to Save Our GPS which was made up of companies in the GNSS industry concerned about the proposed LightSquared terrestrial broadband system interfering with the GPS signals. The study covers commercial applications in the U.S. Benefits to households and governments are not included. Inclusion of non-economic benefits such as those to safety and the environment was not requested.

ABI Research data on GPS user equipment revenue and shipments by application for 2009 was extended to 2010. Less than half of revenue was for the commercial sector.

Benefits were measured by productivity increases and cost savings. Benefits of sectors were for differing years between 2005 and 2010.

Benefits were estimated for three sectors: precision agriculture (crop farming), heavy and civil engineering

> In addition to estimating current adoption rates, values for adoption rates of 100% in each sector were used as the upper limit. This greatly inflated the range of benefits for each of the sectors and the total.
>
> A major assumption was then made that the gains in commercial sectors outside the three sectors for which benefits were estimated were as large as those in the sectors that were measured…

[55] The American Society for Photogrammetry and Remote Sensing assessed remote sensing revenue alone as $7 billion in 2010, with forecasts of $8 billion in 2012 and $12 billion in 2014, based in its Gross Revenue Survey of members. See American Society of Photogrammetry and Remote Sensing, "ASPRS Ten-Year Remote Sensing Industry Forecast, Phase IV," *Photogrammetric Engineering and Remote Sensing* (November 2011), pp.1081-1095 http://onlinedigitalpublishing.com/publication/?i=86396

[56] NDP Consulting, *The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption*, June 2011 http://www.gps.gov/governance/advisory/meetings/2012-08/pham.pdf

construction, including surveying and mapping, and commercial surface transportation.[57] Values for efficiency improvements and market adoption were based on assessment of available studies and discussions with industry.

The study assumed that percentage cost savings in all commercial surface transportation was equal to that for fleet vehicles. Benefits found in studies that largely relate to grains were assumed to apply to all crop faming. These assumptions may significantly overstate the estimates.

In addition to estimating current adoption rates, values for adoption rates of 100% in each sector were used as the upper limit. This greatly inflated the range of benefits for each of the sectors and the total. There was no discussion of when, if ever, 100% adoption rates may be reached. Using 100% as the upper limit has been misleading and has caused members of the press to treat the upper range as equally important as a measure of current benefits.

A major assumption was then made that the gains in commercial sectors outside the three sectors for which benefits were estimated were commensurate with those in the sectors that were measured (using a weighted average of gains in relation to equipment and software costs).

The possibility that relative benefits are greater for sectors that are better measured (i.e. the three sectors included) than in those for which benefits are less well measured was not considered. This could happen, for example, if better results are more likely to be reported where there are better measures or if activities can be better managed where there is good measurement of performance and outcomes.

Annual benefits were estimated in billions of dollars as:

Precision agriculture (crop farming)	$19.9-$33.2
Heavy and civil engineering construction and surveying/mapping	$9.2-$23.0
Commercial surface transportation	$10.3-$15.1
Subtotal of three sectors	$$39.4-$71.3
Extrapolation for other commercial GPS users	*$28.2-$58.1*
Total commercial GPS users in the economy	$67.6-$122.4

Indirect effects were measured by inputs purchased from other industries. Induced effects on the rest of the economy were not included. The current study estimates are compared with these in Appendix E.

The NDP Consulting study estimated the potential cost of LightSquared signal disruption alternatively as a 100% and 50% loss of the benefits calculated for each of the three covered sectors using the lower end of the range of benefits and not the assumption of 100% market adoption. It also estimated investment

[57] The commercial surface transportation estimate assumed the benefits per mile for non-fleet commercial vehicle miles travelled was the same as for fleet vehicles.

losses in GPS equipment and losses in foregone equipment sales and R&D spending by GPS equipment manufacturers. Total losses were $96.0 with 100% signal disruption and $48.3 with 50% disruption.

The Economic Benefits of Global Navigation Satellite System and Its Commercial and Non-Commercial Applications, NDP Analytics, 2013

This follow-up to the NDP Consulting study by NDP Analytics for the PNT Advisory Board was led by its primary author, Nam D. Pham. The primary purpose was to expand benefit estimation beyond the previous focus on commercial applications.[58]

The report displays data from the GSA 2003 report which was discussed previously and restates data extended from ABI Research estimates of GPS user equipment market size from the 2011 NDP Consulting report.

Data from the 2011 Census Bureau's Annual Survey of Manufacturers was presented for three NAICS 6-digit industry categories and labeled as the GNSS manufacturing industry. The sectors are vastly larger than the GNSS user equipment, software and services industry. Despite that, the report goes on to estimate "economic benefits" for the total of the three categories, including revenues, value added and indirect inputs.

Benefit estimates from the 2011 report were then restated without updating and three estimates of benefits from other sources were cited. Geospatial services were cited uncritically from the BCG study as generating $1.6 trillion in economic activities and $1.4 trillion in cost savings.[59] For aviation, a projection of $123 billion to be saved by NexGen through 2030 was cited based on an FAA analysis.[60] An intelligent transportation systems projection attributed to DOT as referenced in a GAO report was cited without explanation as showing a present value of savings of $30.2 billion through 2018, including economic, environmental and safety benefits.[61] The report also cited the Oxera estimate of global value added for geospatial services and the BCG estimate of geospatial services industry U.S. revenues.

The study did not make any new benefit estimates.

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[58] NDP Analytics, *The Economic Benefits of Global Satellite System and Its Commercial and Non-Commercial Applications, December 2013* *http://static1.squarespace.com/static/52850a5ce4b068394a270176/t/52d57f29e4b0dad117c5e3bb/1389723433433/Economic+Impacts+of+GPS+December+2013.*pdf

[59] As noted, the BCG estimates are not sufficiently documented to evaluate their validity.

[60] This is apparently taken from the July 21, 2011 letter and appendices to Karl B. Nebbia, Associate Administrator of NTIA by Joel Szabat of the Office of the Secretary of DOT for testimony on the impacts of LightSquared http://science.house.gov/sites/republicans.science.house.gov/files/documents/Letters/2011%2007%2021%20DOT%20LSQImpact%20Assessment.pdf The letter also stated that current GPS efficiency benefits for aviation are at least $200 million per year.

[61] The number is likely from a report: Transparency Market Research," Intelligent Transportation Systems Market (ITS) Is Expected to Reach USD 30.2 billion by 2019,"April 20, 2014. The press release is at http://www.transparencymarketresearch.com/pressrelease/intelligent-transportation-system-market.htm

Current U.S. Economic Benefits of the Global Positioning System, Irving Leveson for Aerospace Corporation (Internal), 2010

The Leveson study was designed as the first stage of an initial effort to determine the overall quantitative civilian benefits of GPS to the United States. It was conducted for the National Coordination Office for Space-Based Positioning, Navigation and Timing under the auspices of the Aerospace Corporation.[62] Estimates were for 2008. The second half of the study, which was to have refined the estimates and conducted other analysis, was not funded, and the initial report has not been released.

The study examined many source materials and made rough estimate for 18 categories. Benefits included direct and indirect economic benefits and aspects of broader benefits to society such as those to safety-of-life and the environment. Direct economic benefits were measured by improvements in productivity or cost savings. The study covered commercial and some household and government benefits.

Information on economic benefits was too limited to provide robust estimates for many sectors. Some estimates were crude or partly "notional." Since not all important applications could be included, the overall estimates were referred to as "at least." Because of the assumptions required they were described as "ball park." It was suggested that the sector estimates might be sufficiently unbiased or conservative that their total could yield a reasonable minimum order of magnitude as a result of averaging errors across sectors based on the Law of Large Numbers.

Canadian Geomatics Environmental Scan and Economic Value Study, 2015

Natural Resources Canada's Mapping Information Branch, in collaboration with the Canada Centre for Remote Sensing and the Surveyor General Branch, commissioned the study to include:

- The state of the geomatics sector in Canada
- Global trends involving geospatial information and Canada's position relative to those trends
- The significance and value of the geomatics sector and geospatial information to the Canadian economy
- The current new and alternative roles for government, industry and academia in driving, supporting and using geospatial information

The economic value study estimated the direct and indirect value and contribution of private firms to the Canadian economy and examined the value of open geospatial information within the Canadian economy.

[62] Irving Leveson, *Current U.S. Economic Benefits of the Global Positioning System*, Interim Report to the National Coordination Office for Space-Based Positioning, Navigation and Timing, The Aerospace Corporation, internal interim report, March 16, 2010.

The study was carried out by Hickling Arthurs Low in partnership with ACIL Allen Consulting, Fujitzu Canada and ConsultingWhere. The summary report was released in May 2015 and two more detailed reports are planned.

The study found:

- Firms in the private geospatial sector contributed $2.3 billion to Canada's GDP in 2013. The sector includes location-based services, broadly defined.
- Geospatial information use resulted in $20.7 billion in additional GDP, an increase of 1.1% of GDP, 19.6 million additional jobs and a $2.8 billion increase in the net trade surplus.

The economy-wide effects were based on inter-industry and international relationships estimated from productivity data for sectors in a Computable General Equilibrium (CGE) model. The productivity estimates for applications that were entered into the model were not included in the summary report.

The results imply increases of over $1 million per added job. It is reasonable that job increases were low compared to revenue increases because productivity improvements reduce some jobs at the same time as lower prices from productivity gains raise demand for others. The statistic by itself does not say anything about whether there were gains in high wage jobs.

The Value of Augmented GPS in Australia, 2013

This is a series of nine sector reports and a summary report. The summary report is titled *The Value of Augmented GPS in Australia* and the sector reports are titled *Precise Positioning in Australia.*[63]

The studies examined productivity and related benefits in 2012, relying on case studies, discussions with industry and findings of previous studies. The breadth of the study is ambitious, but for some sectors the quality of the estimates is constrained by the limited numbers and scope of case studies and interviews. Quantitative benefit estimates are not provided for all sectors. Adoption rates utilized appear to be very rough assumptions.

Aggregate effects are calculated using a Computable General Equilibrium model of the economy. The study found that by 2012 Australia's real GDP was between $2.3 billion and $3.7 billion higher than it would have been without the accumulated productivity improvements arising from augmented GNSS

The Value of Spatial Information in Australia, 2008

The value of spatial information in Australia was examined by ACIL Tasman in a March 2008 report for the Cooperative Research Centre for Spatial Information and ANZLIC – The Spatial Information Council. [64]

[63] The summary report is ACIL Allen Consulting, *The Value of Augmented GNSS in Australia*, Prepared for the Australian Department of Industry, Innovation, Climate Change, Research and Tertiary Education, June 2013 http://www.acilallen.com.au/cms_files/ACILAllen_AugmentedGNSS.pdf The full set of citations is in the references at the end of the present report.

The value of spatial information was defined to include the difference in economic performance with vs. without spatial information. The study used estimates and assumptions drawing on available case studies and literature to develop productivity effects and levels of adoption for applications in each spatial information category for the single year 2006-2007.

Productivity was taken to include cost savings, revenue gains and/or facilitation of new applications. Direct impacts of spatial information on productivity and resources were measured along with the extent of adoption, which in many cases was low. Non-economic benefits were discussed but not quantified.

The study relied on extensive quantitative information available from case studies and reported literature and interviews. These were synthesized in conservative judgments about magnitudes of benefits in individual application areas. In many cases assumptions were made about adoption rates because of the absence of information. For each application a "quantifiable lower bound" little documented number that was designated a "realistic" value. While the framework for assimilating the estimates attempts to be complete, the conclusions depend heavily on these assumptions, especially with regard to the "realistic" values and projections.

The productivity values were entered into a CGE model that included an Input-Output framework to take account of secondary effects on other sectors, including productivity changes in other sectors and expansion of resources.[65] Including the expansion of resources through the model raised the size of the productivity gains by about 20%.

The model analysis of overall effects used a different classification than was used for direct productivity effects. The authors were able to directly match eight of 22 categories between tables 18 and 20 of the study and had to make adjustments for the rest.[66]

Since benefits were compared with the gross value added of the spatial industry, the benefit/cost ratio should be understood as describing what the benefits of spatial information would be *given* that investments already had been made in GPS, telecommunications, equipment to collect or make use of the information (such as automated tractors) and other systems.

This CGE model traced the effects of productivity increases across the economy. The use of historical relationships in the model could have limited the ways in which spatial information impacts can occur, such as by facilitating new products, markets and production methods.

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[64] ACIL Tasman, *The Value of Spatial Information*, prepared for the Cooperative Research Centre for Spatial Information and ANZLIC – The Spatial Information Council, March 2008.

[65] The Tasman-Global model used is a Computable General Equilibrium model developed from the Global Trade Analysis Project database (GTAP) constructed at the Center for Global Trade Analysis at Purdue University. The input-output model was developed to study international trade. Insufficient information is given in the report to determine in the aggregate how much difference was made by including general equilibrium effects that were added to direct productivity effects.

[66] Five of the eight categories showed greater overall productivity effects than direct effects while three showed lower effects. In the five cases with greater direct effects, the addition of effects on expanding resources raised the gains further.

Adding less well-measured influences in the "realistic" scenario doubled the *aggregate* impact of spatial information on GDP. This result occurred despite far smaller differences between the base and realistic scenarios for almost all individual industry categories.[67] [68]

The impact on GDP between the more conservative lower bound scenario and the "realistic" scenario ranged from $6.43 billion to $12.57 billion Australian dollars, or from .61% to 1.20% of GDP.[69] Cumulative impacts on GDP in the single year examined were 10-18 times the $682 million Australian dollars of gross value added of the spatial industry.[70]

Since benefits were compared with the value added of the spatial industry, the resulting benefit/cost ratio should be understood as describing what the benefits of spatial information would be *given* that investments already had been made in GPS, telecommunications, equipment to collect or make use of the information (such as automated tractors) and other systems.

High Resolution Positioning Services in Australia, 2008

Allen Consulting group estimated Australian productivity gains for agriculture, mining and construction and projected market penetration rates to 2030.[71]

Aggregate effects were calculated using a CGE model that included both economic benefits to using firms from assumed cost savings and higher outputs and benefits to upstream and downstream industries.

The study found 2008 benefits to the Australian economy from use of high resolution positioning services in agriculture, mining and construction of between $829 million and $1.5 billion.

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[67] Insufficient information is given in the report to determine in the aggregate how much difference was made by including general equilibrium effects that are added to direct productivity effects vs. other factors introduced by using the model.

[68] The difference between the aggregate and the specific industries may be attributable in part to a large role assumed for government. The scenario for government that includes unmeasured productivity gains showed three times the size of the narrower one (1.05% of GDP vs. 0.34%). ACIL Tasman, *The Value of Spatial Information*, prepared for the Cooperative Research Centre for Spatial Information and ANZLIC – The Spatial Information Council, March 2008, pp.128-129.

[69] *Ibid*.

[70] *Ibid*. p.135 and pages 5-6.

[71] Allen Consulting Group, *Economic Benefits of High Resolution Positioning Services*, Final Report prepared for the Victorian Department of Sustainability and Environment and the Cooperative Research Centre for Spatial Information, Australia, November 2008 http://crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf

Selection of Categories for Estimation

Scope of Analysis of Available Studies of Civilian Economic Benefits

Benefit information is compiled from several dozen studies in Appendix A, with emphasis on those reporting productivity, cost and time savings and cost avoidance, and willingness-to-pay. Direct productivity and cost savings benefits are included in most studies.[72] Costs of using GPS and associated equipment are not reported in many of the studies considered. Analyses are for the U.S. except where indicated.

Great differences exist in which activities are covered. For example benefit information may be provided for only some agricultural functions such as seeding, fertilizing, placing pesticides, and harvesting. They also can be highly concentrated on one activity, such as earthmoving in construction. Differences in scope affect the ability to make estimates and can allow estimation for specific functions only.

Because technologies are used or introduced together, even the best comparisons between outcomes with and without GPS typically do not fully distinguish the contributions of GPS from those of other systems and equipment. Also, while most of the studies involve only GPS, some apply to situations where GLONASS is in use, as with Australian Studies and recent high precision applications in the U.S. Available analyses do not attempt to separate the effects of use of GLONASS from GPS. Where benefit information is available for application systems that employ or are enabled by GPS along with other technologies it is necessary to designate a portion of benefits as applicable to GPS.

The sector categories in the analysis are those that are used by the GNSS industry. Thus, agriculture, construction and mining are grouped under “machine control” and broadband communications and the Internet, electricity generation and transmission and financial services are grouped under “timing.” There are categories for Geographic Information Services (GIS) and Location-Based Services (LBS). Within categories and for industries that are not in groupings used by the GNSS community, listings are in the order of the 2012 North American Industry Classification System.

The classification of benefits is intended to focus on applications wherever they occur. There are no separate categories for government vs. private services. Surveying, nautical charting and remote sensing are considered separately.

Some studies appear under more than one industry category because the function (e.g. surveying, asset management) takes place in specialized firms as well as within other sectors or because the function occurs in multiple sectors.

[72] Exceptions are made in a couple of cases to note magnitudes in the absence of other data.

Overview of Availability of Benefit Information

The most extensive information is available for agriculture, construction, surveying and fleet vehicle navigation and routing. Availability of information on benefits in other transportation sectors is mixed. Information is very limited for location-based services other than those that are vehicle-related and for mapping and other geographic information systems and services.

GNSS uses in manufacturing largely consist of communications, surveying and mapping, asset tracking, vehicle navigation and locating people, which are considered without regard to industry. Except for surveying and vehicle navigation, these not have sufficient information to estimate.

Surveying within other sectors such as agriculture and construction is in the separate surveying category. Commercial vehicle use within other sectors is in the separate categories for fleet vehicle and for household plus commercial vehicle other than fleet.[73]

Nautical charts are included in marine transportation because they are primarily used for marine navigation and situational awareness.

Timing applications are especially important in communications, power generation and transmission and financial services. Some information is available to estimate overall benefits of sectors that use precise time and sychronization. However, quantitative information on direct benefits of timing to economic sectors is not readily available and data on use of GPS for timing is scarce. Timing benefits of GPS are estimated based on avoided costs of alternatives so as not to attribute overall timing benefits to GPS. However, this may not fully recognize the benefits that GPS timing provides.

Categories for which sufficient quantitative economic benefit information for a national estimate has not yet been found or developed include emergency response services, search and rescue, forestry, mining and energy exploration and development, location-based services for recreation other than boating and for health and fitness, structural deformation monitoring of bridges, dams and buildings, earthquake monitoring, radio occultation and other weather forecasting applications, space other than remote sensing such as positioning satellites, and other science and environmental applications.

Some applications that may be important in the future are not included because they are new, use is not yet large and/or information on benefits is limited or unavailable. These include Intelligent Transportation Systems, NG911 emergency calling, wearables, tolling and UAVs. Estimates of NextGen benefits for aviation are included in the tabulation because of their possible value in understanding magnitudes of current GPS benefits.

[73] Some of these activities also may be covered in other sectors, depending on whether they were included in sources that were relied on. In principle, it would be desirable to count the benefits of that portion of surveying which sets up geodetic controls, creates 3D models for the machine control system and monitors machine control operation as benefits in agriculture, construction, mining and other industries that use machine control.

Criteria for Benefit Estimation and Their Application

The potential for making estimates of economic benefits was categorized in three basic levels In Table 4. Emphasis was on including the more robust estimates.

A. confident based on one or more robust estimates
B. indicative based on one or more less robust estimates
C. notional illustrative, if major contributions of other technologies are not separated and estimates must be based on a plausible percentage of a larger benefit, or if information is not available and estimates must be based on a percentage of market size

Choices among categories for estimation and among estimation methods depend not only on which of the basic criteria are satisfied but also on the following additional criteria:

1. The importance of the sector to the economy, for example as an enabler of other activities
2. The potential use of benefit estimates for the category as an input into analyses of the effects of signal disruption.

Communications, power and financial services were included in Table 4 to reflect the initial review of evidence before the decision was made to estimate timing benefits based on the avoided costs of alternatives.

Studies were assessed using explicit criteria to determine categories for inclusion and to select studies that can form the basis of estimation. Studies to rely on as a basis for estimates of benefits in a category were selected according to how well they met the following criteria:

GPS: A test of introduction of GPS or comparison with and without GPS rather than benefits of a broader service

Coverage: Estimates that cover a major part of the category

Robustness of estimates, including the type of review the source is likely to have had

Consistency: If alternative better estimates are not in such a wide range that an average is less meaningful except where explainable by expected sources of variation.

Timeliness: Preference to a recent period being covered by the estimates

Table 4. Applicability of Criteria for Estimation			
Application Category	**Basic Criteria Met**	**Additional Criteria Met**	**Comments**
Precision Agriculture	A, B		Sufficient information available only for grain
Construction	A		Sufficient information available only for earthmoving
Open Pit Mining			Insufficient information
Forestry and Fisheries			Insufficient information
Energy Exploration and Development		1	Insufficient information
Broadband Communications and Internet Connectivity	C	1, 2	Rough estimates are possible for the value of the industries but not for GPS
Electricity Generation and Transmission	C	1, 2	Information is available for overall costs of loss of power
Financial Services		1, 2	Insufficient information
Air Transportation	A	1, 2	Estimate supplied by FAA
Rail Transportation	B	1, 2	Information contributing to estimation provided by FRA
Marine Transportation	C	1, 2	Estimated based on nautical charts
Commercial Vehicle	A	1	Information available for fleet telematics
Surveying	A	1	
Land and Coastal Mapping		1	Insufficient information
Nautical Charts and Related	B	1	Included in marine transportation
Other GIS			Insufficient information
Emergency Services		1	Benefits are largely in reduced loss of life
Asset Tracking and Management n.e.c.			Insufficient information
Consumer LBS	B	1	Non-fleet vehicle
Recreation - LBS			Insufficient information
Health - LBS			Insufficient information
Education			Insufficient information
Space n.e.c.		1	Some information is available for remote sensing
Weather Forecasting	C	2	Some information is available on benefits of weather forecasting. Radio occultation is vulnerable to disruption but quantitative information on benefits is not available

The categories in Table 5 were selected for GPS benefit estimation.

Table 5. Categories for Benefit Estimation	
A	Precision Agriculture – grain
A	Earthmoving with machine guidance in construction
A	Surveying
A	Air Transportation
C	Rail Transportation – Positive Train Control
C	Marine Transportation – private sector use of nautical charts and related marine information
A	Fleet Vehicle Connected Telematics
A	Timing 1 – Loran
A	Timing 2 – GEOs
B	Consumer and other Non-Fleet Vehicle 1 –willingness to pay
A	Consumer and other Non-Fleet Vehicle 2 –value of time

Benefit Estimates for Applications

Precision Agriculture – Grain

Market Value of Grain Products Sold

The analysis focuses on grain in large farms because it has the most use of GPS and information on benefits and adoption, and makes up the greater part of GPS's agricultural contribution.[74,75] The market value of grain products sold in farms with sales of $250 million or more in 2012 was $114.0 billion.[76] This value is used for 2013. It contains small amounts for oilseeds, dry beans and dry peas. Since the separate category "other grains, dry peas and dry beans" was $2.1 billion, $1.0 billion is deducted for the non-grain portion included with grain sales, resulting in a value of $113.0 billion.

Government payments are included as well as product sales. The market value of all products sold without government payments was 98.7% of the total revenue for all farms and products. Assuming that percentage applies to large grain farms the value of their sales is $111.5 billion.

Productivity and Cost Savings

Systems utilizing GNSS are estimated to save 10%-15% in operating costs and purchased inputs for grain farming based on a composite of estimates of several studies.

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[74] Grain represents the majority of the value of agricultural revenue, the overwhelming share of grain production is in of large farms and there is evidence of higher GPS adoption rates and yield improvements in grain than in other crops.

[75] Non-grain farming was not estimated both because GPS use and savings are less certain and any estimate would be small. Non-grain farming is smaller than grain farming, efficiency benefits may be on the order of 2% and market penetration may be on the order of 15%.

[76] Data on market value of grain products sold is from U.S. Department of Agriculture, *2012 Census of Agriculture*, May 2, 2014 http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf and U.S. Department of Agriculture, *2013 Agricultural Statistics Annual*, http://www.nass.usda.gov/Publications/Ag_Statistics/2013/Agricultural_Statistics_2013.pdf

A composite of estimates of yield increases associated with improved plant health is an additional gain of roughly 8%-10%.[77] This also applies to the total market value of products sold rather than just to value added since yield derives from both operations and purchased inputs.

The combined percentage of efficiency benefits is 18%-25%.

Adoption

Adoption rates for grain farming apply to use of any GPS-related machine technologies. In the absence of more complete data, the adoption rate for GPS in agriculture is taken to be the rate of the process or technology which has the highest adoption rate and the gain from that process is used. Whether this results in an underestimate or overestimate of what a combined impact of all technologies using GPS would show depends on what the evidence on productivity or cost savings applies to.

If the gains from the process apply to the whole sector and there are other processes with lower adoption rates which also benefit from GPS, the contribution of GPS will be underestimated. If the gains from the process apply to part of the sector and there are other processes involving GPS, the result may be either an underestimate or an overestimate. If the gains from the process apply to part of the sector and other processes involving GPS have low rates of adoption, there may be an overestimate from treating the most widely adopted process as applying to the whole sector.

John Deere estimated that auto-guidance was used in 2011 by 65% of grain farms with $250 million or more in products sold and assessed that it may have increased to 70% in 2014.[78] Consequently, adoption of 68% is used for 2013. The adoption rate is consistent with estimates of USDA for corn, soybeans and rice.

Contribution of GPS vs. other Technologies

The contribution of GPS vs. other technologies and GNSSs associated with its use is assumed to be 60%-70% based on consideration of the complementary technologies in use. Other technologies may include improved seed and pesticides that may be introduced along with adoption of GPS technology and methods such as improved field surveying and mapping, improved irrigation, non-GPS yield monitoring

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[77] The additional gain from yield improvements has been recognized explicitly in estimates by John Deere, for example in Benjamin Smith, "Economic Benefits of Precision Agriculture," presentation at the meeting of the National Space-Based positioning, Navigation and timing Advisory Board, August 14, 2012 http://www.gps.gov/governance/advisory/meetings/2012-08/smith2.pdf and in studies such as Allen Consulting Group, *The Economic Benefits of Making GPSnet Available to Victorian Agriculture*, Final Report to the Victoria Department of Sustainability and the environment, July 2007.

[78] John Deere estimated that yield mapping was used by about 70%-75% of all crop farms in 2014 and autoguidance by 70% of large farms (over $250,000 in sales), up from 65% in 2012. Autofeeder use was 10%-20% in 2014. Benjamin Smith, "Economic Benefits of Precision Agriculture," presentation at the meeting of the National Space-Based positioning, Navigation and timing Advisory Board, August 14, 2012 http://www.gps.gov/governance/advisory/meetings/2012-08/smith2.pdf and discussions with John Deere.

and other changes that may have been brought in at the same time a GPS-enabled functions were being introduced or upgraded.

Benefit Estimates

The calculations are shown in Table 6. Note that the value of production is calculated before the gain is applied (line 2) by adding the gain to the total.[79] The percentage by which line 2 values are greater than those in line 1 is that which yields the line 1 value when the efficiency gain is applied to line 2. If instead the gain was applied to the observed value of production in line 1, the amount of the gain would be understated. The understatement would be particularly great if the percentage gain were large.[80] This procedure is used in calculations of benefits for other sectors where required.

The average of the adjusted benefit estimates is $13.7 billion, the mid-range is $13.9 billion and the range is $10.0-$17.7 billion.

Table 6. Calculation of Grain Farming Productivity Gains Associated with GPS in Large Farms

	18% efficiency gain	**25% efficiency gain**
line 1. market value of grain products sold in 2013 net of government payments	$111.5	$111.5
line 2. value before productivity gain = 1/(1- fraction of gain) x line 1	$136.0	$148.7
line 3. productivity benefits if 100% adoption = line 2 x % productivity gain	$24.5	$37.2
line 4. **benefits with adoption rate of 68% applied to line 3**	**$16.7**	**25.3**
line 5. % of benefits assumed attributable to GPS vs. other technologies and GNSSs	60%-70%	60%-70%
line 6***. adjusted benefits of GPS in grain farming*** (line 4 x line 5)	***$10.0-$11.7***	***$15.2-$17.7***

[79] For this purpose yield improvements are treated as equivalent to a higher value of production.

[80] The method does not include effects of price declines with cost and productivity gains that may lead to further output by expanding demand for farm products. Some benefits of reduced output prices accrue to other parts of the economy and may be reflected in a multiplier analysis.

Earthmoving with GPS Machine Guidance in Construction

Sufficient information on construction productivity and cost savings is available only for estimating benefits of earthmoving functions. Earthmoving includes bulldozing, scrapers unloading or removing topsoil, loading excavated material into trucks, truck dumping of fill material, road base or other materials, grading and compacting.

Value of Construction Put in Place in 2013

The value of public and private construction put in place in 2013 was $898.4 billion.[81] Value added in construction was $619.9 billion in 2013, or 69% of the value of construction put in place.[82] The gains are applied to the value of construction put in place because savings occur in purchased inputs for the construction process as well as in productivity gains.

Earthmoving as a Percent of Construction Activity

ACIL Allen estimated in 2013 that earthworks represents "*up to approximately* 10-15% [italics added] of non-residential construction activities" in Australia based on a 2008 report of Allen Consulting that relied in part on unspecified current estimates by engineering firm SKM. The study used the 15% figure for its economic modeling.[83]

A 2011 survey of members of the Commercial Real Estate Development Association found that site development, which includes grading, infrastructure, parking and landscaping, was 16.6% of total office, industrial, warehouse and retail construction costs.[84]

Because the ACIL Allen estimate of the share of earthmoving in construction is "up to" 10%-15% and the Commercial Real Estate Development Association number of 16.6% includes other items, a lower range of 8%-12% is used. In the absence of a more comprehensive estimate this value for non-residential construction is applied to all construction. Applying 8% and 12% shares of construction, the value of earthmoving activity is

[81] U.S. Department of Commerce, "December 2013 Construction at $930.6 Billion Annual Rate," U.S. Census Bureau News, CB14-16, February 3, 2014 https://www.census.gov/const/C30/release.pdf Subsequent revisions would not significantly affect the estimates.
[82] U.S. Department of Commerce tables of GDP by industry.
[83] ACIL Allen Consulting, *Precise Positioning Services in the Construction Sector*, Prepared for the Australian Department of Industry, Innovation, Climate Change, Research and Tertiary Education, June 2013, p.A-10. http://www.ignss.org/LinkClick.aspx?fileticket=ntyClJz4fh8%3D&tabid=56
[84] Stephen S. Fuller, *How Office, Industrial and Retail Development and Construction Contributed to the U.S. Economy in 2011*, NAIOP Research Foundation, May 2012 http://www.epra.com/media/2011_RE_Contribution_to_US_economy_NAIOP_1357139352294.pdf

$71.9-$107.8 billion.

Productivity and Cost Savings

Savings in project time result in the use of less operator labor and fewer bulldozers and other equipment. Integration of surveying into the construction machinery saves time of surveyors and inspectors. Speeding up work produces savings in operator labor, fuel and use of machines, better scheduling within jobs, coordination of equipment and personnel availability with other jobs and obtaining benefits of the product sooner. Use of GNSS in construction has been shown to result in fuel saving that are much larger in percentage terms than productivity increases in the studies that measured it. There may be savings in materials as well. One study found large savings in the volume of sand required in excavating a trench for laying pipe.[85]

Productivity improvement of 10%-30% is a composite of estimates of several studies and is the range utilized by ACIL Allen in its 2013 study of precise point positioning.[86] The wide range reflects variation in sites and equipment used. A more realistic range of 18%-22% is used as an estimate for the average across sites for the industry as a whole.

Adoption

The estimate of adoption must take into account use of different technologies. Not all machine control uses GNSS. In machine guidance GPS is sometimes used exclusively and sometimes with Lidar. As with agriculture, adoption is defined here to include any use of GNSS-related machine technologies.[87]

The Transportation Research Board reported results of a March 2012 survey covering 97 representatives of state transportation departments and 13 representatives of service providers. Twenty percent of DOT representatives reported that machine control was a standard operating procedure and 20% were implementing it. Two thirds of representatives using machine control were using it for construction and one forth were using it for design. Sixty two percent of service providers were using machine control.[88] As noted, however, not all machine control relies on GNSS.

Projecting from a 2012 estimate to 2013, ACIL Allen finds about a 20% adoption rate for machine guidance and about 3% for machine automation in Australia.[89] Available studies of benefits primarily apply to machine guidance. Movement from 2D to 3D modeling which relies on GNSS and greatly reduces the costs of traditional surveying is very much in transition in the U.S. in recent years. The U.S. is

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[85] Aδalsteinsson, Daδi Hranner, "GPS Machine Guidance in Construction Equipment," Working Paper, School of Science and Engineering, Reykjavik University, Spring 2008, p.35 http://construction.trimble.com/sites/construction.trimble.com/files/marketing_material/%20white%20paper%20-%20Productivity%20Report%20GPS%20For%20Excavators%202008.pdf

[86] *Ibid*.

[87] See earlier discussion.

[88] Transportation Research Board, *Use of Advanced Geospatial Data, Tools, Technologies, and Information in Department of Transportation Projects*, NCHRP Synthesis 446, 2013 http://www.trb.org/main/blurbs/160202.aspx

[89] *Op*. *cit*.

assumed to have greater overall GNSS adoption than Australia because of its concentration of technology development and economies in marketing with a large market size.

Adoption of 20%-25% is assumed for the U.S. to allow for an expected somewhat higher adoption than in Australia.[90] The adoption rates used apply to any GPS techniques on heavy earth moving equipment.

Contribution of GPS vs. Other Technologies

The contribution of GPS vs. other technologies and GNSSs associated with its use is assumed to be 80% to 90%.

Benefit Estimates

The calculations are shown in Table 7.

Table 7. Calculation of Earthmoving Productivity Gains Associated with GPS

	18% productivity gain		**22% productivity gain**	
	earthmoving 8% of construction	**earthmoving 12% of construction**	**earthmoving 8% of construction**	**earthmoving 12% of construction**
line 1. value of construction put in place in 2013	$898.4	$898.4	$898.4	$898.4
line 2. 2013 earthmoving value at 8% or 12%	$71.9	$107.8	$71.9	$107.8
line 3. value before productivity gain = 1/(1- fraction of gain) x line 2	$79.9	$154.0	$79.9	$154.0
line 4. productivity benefits if 100% adoption = line 3 x % productivity gain	$14.4	$27.7	$17.6	$33.9
line 5. **benefits with adoption rates of 20%-25% applied to line 4**	**$2.8-$3.6**	**$5.5-$6.9**	**3.5-$4.4**	**$6.8-$8.5**
line 6. % of benefits assumed attributable to GPS vs. other technologies and GNSSs	80%-90%	80%-90%	80%-90%	80%-90%
line 7. ***adjusted benefits of GPS in earthmoving*** (line 5 x line 6)	***$2.2-$3.2***	***$4.4-$6.2***	***$2.8-$4.0***	***$5.4-$7.7***

[90] In comparison, the 2011 NDP estimate of 40% adoption not only includes all construction but also all surveying and mapping in construction. Surveying and mapping have very high productivity and cost saving benefits and have very high adoption. Moreover, the lower result is stated as "potential benefits," not actual, and the upper limit calculation using a 100% adoption is not an estimate of current benefits. The rate is applied to 2007 data and not updated. The lower estimate, based on 2007 data, was $9.2 billion. NDP Consulting, *The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption*, June 2011 http://www.gps.gov/governance/advisory/meetings/2012-08/pham.pdf

The average of the adjusted benefit estimates is $4.5 billion, the mid-range is $5.0 billion and the range is $2.2-$7.7 billion.[91,92]

Surveying

Surveying is defined here to include all surveying, whether in private survey firms, by self-employed or in business or government organizations.

Market Size

Revenue of private surveying and mapping firms in 2012 was $4.6 billion in geophysical surveying and mapping and $5.8 billion in other surveying and mapping, a total of $10.4 billion.

These values are used together with employment data to separate surveying from mapping and to estimate the cost of surveying across all economic sectors.

Separating Surveying from Mapping

Surveyors represented 90.4% of all surveyors, cartographers and photogrammetrists in the NAICS engineering services category (code 541330) in 2012, according to the Bureau of Labor Statistics tables of occupation by industry. Applying that percentage to the revenue of $10.4 billion yields an estimate of the surveying revenue in private surveying and mapping firms of $9.4 billion.

Note that the calculation implies $1.0 billion for mapping in private surveying and mapping firms only. The mapping industry also includes publishers of maps, online mapping services and work of people in many businesses and occupations.

Surveying Spending in the Economy

An estimate is made for spending in the whole economy that takes into account all costs associated with surveying activities including other personnel and overhead costs.

Revenue per employee in private surveying and mapping firms was $145,300 in 2012 based on 61,941 employees. The firms had 15,000 surveyors and a total of 16,700 surveyors, cartographers and photogrammetrists. Assuming average revenue per employee is the same for surveyors as for the total of surveyors, cartographers and photogrammetrists, the average revenue per surveyor was $623,766.

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[91] The method assumes that cost declines with productivity improvements do not increase revenue in earthmoving.

[92] If value added had been used instead of the value of construction put in place, benefits would have been 31% lower. If the ratio of value added to revenue is higher in earthmoving than all construction, benefits would be in between this and the estimated values.

Private firms may have a higher skill mix than found in industry and had substantial sales and marketing costs. They also may have had a greater proportion of support personnel than in the rest of the economy.

Revenue per surveyor, cartographer and photogrammetrist in private surveying and mapping firms is reduced to $500,000 to take out selling costs on the assumption that GPS efficiencies would not affect those costs. The reduction is 500,000/622,517 or 80.2% to $7.5 billion.

The median salary of a surveyor was $56,230 nationally according to the January 8, 2015 version of the online BLS *Occupational Outlook Handbook*. The average salary would have been higher than the median, probably in large part because of inclusion of those in consulting firms. The median is taken as the average for surveyors outside of private surveying and mapping firms. Fringe benefits and overheads would add substantially to the figure. Also, there were 54,000 survey and mapping technicians in the economy vs. 42,000 surveyors. Those outside of private surveying and mapping firms need to be included in the cost per surveyor for the rest of the economy. A value of $180,000 per surveyor was used for the rest of the economy to include all costs associated with the survey process including other personnel. With 15,100 surveyors in private surveying and mapping firms and 27,300 in other settings, the full cost of surveying in the economy including associated personnel, but not selling costs of private surveying and mapping firms, is estimated at $12.5 billion.[93]

Productivity and Adoption

A composite estimate based on many studies is 45%-55% savings over conventional surveying over all types of surveying, including effects of using various augmentations.

Adoption of modern surveying is assumed to be 100%.

Contribution of GPS vs. Other Technologies

Surveying makes use of optical technologies, software and other technologies and GNSSs. Allowing for these, the contribution of GPS is taken as 80%-90%.

Benefit Estimates

The average of the adjusted benefit estimates is $11.6 billion, the mid-range is $11.6 billion and the range is $9.8-$13.4 billion. The calculations are in Table 8.

[93] This is comprised of $9.4 billion in private surveying and mapping firms and $4.9 billion in the rest of the economy. Selling costs of private surveying and mapping firms would add an estimated $2.0 billion to this spending on surveying and mapping.

Table 8. Calculation of Surveying Productivity Gains		
	45% productivity gain	**55% productivity gain**
line 1. value of surveying in 2013 excl. private firm selling costs (billion)	$12.5	$12.5
line 2. value before productivity gain = 1/(1- fraction of gain) x line 1	$22.7	$27.8
line 3. productivity benefits at 100% adoption = line 2 x % productivity gain (billion)	**$12.3**	**$15.3**
line 5. % of benefits assumed attributable to GPS vs. other technologies and GNSSs	80%-90%	80%-90%
line 6***. adjusted benefits of surveying*** (line 4 x line 5) (billion)	***$9.8-$11.1***	***$12.2-$13.4***

Air Transportation

Previous Benefit Estimates

The FAA NextGen Systems Analysis Office estimated in 2011 that GPS provided at least $200 million in efficiency benefits for aviation each year.[94]

The 2009 WAAS Business Case Analysis Report found economic benefits to users compared to instrument landing systems (ILS) of $46 million, of which $39 million was savings in passenger time.[95] Aircraft operator cost savings were not included. The projection for 2013 was $122 million.

[94] Joel Szabat, "Letter to Karl B. Nebbia, Associate Administrator, National Telecommunications and Information Administration, on the impact of the LightSquared Concept of Operations, and Appendices," U.S. Department of Transportation, Office of the Secretary, July 21, 2011 http://science.house.gov/sites/republicans.science.house.gov/files/documents/Letters/2011%2007%2021%20DOT%20LSQ%20Impact%20Assessment.pdf

[95] Federal Aviation Administration, *Wide Area Augmentation System (WAAS) Business Case Analysis Report*, Exhibit 300, Program Baseline Attachment 2 for WAAS Service-Level Mission Need Statement #0050, August, 2009.

Updated Benefit Estimates

The NextGen Systems Analysis Office prepared new estimates for 2013 for this study with a contribution from MITRE. Benefits came primarily from flight efficiency (time and fuel) with Performance-Based Navigation (PBN) and reduced delays in taking off to airports with low visibility made possible by WAAS. The analysis attributed benefits of $198 million to systems using GPS including WAAS.

Contribution of GPS vs. Other Technologies

60%-85% is taken to obtain a value for benefits of GPS, to roughly exclude the contribution of other components of the systems and equipment that use GPS, such as specialized communications, weather information, software and databases. The result is an estimate of $119-$144 million.

This is a minimum estimate since the analysis didn't include Area Navigation (RNAV) Standard Instrument Departure Routes (SIDs) and Standard Arrival Routes (STARS) or Require Navigation Performance (RNP) which may use GPS.

Rail Transportation

The focus of benefit estimation is on Positive Train Control (PTC) because it accounts for much of GPS benefits to railroads and several studies have been done. PTC is a family of technologies that often include RF communications and GPS positioning to keep track of train locations and movement authorities. The deadline for PTC implementation for statutorily ordered routes is December 31, 2015. The industry is far behind schedule and implementation was less complete in 2013 than currently, limiting the size of benefits.

Studies of Positive Train Control Benefits

Available studies project benefits prior to implementation rather than estimating actual benefits and are 5-10 years old. The Federal Railroad Administration (FRA) July 2009 study found that the value of benefits was likely to be below costs, and benefits to shippers were uncertain.[96] Potential benefits to shippers could include substantially improved reliability of shipment arrival times but that would come later when capacity increased. Significant safety benefits might be possible due to diversion of traffic

[96] Federal Railroad Administration, Positive Train Control Systems: Regulatory Impact Analysis 49 CFR Parts 229, 234, and 236, REPORT NUMBER: FRA-2006-0132, NOTICE NO. 1; RIN 2130-AC03, December 8, 2009 http://www.fra.dot.gov/eLib/Details/L01344

from highways. FRA did not include shipper or societal benefits in its conclusion but previous FRA research did.

Subsequent private studies differed greatly in what they counted but the most favorable still had marginal results. Estimates of PTC efficiency benefits vary greatly among studies because of differing definitions of PTC and partisan interests. The range of benefits is roughly $0.5-$2.5 billion per year at full implementation.

Adoption

PTC has been installed on about 8,200 miles of track out of 60,000 miles that are federally required to have it. At the end of 2014, about 15% of locomotives were fully equipped and railroads had installed on about 56% of the track systems. Only 1 or 2 rail lines are expected to meet the deadline. For most completion is expected in 2017-19.[97]

Adoption in 2013 is assumed to provide 5%-10% of benefits that would occur at full implementation.

Benefit Estimates

Railroads that have completed implementation of track, back office, wayside and communications subsystems can still get safety benefits but many have not. Business benefits depend on the functionality implemented.

Because of the difficulties in deriving unbiased estimates a wide range is used based on the high and low from available studies. Economic benefits include both benefits to railroads and those passed on to shippers. The range for 2013 benefits is placed at $25-$250 million per year.

Contribution of GPS vs. Other Technologies

40% of benefits are assumed to be attributable to GPS. This allows both for some PTC not using GPS and for GPS being used with other technologies.

Benefits of GPS

Taking 40% of $25-$250 million results in benefits of $10-$100 million. The state of knowledge is such that more precise values cannot be determined at the low levels of adoption in 2013.

Marine Transportation – Nautical Charts and Related Information

Vessel and other marine systems provide benefits by avoiding groundings and collisions that would otherwise result in injury and death, loss of ships, port shutdowns and other shipping delays, oil spills

[97] Based on discussion with FRA.

and damage to onshore property. Unfortunately, information is not readily available on how much is avoided or how much would still be avoided if non-GPS alternatives were used. Marine benefits of GPS are instead estimated based on the value of nautical charts to private users above the value of paper charts, which may be only a small part of overall marine benefits of GPS.[98] An example of a nautical chart is in Figure 9.

The Value of Nautical Charts

An estimate of the value of electronic nautical charts above the value of paper charts for commercial shipping and recreational boating was made by Kite-Powell using survey data from 2005-2006.[99] Since the benefits are those above paper charts they do not include the benefits of the data collection and charting required to produce charts at the level of those on paper. Benefits applied to "ideal" rather than the currently available charts and were measured by consumer surplus.[100] Figure 9 shows an example from NOAA of source information on nautical charts.

Leveson updated the estimates to 2011 based on industry size. He added commercial fishing and calculated total benefits combining spending and consumer surplus. (Table 9)[101] The assumption was made that what were considered ideal charts in 2005-2006 had approximately the same benefits as actual charts in 2011. Benefits of electronic nautical charts above those of paper charts were found to be $236.2-$262.5 million.

The updated estimates did not take into account the subsequent increased use of capabilities that were available in 2005 or the full increase in the number of systems and capabilities between 2005 and 2011 or since 2013. Further updating the 2011 estimates to reflect only industry size would not include the benefits of the explosion that has taken place in information and systems to display them.

Table 9. Direct Annual Benefits of Nautical Charts to Mariners, by Sector, 2011

Sector	**Benefits** ($ millions)
Commercial boating	35.8-39.8
Recreational boating	121.6-135.1
Commercial fishing	78.8-87.6
Total	***$236.2-$262.5***

Leveson, Irving, *Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program, report to the Remote Sensing Division, National Geodetic Survey, National Oceanic and Atmospheric Administration, March 8, 2012* *http://geodesy.noaa.gov/PUBS_LIB/CMP_Socio-Economic_Scoping_Study_Final.pdf*

[98] Since the basis of the nautical chart benefit estimates is willingness to pay, the data take into account some of the broader economic effects and may implicitly include some of the safety effects as well.

[99] Hauke Kite Powell, *Use and Value of Nautical Charts and Nautical Chart Data in the United States*, report to the NOAA Office of the Coast Survey, Woods Hole Oceanographic Institute, August 2007.

[100] Willingness to pay likely includes some safety as well as economic benefits to users. However, it may not put full value on the economic benefits to others. These influences are assumed to be sufficiently offsetting to take the estimates as economic benefits.

[101] Irving Leveson, *Socio-Economic Study: Scoping the Value of NOAA's Coastal Mapping Program*, report to the Remote Sensing Division, National Geodetic Survey, National Oceanic and Atmospheric Administration, March 8, 2012 http://geodesy.noaa.gov/PUBS_LIB/CMP_Socio-Economic_Scoping_Study_Final.pdf

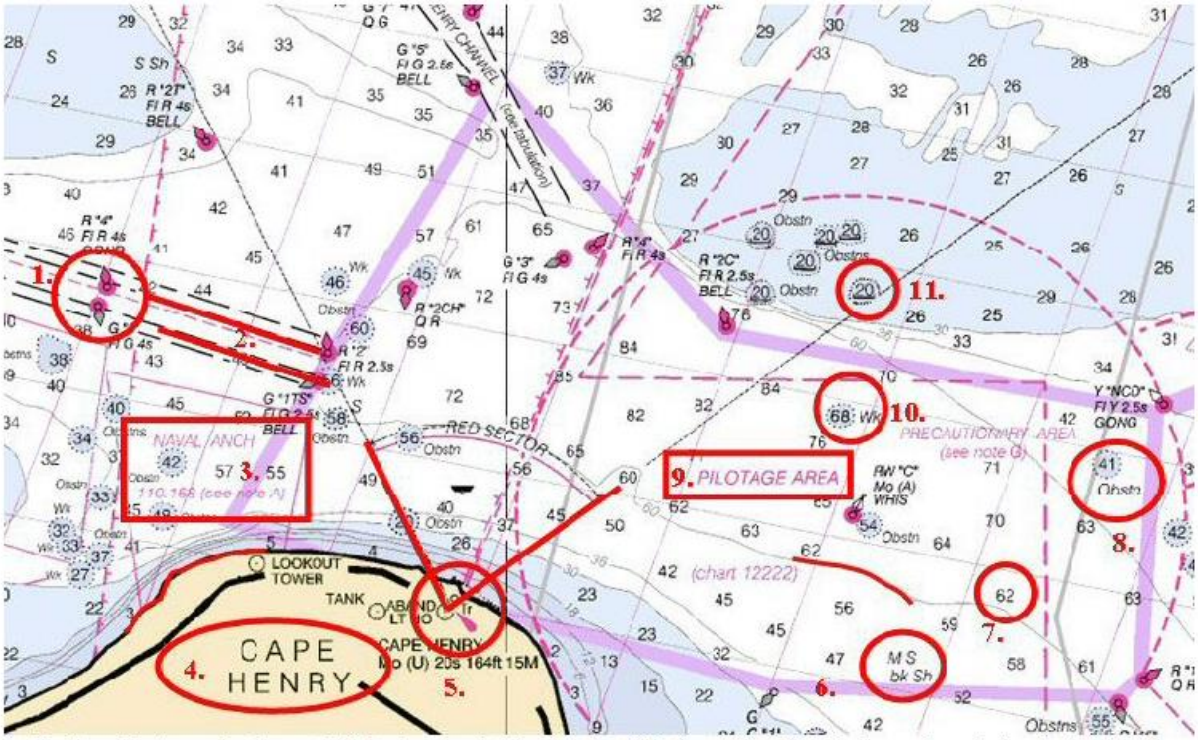
Information is not readily available to determine the current benefits and adoption rates of the various charting and communications systems that came into use. Moreover, a detailed study is under way by Econometrica for the NOAA National Ocean Service that will have some updated estimates later in the year. Under the circumstances, rather than update the 2011 estimates under limited assumptions, a rough indication is suggested for the 2013 impact of current systems.

Benefits of the systems available in 2013 are assumed to be 50%-100% higher than those in the more limited estimate of $236.2-$262.5 for 2011 because of the increase in the number of ship systems using GPS and the extent of their use since 2005. That places benefits at $354.3-$525.0 million.

Figure 9

Source Information on Nautical Charts

The nautical chart conveys a wealth of information to the mariner. The graphic below illustrates a sample of the type of information that appears on nautical charts.



1. Floating **aids to navigation** established and maintained by the U.S. Coast Guard mark channels and other features such as wrecks and obstructions.
2. The U.S. Army Corps of Engineers dredges **channels** so that deep draft vessels can transit into and out of ports. Mariners must know the position and depth of these channels.
3. Nautical charts delineate the location of **anchorages** for military, commercial, and recreational vessels.
4. NOAA shows official **geographic names** in conformance with the U.S. Board of Geographic Names.
5. Fixed **aids to navigation** , such as lighthouses maintained by the U.S. Coast Guard, help mariners navigate safely.
6. Mariners need to know **bottom characteristics** in order to determine where adequate holding grounds for anchoring are located.
7. **Depths** determined by NOAA surveys are critical to safety of navigation.
8. Mariners must know where underwater hazards and **obstructions** are located. The chart shows the precise position and depth of water over the obstruction.
9. Most commercial ships entering a harbor need to know where **pilotage** areas are located. These areas are used for taking on and leaving off marine pilots.
10. Mariners need to know the position and depths of **dangerous wrecks** , so they can lay out a track to avoid these features.
11. **Wire drag cleared depths** show the safe navigation depth. This charting symbol indicates that there was at least 20 feet of depth available over the top of the obstruction located here.

Contribution of GPS vs. Other Technologies

There is no specific way to allocate a share of benefits to GPS relative to the contributions of databases, software, specialized communications systems and other elements of navigation. In the absence of analysis of the alternative evolution of navigation technologies, the annual contribution of GPS and its augmentations is assumed to be 30%-50% of the total of $354.3-$525.0 or $106-$263 million.

Fleet Vehicle Connected Telematics

Telematics is generally defined to include the combination of computer and mobile communications systems. Vehicle telematics also relies on GPS, and on maps and other databases.

Vehicles and Adoption

Information on market size from a number of sources provides building blocks for the benefit estimation.

- 244.4 million vehicles were in use in 2012 according to the Federal Highway Administration and 251.5 million according to R.L. Polk, averaging to 248 million.[102]
- 29.5% of vehicles had embedded or hybrid (including infotainment) systems installed in 2013.[103]
- An additional 19.5% of vehicles used personal navigation devices (IHS).
- 11.7 million fleet vehicles were in service in Jan. 2013, including leasing and government.[104]
- The fleet management market was $10.9 billion in 2013.[105]
- 12.6% of all commercial [fleet] vehicles in the U.S. and Canada had telematics on board to aid optimization in 2012.[106,107]

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[102] Oak Ridge National Laboratories, *Transportation Energy Data Book*, Table 3.4 http://cta.ornl.gov/data/
[103] IHS, *"Telematics Market Status*," June 2014 https://www.ihs.com/newsletter/automotive/june-2014/telematics-market-status-html
[104] Bobbit Publishing Co., *Automotive Fleet Factbook, 2013*, http://autofleet.epubxp.com/i/140727-factbook-2013/5
[105] Fleetmatics, *Fleetbeat Report*, 2014 http://www.fleetmatics.com/fleetbeatreport
[106] Frost & Sullivan 2012 study conducted for Fleetmatics cited in Fleetmatics *Fleetbeat Report*, 2014 http://www.fleetmatics.com/fleetbeatreport
[107] The 12.6% is assumed to be the percent for optimized commercial vehicles in fleets. If it wasn't it would imply that a large number of commercial vehicles were optimized. That would be inconsistent with the data cited in the *Fleetbeat Report* from Markets and Markets that the fleet management market would grow from $10.91 billion in 2013to $30.45 billion in 2018.

Fleetmatics Study of Benefits of Fleet Vehicle Telematics

In the 2014 *Fleetbeat Report*, Fleetmatics compared its customers – roughly 20,000 commercial fleets and 417,000 actively subscribed vehicles in the U.S. and Canada – before and after using a fleet management system.[108] The study examined five years of data and found:

- A 13% increase in stops after implementing a fleet management solution.
- A 15% increase in utilization of vehicles.
- A 20% decrease in the average workday from 10.6 hours to 8.5 hours across verticals (types of businesses) studied.
- Annual fuel cost savings worth $540 per vehicle per year from reduced driving and idle time.
- If the technology were applied to all commercial vehicles in the U.S. and Canada with the results of Fleetmatics customers, it would have resulted in fuel savings would have been $2.2 billion, reduced payroll hours of 1.3 billion and payroll savings of $34.9 billion.[109]

The Fleetmatics study is significant because of the large number of vehicles, extended period of observation and the sophisticated information systems of the company.

Estimating Fleet Vehicle Benefits from Telematics

The number of fleet vehicle in the U.S. with telematics is 1.4 million based on 12.6% adoption in 11.7 million fleet vehicles.

Fuel savings are $748 million for U.S. fleet vehicles with telematics based on the Fleetmatics estimate of $540 per vehicle per year.

Payroll savings are 16.22 times as large as fuel savings in Fleetmatics extrapolation of telematics benefits if they applied to all commercial vehicles. This ratio is multiplied by the estimate of fuel savings to derive a value of payroll savings for U.S. fleet vehicles with telematics of $12.13 billion.

For the remainder of value added, the Fleetmatics finding of a 15% increase in vehicle utilization is used. Since Fleetmatics found a 20% saving in payroll for fleet users of telematics, the benefits are ¾ of those for payroll times the ratio of non-payroll value added to payroll. To obtain this, first the ratio of payroll to value added is calculated.

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[108] *Idem*.

[109] The U.S. is 88.9% of the U.S. plus Canada total of all vehicles. Statistics Canada, "Motor Vehicle Registrations, by Province and Territory, modified June 26, 2014 http:/www.statcan.gc.ca/tables-tableaux/sum-som/101/cst01/trade14a-eng.htm and Oak Ridge National Laboratories, *Transportation Energy Data Book*, Table 3.4 http://cta.ornl.gov/data/

To calculate the ratio of payroll to value added, the ratio of revenue to value added for commercial vehicle transportation industries from the National Income and Product Accounts and the Census Bureau's 2012 Services Annual Survey. This is multiplied by the ratio of payroll to revenue for the total of the truck and the transit and ground passenger transportation industries using data from the 2012 Economic Census.

The ratio of revenue to value added is 2.04 and the ratio of payroll to revenue is .258. Multiplying the two yields 0.526 for the ratio of payroll to value added. Hence the ratio of non-payroll to value added is the inverse or 0.474. The relative size of non-payroll value added is 0.474/0.526 or 0.901. Multiplying this by ¾ of the value of fuel savings or $9.10 billion yields $8.20 billion as the value of savings in non-payroll value added, which is referred to as "other direct savings."

Combining the estimates, the direct benefits of vehicle telematics for fleet vehicles are:

Payroll savings	$12.13 billion
Other direct savings	$8.20 billion
Total	$20.33 billion

The estimate of fuel savings of $0.75 billion cited previously is the only savings of a purchased input calculated so far. A more comprehensive measure can be computed.

Purchased inputs are about the same magnitude as all of value added based on the Economic Census data for commercial vehicles, so savings can substantial. Savings can come from reduced purchases of vehicles and other equipment, tires and other parts, maintenance and repair, insurance and other items as well as fuel. Assuming savings in indirect costs were 50%-100% of savings in direct costs they would be $10.16-$20.33 billion (including fuel savings) and the combined savings in direct and indirect costs would be $30.49-$40.66 billion.

These estimates do not include use of personal navigation devices, cell phones and navigation systems embedded in vehicles that are independent of a connected system for monitoring and dispatching vehicles and collecting information on vehicle use. These are addressed later in a separate set of calculations.

Contribution of GPS vs. Other Technologies

While GPS is indispensable, a number of other technologies including software, maps and other databases and systems for monitoring personnel, equipment and costs are used as well. Consequently, the contribution of GPS is placed in a range of 25%-40%. The resulting direct benefits from GPS are $5.08-$8.13 billion and the combination of direct and indirect benefits are $7.6-$16.26. The midpoint of the range of combined benefits is $11.93 billion.

Timing

The Counterfactual Approach for Timing Recognizes Evolution of Alternatives

The most common method of determining benefits is comparisons with technology that was in use when the new technology became available. This was not possible for timing because there was no way to even roughly apportion a share of benefits of applications to GPS and it would not have been reasonable to attribute all of the benefits of timing applications to GPS. Instead, benefits are compared with those of technologies that would have been expected to evolve in the absence of GPS capabilities. Benefits are measured by avoided costs of timing and sychronization alternatives and do not include a portion of the benefits of timing applications. As a result, the benefits that are estimated are a minimum.

Comparison with technologies that would have come into use is especially appropriate when those technologies were already developed or in partial deployment when GPS became available, or when strong demands would have motivated development of an alternative source of the capability. The latter especially applies in the case of timing.

While scenarios about alternatives that would evolve are subject to uncertainty which reduces *precision*, they can provide a more *accurate* measure of incremental benefits than assuming older technologies would have remained in use. Moreover, failure to take benefits of expected technologies and market changes into account can result in very large overestimation of benefits

Benefits are estimated by the costs that are avoided by not having to install eLoran or a system of GEOs in the absence of GPS precise time.

Consideration of Alternative Technologies and Systems

GLONASS could have provided a comparable timing source. However, there were concerns about its continuity for many years, and ongoing concerns about relying on Russia for critical infrastructure would have been likely to have spurred other solutions.

eLoran, a terrestrial system, could have provided a primary source with 50 ns time accuracy and stratum 1 frequency (Text Box 3).

Text Box 3. eLoran Features and Capabilities

Infrastructure: solid state transmitters, state-of-the-art time and frequency equipment, uninterruptable power supplies

Operating concepts: time of transmission, all-in-view signals, message channel with differential corrections, integrity, etc.

User equipment: digital, (processes eLoran and GPS signals interchangeably,) compact H-field equipment to eliminate "p-static"

Source: Mitch Narins, "The Global Loran/eLoran Infrastructure Evolution," presentation to the Space-Based PNT Advisory Board, June 3, 2014 http://www.gps.gov/governance/advisory/meetings/2014-06/narins.pdf

A system of geostationary satellites (GEOs) with precise time capabilities could have been developed.

Purchase of precise clocks by users would not provide a uniform time and frequency standard for coordination of time across locations where required.

A private alternative (even using GEOs) might not have universal participation and would not provide a guaranteed time standard to all or at a comparable cost. A less open system could have entailed less innovation in receiver development and other areas in the absence of energies from other providers and strong competition.

The conclusion is that costs saved by not using eLoran or GEOs are satisfactory ways of measuring the value of benefits of GPS for timing under the counterfactual approach.

Cost of eLoran As a Timing Alternative to GPS

The Institute for Defense Analysis January 1999 report estimated 20-year infrastructure and operating and maintenance costs at about $67 million per year for a full system.[110]

The Volpe November 1999 benefit cost assessment refresh estimated costs at about $30 million per year for a full system.[111] These numbers do not include decommissioning costs.

The upgrades of Loran C are assumed not to have been completed by 2013, the base year for this analysis.

Based on the two studies an estimated cost of $25-$50 million per year is used as the alternative cost of a configuration that would have been completed and adapted to by users by 2013.

Cost of GEOs as a Timing Alternative to GPS

Precise time could be provided with a system of 3 geostationary satellites (GEOs), 1 to cover the continental United States, 1 for Alaska and 1 for redundancy.

Very preliminary calculations by Tetra Tech AMT, a consultant to FAA, done for this study, suggest a cost somewhat higher than $50 million per year. The estimate was based on small satellites with clocks. Other possibilities include rented or shared space on other satellites and clocks on the ground. 2-way satellite transfer was not considered viable since each user would have to do their own broadcasts and that would be expensive.

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[110] Institute for Defense Analysis, *Independent Assessment Team (IAT) Summary of Initial Findings on eLoran*, January 2009
http://ntl.bts.gov/lib/31000/31300/31359/24_2009_IAT_Summary_of_Initial_Findings_on_eLoran.pdf

[111] John A. Volpe National Transportation Systems Center, U.S. Department of Transportation, *Benefit-Cost Assessment of the Use of LORAN to Mitigate GPS Vulnerability for Positioning, Navigation, and Timing Services*, Final Report Refresh, Prepared for the Under Secretary for Transportation Policy, November 5, 2009
http://rntfnd.org/wp-content/uploads/Benefit-Cost-of-eLoran-Volpe-Center-2009.pdf

Combined Estimates

Taking the eLoran and GEOs alternatives together, the cost that is avoided by having GPS is taken to be in a range of $25-$75 million per year. The midranges of the estimates are $37.5 million for eLoran and $50 million for GEOs, which averages to $43.8 million

Consumer Location-Based Services: Mapping and Directions

Use of Cell Phones for Location Information

Smart phone adoption was 56% in 2013 vs. 35% with other mobile phones and 9% with no cell phone.[112] The U.S. had 188 million smart phone subscribers in 2013.[113]

A Pew Research Center survey found that 49% of all cell phone owners in the U.S. use their cell phone to get directions, recommendations, or other location-based information in 2013.[114] Another Pew survey for 2013 reported that 74% of *adult smart phone* owners ages 18 and older say they use their phone to get directions or other information based on their current location.[115] Twenty percent of U.S. mobile phone users get up-to-the-minute traffic or transit information.[116]

Consumers' Willingness to Pay for Mapping and Directions

A study by Patel examined U.S. consumers' willingness to pay for maps and directions on mobile phones in 2008 when use of personal navigation devices was still dominant and mobile navigation services were not yet free. Half of respondents were willing to pay for maps and directions. The average amount they were willing to pay was $3.80 per month (read from graph), which equals $45.60 per year.[117]

Google announced free cell phone navigation in October 2009 and others followed. That resulted in a huge shift away from personal navigation devices. Before the shift the typical charge for phone navigation was $10 per month, albeit with few users. The price for mobile services since then is being paid for by advertising on navigation and mapping apps and by collection of location data that supports even more advertising.

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[112] Aaron Smith, Smartphone Ownership in 2013," Pew Research Center, 2013," Pew Research Center, 2013 http://www.pewinternet.org/2013/06/05/smartphone-ownership-2013/ The Pew Research Center found 2015 adult smart phone ownership has risen to 64%, up from 35% in 2011.

[113] Mary Meeker, *KPCB Internet Trends 2014* www.kpcb.com/InternetTrends

[114] Maeve Duggan, *Cell Phone Activities in 2013*, Pew Research Center, 2013 http://www.pewinternet.org/2013/09/19/cell-phone-activities-2013/

[115] Kathryn Zickuhr, *Location-Based Services*, Pew Research Center, September 12, 2013 http://www.pewinternet.org/2013/09/12/location-based-services/

[116] U.S. Department of Transportation, *Beyond Traffic: Trends and Choices*, draft, 2015 http://www.dot.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf

[117] It is assumed that this is what consumers would be willing to pay without advertising.

A McKinsey study of the value of Web services for the U.S. and Europe found that consumers would be willing to pay one third of their perceived value from free services to avoid advertising clutter and privacy concerns.[118] Privacy is more of a concern in Europe that the U.S. but advertising clutter may be greater in the U.S. The willingness to pay to avoid both is taken to be 25% of perceived value in the U.S.

It is assumed that mobile navigation and maps were worth $5 per month or $60 per year on average to U.S. consumers in 2013 after deducting the negative value of unwanted aspects. This is higher than the Patel 2008 number because increased capabilities of mobile mapping and directions make them more valuable to consumers.[119]

Many people paid far more than $60 per year in 2013, often paying $1,500 for a navigation system when buying a new vehicle. This translates into about $150 per year over the life of the vehicle or the system. IHS estimated that 29.5% of autos were equipped with an embedded system vs. 19.5% that used a personal navigation device or cell phone.[120] Using $150 for 29.5% and $60 for 19.5% puts the average at $124.50.[121] This figure doesn't yet count the surplus – the value to some embedded system users above their purchase price—for embedded systems. The average value to consumers is therefore taken to be at least $130 per year.

Estimating Consumer and Commercial Benefits Other than Connected Fleet Telematics Based on Willingness to Pay

A count of commercial vehicles is not publicly available and the public IHS data does not distinguish between commercial and personal vehicle telematics use. As a result, an estimate of benefits of vehicle navigation is made that combines consumer use with commercial use other than for commercial connected telematics systems in fleet vehicles.

The average of the numbers of vehicles in 2012 reported by the Federal Highway Administration and R.L. Polk is 248 million.[122] With the same number assumed for 2013 and 49% using any vehicle telematics systems in 2013, the number of adopters is 121.5 million.

With 121.5 million users of any type of vehicle telematics except connected fleet systems and benefits of $130 per year, the total value of benefits is $15.8 billion.[123]

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[118] John Bughin, "The Web's €100 billion Surplus," McKinsey Quarterly, January 2011 http://www.mckinsey.com/insights/media_entertainment/the_webs__and_8364100_billion_surplus

[119] It is equal to $80 per year (vs. $45.60 from Patel) before the deduction for unwanted aspects and without adjustment for inflation.

[120] Anna Buettner, "Telematics Market Status," IHS https://www.ihs.com/newsletter/automotive/june-2014/telematics-market-status.html The 1.4 million fleet vehicles using connected telematics are assumed to not be included in this figure.

[121] Fleet vehicle commercial telematics use is assumed not to be in the 49% IHS adoption rate. If it was, the estimate for fleet vehicles would have to be subtracted and the result would be implausibly low.

[122] Oak Ridge National Laboratories, *Transportation Energy Data Book*, Table 3.4 http://cta.ornl.gov/data/

[123] This can be an understatement if business users that do not have connected fleet telematics have savings valued at more than the value for households. For example, savings in travel time would be valued based on

Contribution of GPS vs. Other Technologies

Consumer navigation and location applications depend on software, maps and specialized communication systems as well as GPS. The share of benefits attributable to GPS is assumed to be 30%-40%.

Benefit Estimates Based on Willingness to Pay

At 30%-40% of $15.8 billion, the benefits are $4.7-$6.3 billion, with a midpoint of $5.5 billion.

Benefits as Time Saved for Consumers – an Alternative Calculation

Time Saved

Another approach is to examine the value of time saved from the use of navigation systems. Levinson tabulated 10 earlier studies containing 16 estimates of time saved with advanced traveler information systems for route choice like those expected to appear in vehicle navigation systems. [124] The median value of time saved was 7% among estimates with a wide range. This is the most generalizable of the studies available. Other studies tend to deal with particular conditions or aspects and/or do not cover many cases.

Value of Time

The Federal Highway Administration estimated that the average household travelled 19,900 vehicle-miles in 2009. If 49% of those miles were travelled with a phone or vehicle navigation system the number equipped would be 9,751. If the travel took 2.0 minutes per vehicle mile (30mph) the time per household using the systems would be 19,502 minutes.

If 7% of that time was saved with a phone or vehicle navigation system, the savings per household would be 1,365 minutes or 22.75 hours.

The US had 122.46 million households in 2013 according to the U.S. Census Bureau. Multiplying by an adoption rate of 49% yields 60.0 million household users. With savings of 22.75 hour each, total savings is 1.37 billion hours.

Applying the Department of Transportation's value of personal time of $34.50 per hour[125] would result in a value of $47.3 billion.

A more conservative assessment comes from the Transportation Research Board (TRB) of the National Academies, Transportation Economic Committee, which states that: "Personal travel time is usually

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salaries and benefits paid to employees or returns to proprietors rather than on a lower value of time attached to consumer activities. The U.S. Department of Transportation recommends values per hour of passenger time at 70% of that for personal time.

[124] David Levinson, "The Value of Advanced Traveler Information Systems for Route Choice," *Transportation Research*, 2003 http://nexus.umn.edu/papers/ATIS.pdf

[125] U.S. Department of Transportation, Office of Science and Technology, "Economic Information for Investment Analysis," spreadsheet, April 30, 2014

estimated at 25% to 50% of prevailing wages."[126] This conservative range is used to reflect a variety of economic factors.[127]

Benefit Estimates Based on Time Saved

Taking 25%-50% of the DOT business hourly rate of $62.00 yields $15.50-$31.00 per hour. This values the 1.37 billion hours at $39.22-$78.43 billion. If rates used by the U.S. Department of Transportation and other agencies were used to value time the benefits would be much higher.

Contribution of GPS vs. Other Technologies

GPS is assumed to contribute 25%-40% of the benefits.

Benefit of GPS

Based on 25%-40%, the value based on time saved is $9.8-$31.4 billion, with a midpoint of $20.6 billion.[128]

Combining Estimates from the Two Methods

Averaging the highs and averaging the lows of two methods results in a range of $7.3-$18.9 billion, with a midpoint of $13.1 billion.

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[126] Transportation Research Board, Transportation Economic Committee, "Transportation Benefit-Cost Analysis," http://transportationeconomics.org/benefits/travel-time

[127] Productivity can be lower for workers taking on additional hours because of fatigue. Consumer driving includes youth and retirees. In multiple person households with children, a person at home may not develop the same earning power because of less experience and a less regular attachment to the labor force. In some cases market conditions or household decisions can result in the person with lower earning power taking care of children and/or aging parents. People who expect to remain at home may be less likely to make investments in education, training and moving where job opportunities are better for them. Those with greater household responsibilities may be less likely to commute farther for a better paying job. Opportunities available to less regular workers tend to be concentrated in lower paying service industries and part time jobs. Effects of past or present discrimination could also reduce labor force participation and pay.

[128] The benefit estimate based on value of time estimate could be higher than the one based on willingness to -pay if the 7% time savings is high. However, the value of time estimate does not include savings in fuel, maintenance and repairs and vehicle depreciation.

Summary of Benefit Estimates

Current economic benefits are estimated for industry groups comprised largely of those for which the most robust estimates were possible.

In deriving the total, the values for the two alternative estimates for timing were averaged and the two alternative estimates for consumer and other non-fleet vehicle were averaged as shown in Table 10.

Table 10. Averaging of Alternative Benefit Estimates for Timing and Non-Fleet Vehicle
(billions of dollars)

Application Category	Lower End of Range	Upper End of Range	Mid-range
Timing – eLoran	.025	.050	0.0375
Timing – GEOs	.025	.075	0.05
Timing Average	**.025**	**.0625**	**0.04375**
Consumer and Other Non-Fleet Vehicle 1 – willingness-to-pay	4.7	6.3	5.5
Consumer and Other Non-Fleet Vehicle 2 – value of time	9.8	31.4	20.6
Non-Fleet Average	**7.3**	**18.9**	**13.1**
Note: Numbers may not add to totals because of rounding.			

The individual estimates are displayed with a letter indicating the degree of confidence in the values. The largest benefits are in the agriculture, surveying and the vehicle categories.

The sum of the economic benefit estimates in Table 10 ranges from 37.1-$74.5 billion, with a midpoint of $55.8 billion. This is about 0.3% of GDP for the aspects measured thus far.

The midrange estimate for consumer and other non-fleet vehicle based on averaging two methods is $13.1 billion. Combining this with the $11.9 billion for fleet vehicles gives a total vehicle midrange benefit of $25.0 billion.

Marine transportation only includes the value of nautical charts. Other Location-Based Services and Geographic Information Services are not included. Construction only includes earthmoving. The timing estimate includes only the avoided costs of not having to develop alternatives of eLoran of geostationary satellites. It does not include the value of timing in applications.

Government is included in construction, surveying, vehicle and timing estimates. Households are in the consumer LBS vehicle category. Inadequate information was available on the size of the overall LBS market and its benefits to make an estimate. The same was true for GIS. Indirect benefits resulting from cost savings in supplying sectors are included for some categories which are noted in the table.

Table 11. Preliminary 2013 U.S. GPS Economic Benefit Estimates

	Application Category	**Range of Benefits** ($billions)	**Mid-range Benefits** ($billions)
A	Precision Agriculture – grain*	10.0-17.7	13.7
A	Construction – earthmoving with machine guidance*	2.2-7.7	5.0
A	Surveying – independent and in sectors	9.8-13.4	11.6
A	Timing – average of eLoran and GEOs estimates	.025-.063	0.044
A	Air Transportation	.119 -.168	0.144
C	Rail Transportation – Positive Train Control	.010-.100	0.055
C	Maritime Transportation – private sector use of nautical charts and related marine information*	.106-.263	0.185
A	Fleet Vehicle Connected Telematics*	7.6-16.3	11.9
B	Consumer and other non-fleet Vehicle – average of estimates based on willingness-to-pay and value of time*	7.3-18.9	13.1
	TOTAL	**37.1-74.5**	**55.7**

A=confident, B=indicative and C=notional.
*Includes benefits from purchase input cost savings.
Note: Numbers may not add to totals due to rounding.

The focus has been on categories for which the most robust estimates were possible. Nevertheless it has been necessary to make some assumptions. In each case an assumed percentage of benefits attributable to use of other technologies and GNSSs was deducted to obtain values for GPS.

Economic benefits are believed to be underestimated for several reasons. Some sectors are not included because of lack of information on productivity and cost savings, namely location-based services other than vehicle, including asset tracking and locating people, geographic information systems and mapping other than nautical charts, forestry, fisheries, mining, and energy exploration and development, land and coastal management, weather, and scientific applications and space.

Parts of others are not included: non-grain agriculture, construction other than earthmoving, the value of GPS timing applications, GPS in aviation for some Area Navigation (RNAV) Standard Instrument

Departure Routes (SIDs) and Standard Arrival Routes (STARS) and Required Navigation Performance (RNP), and rail other than Positive Train Control.

Some estimates are conservative. The value of time in non-fleet vehicle transportation is based on the recommendation of the Transportation Research Board rather than the much higher value used by the U.S. Department of Transportation.

Some types of benefits are not included; specifically benefits of GPS timing applications above the cost of alternatives, and avoided income loss, property damage and medical costs associated with reduced accidents and improved emergency response.

Increases in benefits between 2003 and 2005 are not estimated.

And, as indicated, non-economic benefits such as those to health, safety, security, reduced loss of life and to the environment are not yet addressed.

Possibilities for overestimation exist as well. Some surveying and vehicle benefits may be double counted by also being included in other sectors. Even the conservative estimates used for the value of non-work time in calculating non-fleet vehicle benefits may be high. There may be some overlap between the fleet and non-fleet vehicle estimates. The adoption rate for grain may be somewhat overstated. Some benefits of reduced injury and death may be included in estimates of willingness to pay for nautical charts. However, the sources of overestimation are judged to be smaller than the sources of overestimation.

Next Steps in the Present Study

The intention in Part 2 of the study to follow the present report is to do the following to the extent resources and data permit:

1. Extend and refine the estimates in Part 1. Estimate multiplier effects and impacts on tax revenues and jobs.

2. Estimate values of current benefits in public safety and reduced loss of life in critical applications and explore possible magnitudes of benefits to the environment.

3. Estimate orders of magnitude of economic benefits of GPS to other regions and the world.

4. Assess potential future applications and markets and make projections of future market penetration and values of benefits of GPS to the U.S. This would be carried out under alternative scenarios to reflect the potential impact of nascent applications, the evolution of GNSS systems and the potential quantitative impacts of continuing innovation.

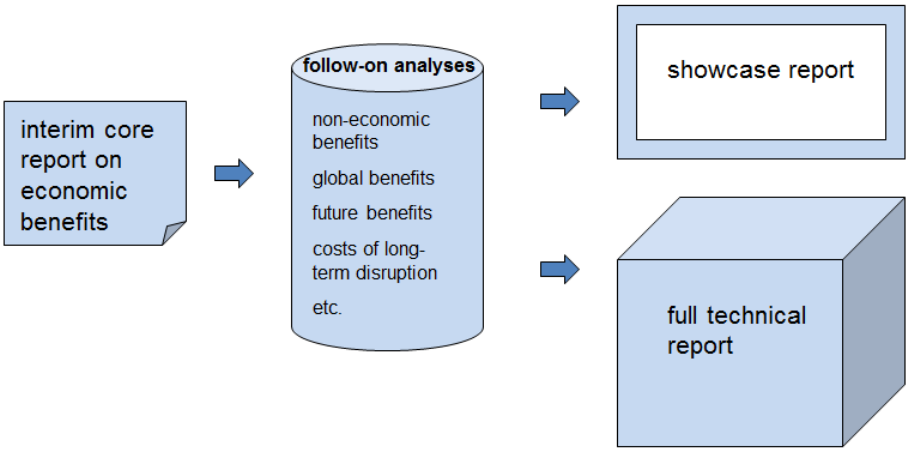
5. Estimate orders of magnitude of economic costs of partial and complete long-term loss of GPS availability in selected applications under alternative scenarios, including rough estimates of economy-wide impacts.

6. Present analysis and findings in ways that can appeal to a general audience, including a summary of benefits that includes discussion of present and future applications with examples in a "showcase report", as well as a technical report.

The stages of the full study are illustrated in Figure 10.

Figure 10

Interim Report Flows Into Next Stages and Final Reports



Estimating costs of long-term signal disruption can be carried out with the following steps:

- Review existing studies of impacts of signal disruption.
- Determine sectors to assess and develop scenarios for length and severity of disruption.
- Examine cases of past major disruption of service of any type and associated losses in the selected sectors.
- Extrapolate losses from previous studies and cases to conditions under the scenarios.
- Estimate losses for selected sectors and possible national impacts based on past experiences and additional analyses.

Data and Research Needs

This study has pieced together data from a wide variety of sources and methods. In the process it has become clear that some areas are particularly in need of improved data.

Large gaps exist in estimates of productivity and cost savings for individual sectors and there is no systematic effort at data collection or research on GPS benefits. Existing studies often predate major technological advances while use of GNSS is increasing rapidly. More benefit information is needed for aviation and other transportation areas. There is an especially great dearth of information about the extent of GPS timing use and the quantitative benefits of timing applications at the industry level.

More generally, information is required on benefits of applications that is much more detailed with regard to particular combinations of technologies and their frequency of use. Studies are needed that take into account specific functions in which GNSS is used (e.g. plowing, seeding, fertilizing, harvesting), the GNSS and non-GNSS technologies used in each function and site, and the extent of their use and outcomes (see Text Box 4).

Robust studies require major and often multi-year efforts of targeted data collection which are rarely done by government or academic researchers for GNSS.

Ongoing research on costs of short and long term signal interference and on costs and benefits of alternative measures for supplementation, backup and mitigation are essential.

Information on market size, adoption and growth from market research firms, which tends to capture recent developments, is based on greatly varying sources and methods. This results in major gaps and greatly divergent estimates, especially in new areas like LBS and GIS. Often definitions and descriptions of methods in available documents are insufficient and information is largely proprietary. More complete and current information on adoption of applications may be needed from government where it is not expected to be available from private firms.

The North American Industrial Classification System (NAICS) which is used in federal data collection such as in the Economic Census lags far behind in recognizing new categories and providing sufficient detail. GNSS user equipment was consolidated into much larger categories a few years ago. An Internet category was first added in 2012.

Lags in data collection and research lead to understatement of the use and benefits of GPS.

Obtaining separate data on market sizes of GPS equipment, software and services is increasingly complicated because of integration with other technologies, both at the micro level such as systems on a chip and in larger systems. In addition, extensive mergers and acquisitions of GPS equipment, data and

software suppliers have resulted in market information becoming internalized with firms having diverse information technology and application businesses.

Special efforts are needed to assess benefits where there is rapid integration of technologies.

Equally difficult is the ability to determine the share of benefits attributable to GPS. This is an area where collective judgment would be useful, possibly to add expertise, but at the very least because it would be more acceptable than that of a single researcher.

Some additional points:

- The use of augmentations and the increasing use of other GNSSs should be tracked for major applications so their benefits can be assessed.
- Safety and health benefits, which are not included in this study so far, are expected to be very large.
- Information on benefits of GPS to other nations and the ways GPS is used in other nations could be important in understanding opportunities and issues and opportunities for the U.S.

Text Box 4. An Example of a Type of Study that Could Provide More Accurate Estimates of GPS Benefits to Agriculture, etc.

- Take an existing sample of farms that have introduced or enhanced GPS technology during the last few years (such as the USDA Agricultural Resource Management Survey)
- Obtain information for each farm or section of farm on:
    - A full set of GPS and non-GPS technologies used before and after the changes
    - Crop costs and yields before and after the changes
    - The mix of crops (or sample just one crop), farm size and shape, soil conditions, weather and other factors that may influence the outcomes
- Perform a multivariate before and after analysis of changes across farms to estimate the contribution of GPS
    - Allow for lagged effects on productivity and yield
    - Examine cases where mainly GPS changed
    - Test for interaction effects between GPS and other technologies among all farms with the same crop or with adjustment for crop mix
- A similar approach might be used for construction and for examining the impacts of improvements in surveying or mapping on agriculture, construction, etc.

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Appendices

Appendix A: Benefit Study Synopses

Benefit Studies Considered in Making Estimates

Available studies are tabulated and examined is in Table A1.

Some applications are included for overall benefits of sectors and not benefits associated with the use of GPS where GPS benefits could not be determined. These include sectors using GPS timing and sychronization for which a different method of estimation was used, specifically broadband communications and the Internet and electricity generation and transmission. However, a study of synchrophasor use which does depend on GPS timing and sychronization for power generation and transmission is included. Overall benefits of weather forecasting and some other areas also are included.

Many entries are in categories for which studies are too limited or unrepresentative to provide a basis for benefit estimation. In some cases studies are listed which are insufficiently reliable to use for this purpose. Examples include forestry and fisheries and open pit mining.

Descriptions of reports that are applicable in multiple sections may be repeated in each section.

Benefit Studies Assessment

Table A1. Benefit Studies Assessment

Application and Source	Value Measure(s)	Date of Data	Form of Information	Date of Report	Reliability	Results and Comments
Machine Control and Vehicle Guidance and Surveying						
Precision Agriculture						Major improvements have occurred since many of the studies were done.
ACIL Allen Consulting (precise positioning in agriculture)	saving in production costs in grain farming in Australia	2012	report	2013	Based on review of practices, studies and assumptions in other studies	Assumed controlled traffic, yield monitoring and variable rate application saved 12.5%-20% in production costs. Very low benefits of GNSS in non-grain cropping and where weather is most variable.
ACIL Allen Consulting (augmented GNSS)	yield increases in broad crop production in Australia	2012	report	2013	Unknown	Cites estimates from ACIL Allen (precise positioning) and McCallum. States that the precise positioning study reported that productivity gains of 10%-20% "are possible." Page 5 states that in the grains industry: "Cost savings of around 67% in labour and 52% in fuel are reported" from automatic guidance and controlled traffic farming, variable rate fertilizer application and inter-row sowing. This is said to correspond to the productivity "estimate" of 10%-20%.
John Deere	input cost savings and yield increases in U.S. grain production	about 2011	presentation slides and interview	2012	Per acre estimates and their locations which were used to get national totals are not provided.	Input cost savings are a minimum of $8.2b including reduced chemical and fertilizer costs $4.8b, reduced seed costs $1.5b, reduced fuel consumption $0.5b and labor saving $1.4b. In addition, there is a minimum of $6 billion of gains annually in improved yield as a result of changes in

						processes. Input costs do not include savings in costs of equipment.
McCallum	yield increases in Australia	2004-2006	report	2011	Controlled experiment.	An average of several studies showed a 9% increase in wheat yields with inter-row sowing. 84% higher canola yields on standing than slashed stubble and 31% higher on burnt stubble. 30% higher yield on inter-row sowing of canola vs. on row. Greatly increased herbicide efficiency in stubble retained ryegrass.
Winstead	efficiency improvement for row crops in Alabama	unknown	blog	2011	Not documented.	The report states that studies have demonstrated a 10% average cost savings and that technologies like RTK guidance systems and automatic section control for planting and spraying can yield tremendous additional savings.
ACIL Tasman	savings in labor, fuel, and chemicals and machine maintenance in grain farming in Australia	unknown	report	2008	Good literature review of findings from older sources but only states their conclusions.	Productivity improvement of 10% in controlled traffic farming assumed for grains. In a study cited, inter-row sowing yield gains were 5% and cost savings 3%-10%. (Assumptions for other agriculture do not separate values for savings from those for market penetration.)
Allen Consulting Group 2008	Increased crop yields and input cost savings largely in Australia	various	report	2008	Extensive literature review of findings from older sources.	Controlled traffic farming and inter-row sowing were taken to raise productivity by 25%-35%. Estimates cited of increased crop yields ranged from 5% to 30%-50% and input cost savings from 15% to 33%
Allen Consulting Group 2007	crop yields and input cost savings in Victoria Australia	various	report	2007	Unknown.	Across 5 crops, assumed 10% reduction in per hectare costs and increase in yields of 15% based on literature review, assumptions made in other studies and discussion with the Victorian Department of Primary Industries.
Martin *et. al.*	input savings and yield increase in cotton farming	2001-2003	article in trade publication	2005	Controlled experiment. Allowed for soil conditions and	Approximate yield increase 10% plus some input savings. Included capital but not operating costs. Benefits were about four times capital costs.

					approximately for weather	
Watson and Lowenberg-DeBoer	field time savings in 1,800 acre corn-soybean rotation	2002 or earlier	report	2002	Controlled experiment.	Field time saved with GPS lightbar (traditional) technology was about 11%, with an additional 6% with DGPS or RTK.
Bowman	whether benefits exceeded costs: operating efficiency	unknown	blog	2001	Unknown. References are not provided.	Almost 60% of farmers thought benefits exceeded costs while 20% thought costs exceeded benefits. Cited a "recent research project" that showed GPS guidance increased operating efficiency in pulling a 42 foot field cultivator from 28 to 31 acres per hour.
Open Pit Mining						
ACIL Allen – Precise Positioning in the Mining Sector	reduction in overall operating costs; reduction in workforce with autonomous haul trucks in Australia	2012	report	2013	Based on limited case studies and literature and on industry consultations	Automated mining was assumed to reduce overall operating costs by 3.3%. Based on one report the study states: "There is a general estimation of between 30-40% reduction in the mining workforce (50% within operational roles) at those operations which adopt large-scale automation, with truck driving the most likely function to be carried out autonomously on a large scale." The study assumed selective drilling to automate drilling operations and target ore bodies increased operating efficiency by 30% and reduced labor costs by 20%.
Allen Consulting Group – High Resolution Positioning Services	increase in productivity and output in an Australian zinc mine	about 2008	report	2008	Case study of one mine and limited literature review	Increase in productivity in the zinc mine of around 6% with accurate selective mining in which GNSS was used to guide excavators. Output increased about 2%. Information about productivity of machines and operators resulted in an increase in and additional productivity of 4% in another study. This led to an assumption that accurate selective mining raised productivity by 5%-10%.
Leica Geosystems	reduction in re-	undated	testimonial	undated	Not documented	The North American Coal Corporation

	handling in a Texas lignite mine					achieved a 5% reduction in re-handle due to better control over bench height with a dozer system and expects to reduce dragline re-handle by 3%, with payback in 24 months on the initial four units.
Construction						
ACIL Allen (precise positioning services in construction)	savings from machine guidance primarily for earth moving; engineering site surveying	various	report	2013	Productivity from machine guidance is based on the firm's 2008 study and estimates by a partner firm. Productivity estimates for surveying are based on four case studies and a review of studies.	Productivity improvements from machine guidance in earthmoving ranged from 10% to 30%. Productivity improvements in surveying are gauged to be 20%-40%.
Aðalsteinsson	time saved in excavation of trench with GPS machine guidance in Iceland; reduced use of fuel and sand	about 2007	report	2008	Controlled experiment	The surveyor prepares the data for the surveying equipment on the construction machine which does the surveying instead of the surveyor. 24% saving in time, 22% saving in fuel, 59% less sand used and reduced deviation from design.
Caterpillar	productivity in road construction	2006	report	2006	Controlled experiment	Time saved in staking (surveying on machinery instead of separately) 74%, bulk earthmoving 5% & 31% depending on equipment, subgrade grading 5% & 63% depending on equipment, base course grading 76% and base course fine grading 79%. Overall saving was 53%. Head count was reduced by about 50% for foremen and operators and 95% for surveyors. In other tests, earthmoving, sub fine grading and base course grading had savings of 20%-50% and fuel savings were 35%, 47% and 68%.

Han, Seung-Woo, *et. al.*	productivity and cost savings in earthmoving	about 2004	article in professional journal	2006	Simulation with information partly based on interviews with site personnel.	Using a bulldozer and a truck in a project with a short hail distance, productivity increased 21.7% over a conventional system and unit costs were 12.9% lower. In a project with a long haul distance, productivity increased 5.7% and costs were lower by 4.8%. The greater the number of work activities applied to a particular piece of equipment, the lower was the improvement in productivity.
Han, Lee and Halpin	productivity and cost savings in earthmoving	about 2004	article in conference proceedings of professional society	2005	Simulation with information partly based on interviews with site personnel.	Examined four excavation and grading projects using either a conventional or GPS system. Productivity increased 32% and unit costs were 23% lower.
Snaebjorn, *et. al.*	productivity and unit cost in grading	about 2001	article in professional journal	2002	Controlled comparison. One of the two projects was hypothetical.	Examined linear and area grading scenarios and one dozing scenario at a golf course and an infield restoration construction site. Compared conventional with ultrasonic, 2D and 3D laser (line of sight) and GPS systems. In linear grading, productivity gains over conventional systems were 21%, 44%, 89% and GPS 101%. Unit costs were: conventional $1.4 per cubic meter, others $1.32, $1.14, $0.98, and GPS $0.92. GPS reduced the number of grade engineers from 2 to 1 over conventional and the number of laborers from 3 to 0, but required the same numbers of employees as 3D laser.
Lorimer	savings in road repair in Europe	EU projections	article in trade publication	2010	Based on EU studies of potential benefits of GNSS.	By optimizing the position solution for different machine types such as paver, truck and compactor and the combined work process, there can be *up to* "€4.5 billion per year in savings in road repair across Europe plus tens of billions in reduced congestion costs."

Alliant Engineering	time saved in grade checking, reduced staking, improved material yields, all weather operation and RTK, robotics stakeout	various, before 2007	report	2007	Questionable. Appears to have chosen the best performing examples after a literature review that doesn't discuss others.	Cites "claims of efficiency" by *as much as* 50% and increased equipment utilization *as much as* 30%. Claims savings from grade checking *up to* 66%, staking *up to* 85%, material yields 3%-6% in volume, lack of interruption by weather 30%-50% and RTK, robotics stakeout over traditional survey more than 100% in speed and 66% in staffing. Use of GPS with 3D machine control technology allowed operating on smaller sites while still realizing the same benefits as seen on large earthwork projects.
Trimble-Productivity	productivity in grading a high-speed rail track in France	undated	testimonial	undated	Not documented.	Jean-Marc Bidault claims productivity in final grading of 8,000 square meters per day vs. 6000 square meters per day without GPS guidance.
Trimble-Productivity	time saved in finish grading for an apartment building complex in California	undated	testimonial	undated	Not documented.	Roxwell Fontenot, President of Roxwell Construction, claimed: "We're completing our finish grading in half the time because we're using GPS machine control."
Allen Consulting Group 2008	productivity in site survey in Australia	about 2008	report	2008	Based on industry consultations.	Estimated productivity improvement of 20%-30% in site survey in construction.
Surveying						
International Federation of Surveyors (FIG)	reduction in cost	2010	report	2010	Authoritative source	Costs of equipment and useful lives were taken into account along with labor costs in making estimates. Costs were reduced by nearly half by the use of geodetic surveying and more than half with both geodetic surveying and CORS. (Read from graphs that showed how total costs would vary with labor costs in each case.)
ACIL Allen Consulting 2013 – Precise Positioning in Surveying and Land	time required for field survey for a photogrammetric survey and for land survey in Australia; productivity	various	report	2013	Based on several case studies	Use of CORS instead of survey control marks reduced time required by 75% according to a 2007 study. States that productivity improvements of 50% are possible in engineering surveys augmented with CORS for infrastructure, such as power

Management	improvements					lines and pipelines in remote areas in 2012. Based on allowing for improved technologies since a 2007 estimate of 30%-50%. Road assessment over long distances in remote areas required 25% less time in the field and 50% less time in the office. A survey for a large rural boundary adjustment using GNSS saved about 66% in number of meters per day surveyed.
ACIL Allen - Precise Positioning in the Mining Sector	productivity in exploration surveying	2012	report	2013	Based on limited case studies and industry consultations	Productivity increased 1.9% in exploration surveying.
Allen Consulting Group 2008	productivity in site survey in Australia	about 2008	report	2008	Based on industry consultations	Estimated productivity improvement of 20%-30% in site survey in construction.
Dewberry & Davis and Psomas & Associates	cost savings in height modernization	about 1998	report	1998	Post analysis of existing survey projects and controlled test surveys comparing methods are authoritative	This key study compared leveling with GPS for measuring orthometric heights with conventional leveling. Variable cost savings ranged from 25% to 90% depending on the type of project. Cost savings were greatest with distances greater than 4km between survey points. With a 4km single baseline, savings were 40% and with 10km they were 76%. Benefits would be substantially higher than that with an expanded survey network. GPS is especially valuable in disasters where monuments are destroyed.
Wisconsin Department of Transportation	cost savings in height modernization	1998-2004	report	2004	Controlled comparison of methods	Achieved an 89% reduction in costs to the Wisconsin Department of Transportation in determining the locations of photogrammetric targets for construction and reconstruction projects, and an 83% reduction in costs to counties in conducting quality control of the photogrammetric products they receive. Similar results were found in a Montana's Department of Transportation study on a Superfund site.
Epstein and	avoided costs	About 1984	report	1984	This study	Avoided costs were estimated in this

Duchesneau					pioneered in demonstrating the use of avoided costs for valuing a geodetic reference system	pioneering pilot study of watershed maintenance costs and of updating through aerial photographs, feature identification and plotting. The ratio of benefits to costs ranged from 1.7 to 4.5.
Hoogsteden and Hannah	cost savings in New Zealand	prospective	report	1999	Estimates of savings in title surveys and cadastral surveys and building/ construction value based on market sizes and expert opinion surveyed in other studies	Savings from title surveys were estimated at $99.4-$118.3 million, cadastral $3.8 million and building/construction $3.8 - $6.4 million, with a ratio of benefits to costs of greater than 2.
Leveson	cost savings if CORS was not available. Prospective cost savings in elevation measurement with a new aerial survey program: Gravity for the Redefinition of the Vertical Datum (GRAV-D) which is in the process of implementation	2008; prospective	report	2010	Comparison of costs with and without CORS, roughly adjusting for alternatives without it. Estimates of expected avoided costs of GRAV-D based on costs of alternative and possible reduction in costs in flood plains	Adapting an estimate by Richard Snay of NOAA's National Geodetic Survey for the cost of field measurement if CORS was not available, benefits were estimated as $758 million per year. The GRAV-D estimate was based on avoided costs of long line leveling plus avoided costs of flood damage in floodplain areas based on a percentage of damage not yet mitigated by flood insurance rate maps. Savings were estimated at $522 million per year once the program is fully rolled out.
Resources						
Forestry and Fisheries						
ACIL Tasman	increase in forest area that can be managed by each manager; productivity in	about 2008	report	2008	One case study of each.	50% increase in area that can be managed by each manager in a hardwood plantation. 12% improvement in productivity from GPS plotting systems in fin fishing.

	fisheries, in Australia					
National Marine Fisheries Service, NOAA	sales and value added	2012	report	2013	Includes wholesaling and retail trade from food service which account for most of the value.	Value added for edible and industrial products was $42 billion and sales were $82 billion. Numbers include imports.
Robins, *e.t. al.*	size of tiger prawn catch in Australia	1988-1992	article in professional journal	1998	Before and after statistical comparisons.	GPS alone increased "fishing power" by 4%. The addition of a plotter raised the power by an additional 7% to 12% (including interaction effects).
Energy Exploration and Development						
ACIL Allen - Precise Positioning in the Mining Sector	productivity in underwater pipeline construction and exploration surveying	2012	report	2013	Based on limited case studies and industry consultations.	Productivity improvement of 0.25% in facilitation of precise positioning and asset management for connectivity to plant in underwater pipeline construction. Productivity increase of 1.9% in exploration surveying.
Transportation						
Air						
Szabat	efficiency benefits with NextGen; safety benefits estimates are included	about 2011	letter	2011	The efficiency benefit estimates is described as conservative. The basis of the estimate is not provided.	GPS provides at least $200 million in efficiency benefits in civil aviation per year. Cumulative investments in GPS infrastructure and equipment of $6-$7 billion would be lost of GPS couldn't operate, including $3 billion of taxpayer investments in NextGen. Investments in civilian government aircraft are not included.
FAA - WAAS	reduced passenger time, safety and other benefits due to	FY2009	report	FY2009	Benefits are compared with ILS. Aircraft operator	Total benefits were estimated for FY2009 at $52.1 million, with a ratio of benefits to costs of 1.78. Passenger value of time

	use of WAAS in aviation				cost savings are not included.	saved accounted for $38.7 million, safety $6 million and other benefits $7.5 million.
FAA - NextGen	avoided delay, reduced flight time, fewer flight cancellations, reduced carbon dioxide, safety improvements and FAA costs with NextGen	FY2013-FY2030	report	FY 2014	Results are in constant dollars. Avoided delay was based on operating costs and value of passengers' time. Value of additional flights was measured by consumer surplus. The FAA System Wide Analysis Capability (SWAC) model was not evaluated. Not all capabilities of NextGen could be modeled.	Total improvements from 2013-2030 in constant dollars without discounting were estimated as $133 billion compared to costs of $29 billion. Gains from avoided delays were $30.3 for aircraft operating costs and $69.3 billion in value of passengers' time, $4.6 billion in reduced flight time, $9 billion in fewer flights, $400 million in reduced carbon dioxide, and $18.9 billion in safety improvements, FAA cost savings and other items. More than half of benefits are value of passengers' time, which may reflect high valuations used by FAA. Cumulative *discounted* benefits using a 7% discount rate exceeded costs by $41 billion, for a benefit/cost ratio of 3.4. This does not include sunk costs. Nevertheless, the present estimates are greatly reduced from previous estimates because of program delays.
Rail						
Szabat	productivity gains from Positive Train Control and other uses of GPS; safety benefits estimates are included	about 2009-2028	letter	2011	Basis of estimate of productivity gains is not provided. Not clear if discounted data are in real or nominal terms.	In 2009 the Federal Railroad Administration (FRA) made a preliminary estimate that without GPS, freight railroad could lose productivity gains of roughly $29 billion over 20 years with a 3% discount rate and $15 billion with a 7% discount rate. In 2009 the sunk costs in PTC systems that rely on GPS was over $1 billion and railroads planned to spend an additional $4.3 billion by the end of 2015. FRA believes that sunk costs in dispatch and other systems improve productivity based on GPS (other than PTC) total over $1 billion.

Federal Railroad Administration (FRA)	Benefits of Positive Train Control (PTC)	2009-2028 projections	report	2009		See Szabat entry above. Included only direct railroad safety benefits. While PTC could have large safety and environmental benefits, the likelihood of business benefits is uncertain and costs exceed economic benefits other than business benefits.
Federal Railroad Administration	Benefits of Positive Train Control	projections to 2020	report	2004		Revised benefit assumptions to arrive at annual benefits including $371 million-$1.22 billion to shippers and a value of reduced accidents by 2020 of $412-$785 million due to fewer highway accidents resulting from diversion of traffic.
L.E Peabody & Associates	Benefits of Positive Train Control	2009-2028 projections	report	2010	The study was for the Chlorine Institute.	Recalculated FRA 2009 report numbers to include railroad, shipper and societal benefits Including shipper and societal benefits which the FRA 2009 report excluded added cumulative $17.3 billion to benefits and resulted in benefits that were 16% higher than costs rather than much lower than costs.
Oliver Wyman	Benefits of Positive Train Control	2009-2028 projections, etc.	summary and slides	2010	The study was for the Chlorine Institute.	Analyzed PTC commercial benefits and compared them with Zeta-Tech and with L.E. Peabody. Claimed that the benefits found by L.E Peabody could be obtained with other technologies and with more technologically advanced PTC systems than the railroads will implement. Estimated $413 million in direct commercial benefits and little in safety benefits. Railroads will incur approximately $20 in costs for every $1 in realized benefits.
Resor, Smith & Patel	Benefits of Positive Train Control		journal article	2005	Authors were formerly with Zeta-Tech Associates	Annual benefits at full implementation were projected at $2.2-$3.8 billion with an internal rate of return of 44%-160%.
Zeta-Tech Associates	Benefits of Positive Train Control		report	2004		Estimated annual benefits of $2.2-$3.8 billion, including shipper benefits of $900 million-$1.4 billion.
Marine						

U.S. Army Corps of Engineers	economic impact	unknown	brochure	accessed 2015	Source not provided.	"The U.S. marine transportation industry supports nearly $2 trillion in commerce and creates employment for more than 13 million."
ACIL Allen – Road Transport	reduction in maintenance and loading costs and staff levels for loading vessel and truck containers in Australia	about 2013	report	2013	Based on case study of one large firm.	Results are for use of large mobile straddles that attach and detach containers and transport them. GNSS is used to capture locality data referenced to a regularly updated site plan. Reduced loading stress lowered maintenance and overhaul costs by about 35%. In one of the four sites operated by the company, staff was reduced by *up to* 50%. Sites operating under semi-automation reduced staff by *up to* 33% and had other large savings.
Volpe Center – Navigation Products	efficiency and safety improvement	2006	report	2009	See above discussion of Volpe report under Nautical Charts and Related.	The $1.2 billion gain in 2006 included $376 million in economic gains. The economic gains included benefits of ship bridge systems and those of electronic navigation charts used in them (above the value of paper charts). Most components of bridge systems included use GPS.
Volpe Center – LORAN	Increased flow of goods through a port	about 1999	report	2009	Uncertain.	Estimated that GPS enables about a 3% gain in the flow of goods through ports in the 2004 study. This was based on scaling back a value suggested by the CEO of a container line that as much as 10%-15% in flow could be obtained if Selected Availability were lifted. The 2009 report updated the estimate from the 2004 assessment based on price changes.
Fleet Vehicle Connected Telematics						
Fleetmatics	increase in fleet vehicle stops and idling minutes and decrease in fuel	2009-2013	report	2014	Results from monitoring over 5 years from 2009-2013 for	Fleetmatics provides a software-as-a-service-based fleet management solution. The study reported a 13% increase in stops (9% including non-service calls) across 12

	consumption				Fleetmatics customers with roughly 20,000 commercial vehicle fleets and 417,000 actively subscribed vehicles.	types of businesses including 20% for heavy construction, 14% for light construction, 21% in for-hire trucking and 4% for passenger transportation. Decrease in idle times per vehicle per day were 12% for all businesses. Fuel savings averaged $540 per vehicle per year from reduced idle time and driving.
CSMG and SkyBitz	trailer-to-tractor ratio; cost savings from decreased need for equipment; reduced driver time looking for trailers	2004-2007	report	2008	Based on interviews with 25 for-hire fleets and industry experts.	SkyBitz customers had an 8% lower tractor-to-trailer ratio than the industry as a whole in 2007and average reductions of 15% over four years. For a typical 3,000 trailer fleet this equates to a saving of $19.8 million over five years in reduced trailer purchases, leases and rentals, lower maintenance costs and decreased tire purchases. Increased cargo capacity can result in a 60% reduction in the number of trailers rented for a typical customer. Customers also saw reductions of 50% in driver time looking for trailers.
Motorola	savings in time and fuel consumption with GPS-enabled technologies in transportation, manufacturing and trucking/warehousing	2008	press release	2008	Over 255 North American IT and telecom decision-makers completed a survey via the e-Rewards global online market research panel.	Savings were 54 minutes per day. Average distance travelled was reduced by 231 miles per week.
Aberdeen Group as reported in Geoforce	reduction in downtime due to maintenance management	2012	blog	company 2012	Report is proprietary.	GPS devices provide engine hours, in-motion hours, idle time, battery voltage, and odometer data for fleet managers to schedule preventive maintenance and prevent unscheduled repairs. The Geoforce software also provides traffic and routing information. Fleet managers realized an average savings of 25% in reduced downtime.

U.S. DOT Federal Transit Administration	value of various efficiency, cost and safety benefits in public transportation	various	report	2000	Provides minimum, maximum and most likely estimates.	The present discounted values of most likely estimates over ten years for public transit programs that were operational or in implementation in 2000 were $1.05 billion for fleet management systems, $550 million for operational software/computer aided dispatching systems and $1.55 billion for advanced traveler information systems.
Levinson	time saved with advanced traveler information systems	about 1989-1996	reports, articles in professional and articles in proceedings	2003	Model-based studies.	Tabulation of 10 earlier studies with 16 estimates shows great variation in time saved with advanced traveler information systems for route choice such as those expected to appear in vehicle navigation systems. The median value of time saved was 7%.
NuStats; GPS World	time, distance and fuel saved using personal navigation devices in Düsseldorf and Munich	2008-2009	press release and article	2009	In-field data collection on behalf of Navteq for 2,158 trips for over 500 hour and 20,000km involving 90 study participants that had not used a navigation device before.	NuStats reported that after the initial learning curve and during peak travel periods, trips were 23% shorter in duration, 36% shorter in distance and fuel efficiency was 24% higher. GPS World reports that the study showed a 12% increase in fuel efficiency for all trips.
Oxera	time saved, reduced mileage and increased fuel efficiency with use of a navigation system compared to conventional maps	about 2007	reference to report	2013	Results “when driving in an unfamiliar area to an unfamiliar destination” are applied to all use for time and mileage.	18% reduction in journey time and 16% reduction in mileage; 12% increase in fuel efficiency
ABI Research	Willingness-to-pay for vehicle infotainment system, including navigation, in six countries	2011	article	2011	1,500 respondents. Full report is proprietary.	Between 59% and 72% of consumers in U.S., U.K., France Germany and Japan, but not China, were either extremely interested or very interested in connected navigation. Among those not currently

						using any infotainment services, willingness-to-pay for services was around $10 per month and no higher than $700 for hardware costs.
Mapping and GIS except Remote Sensing, Including Nautical Charting						
Land and Coastal Mapping						
Bhagwat and Ipe as reported by Cobb	cost savings in Kentucky from state preparing geologic maps instead of users preparing their own	2000	article in conference proceedings	2000	Did not consider an alternative of private development of maps for wide areas at much less that costs than individual making their own maps.	Savings in costs of 1:24,000-scale geologic quadrangle maps would have been $2.25-$3.53 billion if done individually vs. a state program cost of $90 million. Based on questionnaires sent to 440 professional geologists which received a 20% response that was claimed to be representative. Berg reported similar results for Winnebago and Boone Counties, Illinois.
Bernknopf *et. al.*	exploration efficiency and effectiveness in finding exploration targets with updating and improved resolution in bedrock geological maps	hypothetical	report	2007	A simulation model of private sector investment that links exploration decisions to map information.	For one site an updated courser resolution updated map resulted in finding 60% more targets for mineral exploration and an exploration campaign that would be 44% more efficient. Refining the map resolution resulted in a 17% reduction in search effort across all favorable domains and a 55% reduction in the most favorable domain. At another site the value of the updated map ranged from CAN$2.28 million to CAN$15.21 million vs. a cost to produce the map of CAN$1.86 million.
Halsing, Theissen and Bernknopf	changes in benefits and costs of performing geospatial applications without a hypothetical, fully	About 2001	report	2004	A simulation model was developed to project use of mapping information by county and use.	The model attempted to incorporate the complexity of use of mapping information in each county and projected use over the 30 year life span of the map. The map was expected to be fully filled out after 10 years, so many benefits came later.

	implemented National Map				Data were from telephone surveys and literature reviews, with extensive assumptions where data was not available.	Extensive sensitivity testing was done. The study found a net present value of benefits (benefits net of costs, discounted to the present) of $2.05 billion, with a 95% confidence interval of $1.07 billion to $3.03 billion using a discount rate for constant dollar benefits of 3.2%.
Executive Office of the President	addition to the U.S. economy from Federal earth observation activities	2007	report	2014	The John Hillery CSIS report which the OSTP reference traces back to is no longer available on the Web. The CSIS Web site only has an abstract.	The Office of Science and Technology Policy states in its July 2014 report that: "Conservative estimates indicate that Federal Earth-observation activities add $30 billion to the U.S. economy each year." The abstract for the Hillery report says it: "examines the value of better weather forecasting in a number of sectors using two different methodologies." The report has been withdrawn from the Web site.
ACIL Tasman – Earth Observation	productivity and direct and other contributions to GDP	2008-2009	report	2010	Largely based on taking 15% of the value of spatial information found in their 2008 report using its higher scenario.	Earth observation systems were estimated to contribute at least $3.3 billion to Australian GDP in 2008-2009. It was estimated that on conservative assumptions that could grow to $4.0 billion by 2015. The $3.3 billion consisted of direct benefits of $1.4 billion which was almost entirely attributed to government and $1.9 billion in productivity benefits. An additional $1.0 billion was estimated for other benefits including contributing to climate change adaptation, emergency response and natural resource management.
Leveson – Coastal Mapping	willingness to pay; contribution to investments in ports; avoidance of delays in offshore oil and gas production;	2011	report	2012	Varied based on component being estimated	This is a study of the National Geodetic Survey's Coastal Mapping Program (CMP) which provides aerial surveys and other information as inputs into NOAA's Office of Coast Survey's (OCS) nautical charts. CMP consists of 6 services which include nautical

	savings in costs of title insurance, etc.					chart production, change analysis, boundary determination and legal aspects, and emergency response imagery. Direct economic benefits were found to be around $100 million. Indirect and induced benefits and safety benefits also were estimated. About 35%-40% of the total value of OCS nautical charts was estimated to be attributable to CMP based on a sample count of vertices that make up the shape of each chart feature.
Nautical Charts and Related						
Leveson – Coastal Mapping	willingness to pay for nautical charts	2011	report	2012	Adapted and updated a study by Kite-Powell on the value of ideal nautical charts based on willingness to pay.	The direct economic benefits of nautical charts to commercial boating, commercial fishing and recreational boating was estimated at $236-$262 million, about half of which was assumed would have been provided by alternative sources in the absence of the Office of Coast Survey's nautical charting program. This allowed for alternatives such as private vendors providing charts with less information and/or less geographic coverage and fewer charts being used because of higher costs. The value of the charts includes contributions by other agencies.
Volpe Center	reduction in vessel operating costs with electronic navigation charts (ENCs); improved vessel and channel capacity utilization and gains in revenue from	2006	report	2009	Considers gains over paper navigation charts. Some comparisons used in estimation may not represent causality. Contributions of	Benefits for the three National Ocean Service (NOS) programs were $1.2 billion including non-economic safety benefits vs. NOS operating costs of $48.5 million. The value of averted fatalities and injuries was more than two thirds of total benefits.

	scheduling and load optimization from PORTS© Tides and Currents (T&C); avoidance of risk of groundings from services of the Navigation Response Team (NRT)				other components of bridge systems and other programs and agencies are not separated.	
Kite-Powell – PORTS©	high confidence direct economic measures included increased draft, cargo loading and reduced delays for commercial vessels; includes non-economic measures	individual port results were updated for inflation to 2010	Four reports and unpublished summary tables. The reports are listed in the references to this tabulation.	various dates from 2005-2010	Before and after comparisons and various assumptions were used. Both high and lower confidence measures were provided.	The PORTS© Program provides data on currents, tides, wind, water temperature and other measures to assist in ship navigation. Ports covered were Tampa Bay, Houston/Galveston, Columbia River and New York/New Jersey. Annual benefits for the four ports ranged from $10.6 million to $7.6 million per port and greatly exceeded costs. Non-economic measures were included. These tended to be of lower confidence but raised benefit/cost ratios significantly.
Johnston	benefits of hydrographic surveys	about 1992 and about 2008	reports	2011	Applicability to current U.S. circumstances is not known.	Cites a well-regarded study of the Canadian Hydrographic Service in 1992 that found a ratio of benefits to costs of 10 in supporting better, safer and cheaper transportation. Also cites a 2008 study by the Irish Seabed Survey that found a ratio of 6 based on a wider group of stakeholders.
Econometrica	value of nautical charts					Study in progress for NOAA National Ocean Service
Geographic Information Services n.e.c.						
Hickling Arthurs Lowe	geospatial activities in Canada	2013	report	2015	Only the summary has been released to date. The economy-wide	The economic value study for Natural Resources Canada estimated the direct and indirect contribution to the Canadian economy and examined the value of open

					effects are based on inter-industry and international relationships estimated from entering productivity data for sectors in a Computable General Equilibrium (CGE) model. The productivity estimates are not included in the summary report.	geospatial information within the Canadian economy. Firms in the private sector contributed $2.3 billion to Canada's GDP in 2013. The sector includes location-based services, broadly defined. Geospatial information use resulted in $20.7 billion in additional GDP, an increase of 1.1% of GDP, 19.6 million additional jobs, and a $2.8 billion increase in the net trade surplus.
Timing Applications						
Broadband Communications and Internet						
Thanki	consumer and producer surplus from licensed and unlicensed broadband	2006, 2005-2008 and 2009	report	2009	Overall estimates based on 2003 U.S. consumer surplus for cell phone from Hazlett, with allocation among sectors taken from willingness- to-pay in the U.K. by Europe Economics. For U.S. Wi-Fi in homes, willingness–to-pay.	Estimated 2006 U.S. value generated by licensed public mobile spectrum use by households and businesses at $277 billion (consumer surplus $249 and producer surplus $28). *These numbers include use not only by households but also by businesses and governments.* For broadcasting $45 billion (consumer surplus $39 billion and producer surplus $6 billion). For wireless broadband consumer surplus $2.3 billion and $9.3 billion in private mobile radio. For satellite links $21.7 billion. Illustrated consumer surplus derived from Wi-FI in homes based on the findings of Dutz, Orszag and Willig of willingness to pay in the U.S. as $4.3-$12.6 billion based

						on alternatives of 10%, 20% and 30% of broadband value.
Dutz, Orszag and Willig	Consumer surplus for unlicensed fixed-band broadband at home	2005	report	2009	Based on willingness–to-pay and an econometric analysis of transactional data.	Consumer surplus for fixed-line broadband use in U.S. homes in 2005 was $22.8 billion based on a willingness-to-pay survey and $32.0 billion for their preferred transactional data method
Cooper	value and consumer surplus in unlicensed spectrum	year-end 2010	report	2012	User value is estimated based on subscription prices. Consumer surplus is estimated based on Thanki. Assumes 37% of the value of traffic is offloaded on to unlicensed spectrum.	The annual value of activity in unlicensed spectrum in year-end 2010 in the U.S. was estimated at about $27 billion for standalone Wi-FI, $10 billion for hot spot use, $20 billion for offloaded traffic, $40 billion for consumer surplus and $12 billion for consumer surplus from speed. The $40 billion for consumer surplus is based on Thanki's high (30%) alternative which is viewed as consistent with the offloading of cellular traffic..
Bughin	consumer willingness to pay for services on the Internet in Europe and the U.S.	2010	article on Web	2011	Consumer surplus was estimated with a conjoint analysis.	Services on the web were valued at €150 billion in the U.S. and Europe in 2010. After deducting €30 billion for the cost of services and €20 billion for what consumers would pay to avoid ad clutter and loss of privacy, consumer surplus was €100 billion, which equates to around €40 per household per month and was nearly as much as mobile and fixed Internet access subscriptions which were €120 billion. 44% of the 2010 value was in communications, 38% in Web services and 18% in entertainment. Net consumer surplus was projected to grow to €190 billion by 2015, a 13% compound annual growth rate.
Electricity Generation and Transmission						

Carroll and Montgomery	economic loss from unreliable electric power and routine power outages	about 2007	report at professional meeting	2008	Generation, transmission and distribution of electric power by utilities and non-utilities produced annual operating revenues of over $326 billion	Average annual losses to the economy of approximately $100 billion. Commercial and industrial sectors account for 12% of users but 97% of losses. Losses from a 1-hour outage amount to $18.7 billion, with $13.2 billion attributed to commercial losses, $5.1 billion to industrial losses and $309 million to residential losses.
Eyer and Corey	increased revenue and avoided costs with increased storage	10-years forward	report	2010	Potential benefits of increased electric power plant storage may indicate potential benefits from avoidance of loss of GPS timing due to interruption of fuel supplies or disconnection from the power grid.	Maximum potential benefits of improved energy storage over 10 years, assuming 3% inflation and discounted at 10%, were estimated at $6.1 billion for improved electric service reliability and $6.1 billion for improved electric service power quality.
California Energy Commission (Kandel)	Benefits of a program to facilitate synchrophasor use in California through provision of software and other assistance	Projections through 2020	report	September 2014 draft	Several studies were examined and results of multiple methods were presented. The preferred approach uses a probability model that combines estimates and weighs them based on how well they are supported.	Projected benefits to California centered around $286 million per year at full implementation, with the benefits under the preferred method centered around $410 million per year. Estimates were based on impacts of past power outages.
Financial Services						Quantitative studies of current benefits not found.
Other Applications						

Consumer Location-Based Services—Vehicle and Internet-Related Services						
Bughin	consumer willingness to pay for services on the Internet in Europe and the U.S.	2010	article on Web	2011	Consumer surplus was estimated with a conjoint analysis.	Consumers were willing to pay monthly fees of €1.4 for Web mapping, €0.8 for comparison shopping, €0.8 for yellow pages and €0.5 for directories.
Patel	willingness-to-pay for mobile services in the U.S.	about 2008	report	2009	As reported in a survey of consumers.	50% of consumers surveyed were willing to pay for maps and directions on their phones. The average amount they were willing to pay was about $3.70 per month. About 46% were willing to pay for multilmedia messaging and pay an average amount of about $3.10 per month. About 32% were willing to pay for voice calls, with an average amount of about $3.85 per month.
Pantea and Martens	consumer surplus from leisure time on the Internet in Germany, U.K., France, Italy and Spain	2011	report	2014	This use of the revealed preference approach compares with a composite good so substitution possibilities are limited. Assumes the value of time is equal to the wage, but if it is a constant proportion there is no bias with the model.	Leisure time on the Internet generated consumer surplus of between 0.6% and 1% of "full income" according to the most conservative estimate which the authors emphasize because of the great variation among estimates. Total consumer surplus for each country ranged from €18 billion to €44 billion. An alternative measure ranged from 2.20% to 5.33%. The Goosbee and Klenow estimates for the U.S. in 2005 were 2.30% and 12.50% of full income with the alternative measure. *Full income is defined as the income that would be earned if all of a persons free time were spent working.*
Oxera	effects of reduced search costs on competition via	hypothetical	report	2013	Interesting methodology but the impacts appear	Consumer awareness of options available and reduced search costs with geographic information services are estimated based

	effects on transport costs				extremely low.	on assumptions about the number of firms in a local market using a model of monopolistic competition. Downward pricing pressure was estimated in the region of 0.002%.
Levinson	time saved with advanced traveler information systems	about 1989-1996	reports, articles in professional and articles in proceedings	2003	Model-based studies.	Tabulation of 10 earlier studies with 16 estimates shows great variation in time saved with advanced traveler information systems for route choice such as those expected to appear in vehicle navigation systems. The median value of time saved was 7%.
NuStats; GPS World	time, distance and fuel saved using personal navigation devices in Düsseldorf and Munich	2008-2009	press release and article	2009	In-field data collection on behalf of Navteq for 2,158 trips for over 500 hour and 20,000km involving 90 study participants that had not used a navigation device before.	NuStats reports that after the initial learning curve and during peak travel periods, trips were 23% shorter in duration, 36% shorter in distance and fuel efficiency was 24% higher. GPS World reports that the study showed a 12% increase in fuel efficiency for all trips.
Oxera	time saved, reduced mileage and increased fuel efficiency with use of a navigation system compared to conventional maps	about 2007	reference to report	2013	Results "when driving in an unfamiliar area to an unfamiliar destination" are applied to all use for time and mileage.	18% reduction in journey time and 16% reduction in mileage; 12% increase in fuel efficiency
Recreation						
Kite-Powell	consumer surplus from purchasing paper and electronic nautical charts for recreational boating and fishing	2005-2006	report	2007	Estimated the value of "ideal" charts based on demand curves constructed from a survey of willingness-to-pay.	Consumer surplus was an average annual $49.70 or $15 million per year for recreational boating and fishing. This does not include what was paid for hardware and software for digital chart displays.

					Ideal charts in 2005-2006 may be a good approximation to what is available today.	
Health						
Litan	reductions in use of health services with remote health monitoring	various, about 2000-2008	report	2008	Based on studies which are cited but not discussed.	Reduced health care expenditures with telemedicine net of costs over 25 years in constant 2008 dollars discounted at 2.8% were estimated at $153 billion without technological or policy changes and $197 billion with reimbursement and other policy changes. Most of the savings were in hospital expenses followed by nursing home expenses, with emergency services accounting for savings of $355 million per year. Savings in physician visits weren't included because of wide variation among studies. Heart patients accounted for over half of the savings.
Education						
Oxera	effect of GIS software use in the classroom over paper mapping on wages five years after graduation	various 2007-2011	report	2013	Question of causality if better students were in classes that had GIS software or got higher grades regardless of GPS. Sketchy data.	Combines estimates of the percentage of secondary school students that may use or have access to GPS software in a 2002 New Zealand study with a U.S. study of the effects of using GIS on grade point averages and a 1990 U.S. study of effects of a greater grade point average on wages five years after graduation. Result was an increase in wages of 2.67% for the students involved.
Emergency Services						
Oxera	time saved in emergency response journey for cardiac	about 2001 and 2010	articles in professional journals	2013	Too few studies with a wide range of estimates.	Cited the estimate of reduced journey time from the 2010 study of 5.5% and the 2001 study of 24%. Assumed an average reduced

	arrest with automatic vehicle location (AVL)					journey time of 18%. The reduction in time is 2 minutes from 11 to 9. Cited one study's estimate of a 7%-10% improvement in survival rate for each minute of response time saved and calculated the benefit based on the value of a life of $2.4 million used by the UK Department of Transport..
NOAA	ratio of benefits to costs and net benefits of SARSAT	about 2005	report	2006	Details not provided.	AA 2006 study cited in the 2007 NOAA report found that the Search and Rescue Satellite Aided Tracking (SARSAT) program had benefits of more than $11 for every Federal dollar spent and a net benefit in excess of $250 million.
Space						
Space Overall						Available national studies are 40 years old (see Schnee).
Remote Sensing						
Executive Office of the President	addition to the U.S. economy from Federal earth observation activities	2007	report	2014	The John Hillery CSIS report which the OSTP reference traces back to is no longer available on the Web. The CSIS Web site only has an abstract.	The Office of Science and Technology Policy states in its July 2014 report that: "Conservative estimates indicate that Federal Earth-observation activities add $30 billion to the U.S. economy each year." The abstract for the Hillery and Sabathier report says it: "examines the value of better weather forecasting in a number of sectors using two different methodologies."
ACIL Tasman – Earth Observation	productivity and direct and other contributions to GDP	2008-2009	report	2010	Largely based on taking 15% of the value of spatial information found in their 2008 report using its higher scenario.	Earth observation systems were estimated to contribute at least $3.3 billion to Australian GDP in 2008-2009. It was estimated that on conservative assumptions that could grow to $4.0 billion by 2015. The $3.3 billion consisted of direct benefits of $1.4 billion which was almost entirely attributed to government and $1.9 billion in productivity benefits. An additional $1.0 billion was estimated for

						other benefits including contributing to climate change adaptation, emergency response and natural resource management.
U.S. Geological Survey (Forney, *et. al.*)	corn and soybean production in 35 counties of eastern Iowa with use of moderate resolution land imagery from the Landsat and Advanced Wide Field Sensor satellites	2010	report	2012	Multiple environments science models were used in an integrated assessment approach to determine production and environmental impacts with an emphasis on groundwater quality.	Data for 10 years were examined and simulations made for the next 10 years: 2001-2010. Increased output was predicted from moving corn production to lands identified as less prone to nitrate leach and lands with fate and transport properties that render aquifers less vulnerable to leach nitrate. Benefits were measured by equivalent annual income which is the difference between optimal and actual quantity and price. Since price was assumed unaffected by the increase in production, the value reflects the change in production. Production value increased $858 million per year over the study period. This compares with average annual production during the previous decade of about $4 billion or an increase of about 27%.
U.S. Geological Survey (Miller *et. al.*)	willingness to pay for Landsat imagery	2009	report	2011	Based on what users would be willing to pay for equivalent images if Landsat were not available.	The survey respondents included 1392 current Landsat users and past users and users of other services. Mean willingness to pay was about $750 for one scene, over $1,000 for federal government users, over $800 for academic users and about $700 for private users. Lower rates were found for state and local government users and non-profit organizations. Median values were much lower than mean values.
Proteus	benefits of coastal hydrographic surveying with the use of satellite remote sensing	2015	Web page	ongoing assessment	Based on the firm's experience.	The firm stated: "Typically costs are between one tenth and one twentieth of the costs of traditional survey methods."

Space Weather						
American Meteorological Society	adverse economic impact of space weather	2000, 2003 and 2007	policy statement	2008	Conclusions of several studies.	Economists have estimated that the adverse effect of space weather is $200-$400 million per year (on average). Space weather-related losses to satellite companies range from thousands of dollars for temporary data outages to up to $200 million for loss of a satellite. The European Space Agency estimated that a 1% gain in continuity and availability of GPS would be worth $180 million per year.
Weather Forecasting						
PlanetiQ	hurricane reduced warning times, increased detection and reduced cost of unnecessary evacuation with radio occultation	various	white paper	2013	Company is engaged in a public-private collaboration to build small satellites for global GPS-RO.	Cites several studies. A 1999 study found the then annual cost of unnecessary evacuation to be $1 billion. A study of hurricane Ernesto in 2006 found GPS-RO showed a strong and well-defined storm in a 102-hour model but no storm without it. A study of typhoon Shanshan in Korea in 2006 showed inclusion of GPS-RO improved the 3-day track forecast by up to 23%, from 89 miles to 69 miles. Similar results were said to be found in several other studies cited.
ACIL Tasman – Earth Observation	productivity and direct and other contributions to GDP	2008-2009	report	2010	Largely based on taking 15% of the value of spatial information found in their 2008 report using its higher scenario.	Earth observation systems were estimated to contribute at least $3.3 billion to Australian GDP in 2008-2009. It was estimated that on conservative assumptions that could grow to $4.0 billion by 2015. The $3.3 billion consisted of direct benefits of $1.4 billion which was almost entirely attributed to government and $1.9 billion in productivity benefits. An additional $1.0 billion was estimated for other benefits including contributing to climate change adaptation, emergency response and natural resource

						management.
Centrec	cost and time savings from improved forecasting with GOES weather satellites	projections for 2015-2027	report	2007	Various methods and assumptions. Values include some estimates for reduced loss of life.	Reduced economic losses from improved hurricane forecasts with GOES were estimated at $270 million in 2007. Projected values of inflation-adjusted benefits of the Geostationary Operational Environmental Satellite Program (GOES) in 2015 were: aviation $228.6 million, energy $692.4 million, irrigated agriculture $82.0 million and recreational boating $41.9 million.
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Lazo and Chestnut	willingness of households to pay for attributes of weather forecasts	2001	report	2002	Uses conjoint analysis.	The value of weather forecasts to households was estimated as $11.4 billion in 2001 and the value of improvements to their maximum level at 95% confidence was $1.73 billion.

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Appendix B: Consumer and Producer Surplus

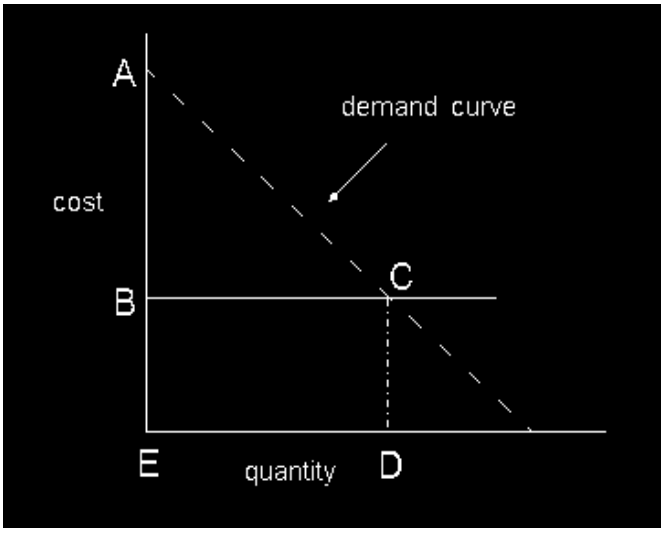
Many households and business consumers of services value services at more than what they pay in the marketplace. That is, they would have acquired the service if its price was higher than charged. The value consumers place on a service above its market price or cost is called consumer surplus. In addition, sellers gain value when prices obtained exceed costs of production. The extra value to sellers is called producer surplus.

The gross economic value of a product is the sum of revenue or cost (quantity x price) and consumer surplus. Producer surplus is included in the cost.

Consumer surplus is defined as the area under the demand curve above the market price. It can be inferred from information about the shape of the demand curve.

The demand curve is a schedule of what customers as a whole are willing to pay, with those with the highest benefit buying when costs are higher (Figure B1). The area under the demand curve AC and above the purchase price B, that is, the area of the triangle ABC, is consumer surplus. The area ACDE is the total value to consumers.

Figure B1. Consumer Surplus



Some studies have estimated consumer surplus from the shape of a demand curve, but they are often based on difficult to verify assumptions about the shape. Linear demand curves are typically used for convenience, but they do not conform to the shapes dictated by bell-shaped or other distributions of preferences.

Many users rely on GPS to obtain productivity gains or cost savings, including gains that are worth more than their cost. This is especially true among commercial users, but it is also true for consumers who may, for

> When benefits are measured by *average* productivity gains or cost savings, much of consumer surplus is implicitly included.

example, save time, fuel and vehicle maintenance and repair costs with better information. When benefits are measured by *average* productivity gains or cost savings, much of the sector's consumer surplus is implicitly included.

When services are free or prices are not observed, willingness-to-pay methods are often used to determine value. Consumers may be offered alternative sets of choices and their values for different attributes determined statistically from the responses. This is generally more reliable than asking how much people are willing to pay. Willingness-to-pay is in contrast with revealed preference, which measures what people actually pay.

Willingness-to-pay includes consumer surplus. It also reflects costs of purchase and other costs which must be incurred by the user, including the value of the user's time in taking advantage of the service.

Willingness-to-pay includes consumer surplus. It also reflects costs of purchase and other costs which must be incurred by the user,…

Proper willingness-to-pay surveys are costly and time consuming so their availability is sporadic. Some shortcut survey methods have been used as have measures of travel time and costs saved (e.g. by having a facility or service nearby). Statistical measures of the impact of amenities or environmental risks on the value of residential real estate also have been used to measure value.

Willingness to pay surveys have not been effective in government and business and are very rare because of difficulty in identifying and combing the values of the various decision-makers.

Producer surplus, the value to sellers above their costs of production, arises when costs rise with the volume of production (upward sloping supply curve), so prices charged are based on the higher costs of the last items produced. Producer surplus is reflected in the level of profits and included in revenue.

Producer surplus is not explicitly included in many studies because of the difficulty of determining costs at each level of production or because it is already included in revenue. Profits are sometimes used as a proxy for producer surplus in the private sector. However, there is no equivalent to profits for the government or not-for-profit sectors.

Appendix C: The Value of Information

Information transmitted through communications systems, the Internet and social media can provide network benefits that grow exponentially as larger numbers of users interact, learn, share, and build on each other's information. Advancing information technologies and systems have greatly increased the value of information since it can be shared quickly and easily across distances and devices. Social media can greatly magnify "network effects," that are already present in communications systems, multiplying the value of information as it becomes available to many users. Electronic interactions can improve safety by relaying warnings about weather, obstructions and accidents and provide alerts to emergency responders.

One economic approach views the value of information as the reduction in uncertainty which it enables. In other words, information is valuable when it results in better choices.

Information has the most value when action can be taken in response to it, when the consequences of making the wrong decision are large, and when the constraints on using the information and the costs of the information are small.[129]

To apply the value of information approach it must be possible to define specific choices and to know or assume the probabilities of different outcomes. The value of the information is the gain in the expected outcome when the information is used. The choices and probabilities necessary to implement the approach are not available in many instances, especially when aggregate data are being used that subsume a great many choices. However, the great variation in the value of benefits in relation to costs or expenditures among studies that have been able to measure the value of information indicates that applying a simple rule of thumb can be extremely inaccurate.

[129] Molly Macauley and Ramanan Laxminarayan, "The Value of Information: Methodological Frontiers and New Applications for Realizing Social Benefit," Conference Summary, June 28-29, 2010, Resources for the Future, August 2010, pp.4-5.

Appendix D; Synchrophasor Use

The number of synchrophasors grew from less than 200 in 2009 to over 1,800 in May 2015 according to data from energy.gov and the National Synchrophasor Initiative (NASPI). Most of the large reliability coordinators that connect power plants and systems are using PMUs, and that is where PMUs can have substantial benefits. One forth to one third of transmission utilities are using PMUs for various purposes.

Few transmission utilities are using PMUs for situational awareness and operational decisions, which is where the largest payoffs are. Remedial Action Scheme (RAS), which is being employed by Bonneville Power Authority but not extensively by others, lets more power flow down the line and reduces the need for generating capacity. Those who are not using PMUs are most commonly using line fault detectors which rely on positioning to determine that the fault is between two points.

Uses of PMUs according to their technical status are indicated in Table D1.

Table D1. Synchrophasor Application Maturity	
Technically Mature Today	**Maturing Quickly**
Model validation	Wide-area visualization
Oscillation detection & mode monitoring	Linear state estimation
Frequency monitoring & compliance	Data quality and availability
Voltage stability monitoring	Diagnosing equipment health & mis-operations
Forensic event analysis	Black-start operations & restoration coordination
Automated RAS scheme (remediation)	Synchrophasor network support & maintenance
	Renewables integration
	Dynamic line loading/dynamic line transfers
	Geomagnetic-induced current identification
	Operator decision support tools
	Automated protection & controls
Source: Alison Silverstein, North American SynchroPhasor Initiative, slides, May 5, 2015.	

Appendix E: Comparison of Economic Benefit Estimates with those of NDP

NDP Analytics (2013)[130] is not discussed because it did not have any original estimates.

NDP Consulting (2011)[131] had a range, the top value of which was for 100% adoption in each sector. There is no discussion of when if ever the 100% limits would be reached. Since 100% isn't a current estimate and its meaning is not clear it is ignored, and the lower limits which are the actual sector estimates are used is this comparison.

NDP Consulting estimated benefits for 3 sectors (agriculture, heavy and civil engineering and surveying and commercial vehicle transportation) and extrapolated to the rest of the economy. This comparison only deals with the actual (sector) estimates.

The sum of the estimated sectors in NDP Consulting is $39.4 billion. The sum for the overlapping estimated sectors in the current study is $55.8 billion. Comparing the totals of sectors for which estimates were made, the current study estimate is higher than NDP 2011 by $16.4 billion.

Comparing the totals of sectors for which estimates were made, the current study estimate is higher than NDP 2011 by $16.4 billion.

NDP Consulting included only commercial sectors but added more in indirect benefits than the current study in the sectors it covered.

The current study included all surveying, all vehicle categories, and some very small (but important) items, but included only earth moving in construction. Government was included for some categories.

The following comparison aligns the 3 sectors from NDP Consulting with the 3 sectors from Leveson 2015. The Leveson estimates are the midpoints of the ranges. They are only shown for the categories that overlap with NDP.

<u>Agriculture</u>
NDP: $19.9b for crops
Leveson: 13.7b for grain

[130] Pham, Nam D., *The Economic Benefits of Global Navigation Satellite System and Its Commercial and Non-Commercial Applications*, NDP Analytics, December 2013 http://static1.squarespace.com/static/52850a5ce4b068394a270176/t/52d57f29e4b0dad117c5e3bb/1389723433433/Economic+Impacts+of+GPS+December+2013.pdf

[131] NDP Consulting, *The Economic Benefits of Commercial GPS Use in the U.S. and the Costs of Potential Disruption*, June 2011 http://www.gps.gov/governance/advisory/meetings/2012-08/pham.pdf

Construction and surveying

NDP: heavy and civil engineering and surveying and mapping in construction $9.2b

Leveson: earthmoving in construction ($5.0b) and all surveying ($11.6b) totaling $16.6b

Vehicle transportation

NDP: for commercial vehicle transportation $10.3b

Leveson: $11.9b for fleet vehicle telematics plus $13.1b for the combination of consumer and non-fleet commercial vehicle telematics

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The contributions of all are greatly appreciated. Responsibility for the substance and findings rests with the author.

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Acronyms

ADSB	Automatic Surveil lance Dependent-Broadcast	GSA	European GNSS Agency
AIS	Automatic Identification System	IPv4	Internet Protocol version 4
ARPA	Advanced Research Projects Agency	IPv6	Internet Protocol version 6
BCG	Boston Consulting Group	LBS	Location-Based Services
CEA	Council of Economic Advisors	NAICS	North American Industrial Classification System
CGE	Computable General Equilibrium Model	NASA	National Aeronautics and Space Administration
CORS	Continually Operating Reference Station	NASPI	North American Synchrophasor Initiative
DGPS	Differential GPS	NextGen	Next Generation Air Traffic Control System
DHS	Department of Homeland Security	NG911	Next Generation 911 emergency reporting system
DOC	Department of Commerce	NOAA	National Oceanic and Atmospheric Administration
DOD	Department of Defense	NIST	National Institute of Standards and Technology
DOI	Department of Interior	PBN	Performance-Based Navigation
DOT	Department of Transportation	PMU	Phasor Measuring Unit
ECDIS	Electronic Chart Display and Information System	PNT	Positioning, Navigation and Timing
ECS	Electronic Charting Systems	PNT EXCOM	National Executive Committee for Space-Based Positioning, Navigation and Timing
EOP	Executive Office of the President	PTC	Positive Train Control
ESA	Economics and Statistics Administration	RAS	Remedial Action Scheme
EPIRB	Emergency Position Indicator Radio Beam	RNAV	Area Navigation
FAA	Federal Aviation Administration	RNP	Required Navigation Performance
FCC	Federal Communications Commission	RTK	Real Time Kinematic
FRA	Federal Railroad Administration	SBAS	Satellite-Based Augmentation System
FTP	File Transfer Protocol	SID	Standard Instrument Departure Route
GBAS	Ground-Based Augmentation System	SSAS	Ship Security Alert System
GDP	Gross Domestic Product	STARS	Standard Arrival Routes
GEO	geostationary satellite	TASS	TDRSS Augmentation Service for Satellites
GIS	Geographic Information System	TRB	Transportation Research Board
GMDSS	Global Maritime Distress and Safety System	UAS	Unmanned Aerial System
GNSS	Global Navigation Satellite System	USGS	U.S. Geological Survey
GPS	Global Positioning System	WAAS	Wide Area Augmentation System

About Dr. Irving Leveson

Dr. Leveson has strong analytical skills in the fields of economics and social science and extensive experience in analyzing programs, markets and technologies. His background includes strategic and economic consulting and research in private industry, prominent research organizations, and government. For the last decade Dr. Leveson has worked extensively on GPS and related matters, cost-benefit analyses of government programs, and analyses of critical trends and issues. Dr. Leveson has been the principal of Leveson Consulting since 1990. He has served as a consultant to the Aerospace Corporation and is an Adjunct Fellow at the Hudson Institute. He currently serves as a consultant to ASRC Federal Research and Technology Solutions, LLC.

Dr. Leveson holds a Ph.D. in economics from Columbia University. He previously served as Director of Economic Studies of the Hudson Institute, Senior Vice President and Director of Research of Hudson Strategy Group, Assistant Administrator for Health Systems Planning for the New York City Health Services Administration, and as a research director for the New York City Planning Commission. He also served as an economist with the RAND Corporation and an analyst with the National Bureau of Economic Research. Dr. Leveson is a member of the Institute of Navigation, the American Economic Association and the National Association for Business Economics.

His publications include *Economic Security*, iUniverse, 2011, *American Challenges: Business and Government in the World of the 1990s*, Praeger Publishers, 1991, *The Future of the Financial Services Industry* (main author), Hudson Institute, 1982, and *Western Economies in Transition* (co-editor), Westview Press, 1980.

His recent work includes:

A scoping study of benefits of the National Geodetic Survey's Coastal Mapping Program.

A preliminary analysis of the socio-economic benefits of the NGS CORS and GRAV-D programs.

An extensive internal analysis of the benefits of GPS for the National Coordination Office for Space-Based Positioning, Timing and Navigation under the auspices of the Aerospace Corporation.

Strategic cost-benefit analyses of modernization of the Global Positioning Satellite System focusing on applications, markets and benefits, conducted for the U.S. Departments of Transportation and Commerce and the Interagency GPS Executive Board.

A study of alternative financing for positioning, navigation and timing for the U.S. National Space-Based PNT Coordination Office.

Examining opportunities for utilizing modernized GPS systems in NOAA.

Analyzing scientific and technical workforce trends for several U.S. intelligence agencies.

Estimating benefits of the National Polar Orbiting Environmental Satellite System for the National Environmental Satellite Data and Information Service.

Assessing societal impacts of high impact weather for the U.S. National Weather Service.

Analyzing public-private partnership issues for the U.S. National Oceanic and Atmospheric Administration.

A comprehensive examination of external trends affecting NOAA, including technology, business models and public/private sector roles, and their implications for NOAA decisions.

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