The Social and Commercial Evolution of the Global Positioning System

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Grant Duemmel

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

M.C. Forelle, Department of Engineering and Society

Introduction

The United States Federal Government spent $857 billion dollars on national security in 2022, including $34 billion invested in funding new technological innovations (Chewning et al., 2022). Evidenced by this spending, the U.S. Government values maintaining their military's competitive edge. U.S. Under Secretary of Defense for Research and Engineering, Heidi Shyu, stated that the U.S. "cannot afford a leveling of technological advantage. It is imperative for the department to nurture early research in emerging technologies to prevent technological surprise" (Vergun, 2022). Consequently, military innovation spending exceeds itself yearly, consistently making new spending records in this category (Chewning et al., 2022). These large yearly expenditures raise the question of how civilians are benefiting from this investment. Some research suggests large military spending projects can create a trickle-down of benefits for civilians (Pollin & Garrett-Peltier, 2009). Specific technologies should be studied to evaluate this claim.

One example of this technological phenomenon is the Global Positioning System (GPS). Today, GPS is a seemingly omnipotent technology, used for navigating on mobile applications and tracking friends and family at the click of a button. These applications have excellent precision at a tremendous ease of access. At the beginning of GPS's development, this was not the case. This technology started as a collection of military research projects with specific uses. Researching the genesis and development process of GPS reveals how military technology can transition to broader society. It is important to see how these technologies create benefits for civilians from immense government spending.

The Global Positioning System relies on communication between GPS receivers on the Earth and the GPS network of satellites. The first iteration of GPS was built in the early era of satellite development. This era began when the Soviet Union launched the first man-made satellite, Sputnik 1, in October 1957. This satellite communicated with its developers with a radio signal. Scientists studying the satellite realized they could locate it based off the relative strength of its signal (Kumar & Moore, 2002, p. 59). Further, these scientists realized that the opposite use could be true, meaning "a person on Earth could obtain [their] position on the globe if they could read the signal from the satellite in conjunction with knowing the exact orbit of the satellite" (Kumar & Moore, 2002, p. 59). This methodology became the basis for the development of GPS. The first innovators and developers of this technology were naturally military entities due to their prominent involvement in satellite and radio communication projects. In the 1940's and 1950's, the Army and Navy each completed projects which sent signals to the moon and back on microwave carriers (Kumar & Moore, p. 60). This made the military primed for the research necessary for GPS. Concurrently, the military found a strong "need to deliver weapons precisely on target and to [expand their] navigation systems" (Sturdevant, 2015, p. 332). To fulfill these needs, the Navy and Air Force commissioned research on the Naval Navigation System (TRANSIT) and Project 621B, respectively, in the early 1960's (GPS World, 2010). The best aspects of each of these systems were brought together to create a single, synchronized locating system known as GPS.

The current breadth of applications of the Global Positioning System could not have been predicted at the dawn of the technology. Over the last fifty years, the development of GPS has transformed the way the system is used. The GPS network now consists of over 30 satellites in equally spaced orbits to provide consistent, continuous locating services for many different sectors across the world. Civilian users' influences on GPS have had a profound impact on its evolution, expanding the scope of its development. The diffusion of GPS from its initial military applications to broader society was the direct result of choices, actions, and communication between the U.S. military, government, and civilian engineers and users.

To analyze this topic, I complete a literature review and synthesis of relevant research and examine the development of GPS through the sociotechnical framework of diffusion of innovation. Throughout this research, I find that commercial influence has widened the scope of the evolution of GPS from its original militaristic intentions and has shaped its technical development. My literature review provides relevant background on the timeline of sources I examined and information on their relationship to the topic. It also details the sociotechnical framework of diffusion of innovation. These sources show that social groups had a profound impact on the development of GPS. The diffusion and adoption of the technology allowed it to evolve from a focused military technology to a tool with wide applications. This research concludes that commercial factors compound benefits with military spending on technologies to create new technical applications, widening the scope of technologies.

Research Methods

To complete my research, I gathered numerous primary and secondary sources. These sources include broad overarching histories, government and military documents, and independent research studies. These types of sources create a breadth of knowledge on GPS technology from different points of view. They supplement each other to encapsulate many facets of GPS. These sources together show the original military intentions of GPS and how it evolved over time.

With this information, I examine how the uses and applications of GPS developed and diffused across society using diffusion of innovation theory. In my analysis, I trace GPS development through diffusion of innovation's six key stages of the innovation development process (Rogers, 1983) to see how it transitioned to broader society. Through this, I analyze how social and commercial factors changed the course of GPS development. By viewing GPS through this framework, the impact of its diffusion is evaluated and understood.

Literature Review

Organizations and individuals have found GPS an intriguing topic for research and discussion for various reasons. Its ever-present use in the twenty-first century brings GPS into the forefront of our minds, even when it is often being used primarily behind the scenes. The three categories of sources I studied give a breadth of information that shows how GPS was developed, spread, and adopted.

Military and government sources on this topic give strong background on the origins of GPS and the development of the technology. Military developers started creating the Global Positioning System to serve their air, ground, and naval forces. The first iterations of this technology were the Navy Navigation System (TRANSIT) and the Air Force's Project 621B. Robert Danchik's "The Navy Navigation System (TRANSIT)" (1984) gives background information into the development of the TRANSIT locating system. TRANSIT was a precise navigating system used for locating submarines. Important lessons were learned from this program that were used to create GPS. Rick Sturdevant's chapter in *Historical Studies in the Societal Impact of Spaceflight* (2015) examines the evolution of GPS from the founding military programs and provides information on its continued use in the military. Sturdevant details the process by which the military combined the founding programs and the reasoning for their actions. This source also gives information on how military and federal developers began to realize the benefits the technology could have for civilian users and the technical features that were put in place to facilitate civilian use.

Broad historical sources overlap with military sources, giving more information on GPS's roots and adding more detail on the developing applications of GPS over time. The Aerospace Corporation's "Brief History of GPS" (2021) details what scientists learned from the first early era of satellite development, GPS's importance, and how GPS has continued to develop up until the present day. Developers' ability to learn from previous satellites has made GPS possible. GPS World's "The origins of GPS, and the pioneers who launched the system" (2010) and "A brief history of satellite navigation" from Stanford News (1995) give information on early United States programs that used this information. GPS World details the government's original intentions for the system and the secret research that was occurring. Project 621B was originally classified information (GPS World, 2010), and was developed to provide locating for Air Force planes and missiles ("A brief history", 1995). These general historical sources give detail on how applications of GPS expanded. The Aerospace Corporation shows how users pushed for the removal of intentional technical barriers and were crucial to the growth of the technology (2021). The expanded uses of GPS are wide ranging and are shown in research studies. These historical sources overlap with military sources in showing the origin of GPS but differ from them by showing the development of GPS over a larger time scale. This larger time scale shows the impact of more social groups on the technology.

Research studies give an analytical, retrospective viewpoint on the development of GPS. These sources give information on the results and consequences of the Global Positioning System. In "Space Diplomacy" (2003), the authors detail the global implications of the development of GPS and how commercial uses arose in a global context. The RAND Critical Technologies Institute performed a research study on GPS (1995) which details the timeline of technological development in relation to national policies. The National Academy of Public Administration and National Research Council also jointly completed a research study (1995) on GPS which was commissioned by the government. These studies provide information on the groups involved in GPS's diffusion and how the key events in the timeline unfolded.

As a result of the development of GPS, many uses have been created. Francis Abulude, Akinyinka Akinnusotu, and Adewale Adeyemi (2015) research the wide variety of uses of the Global Positioning System. This source gives information on the scope of GPS's applications. Another research source relevant to this topic is a detailed economic analysis from the Research Triangle Institute. The contributors to this study list thorough findings of economic benefits in many commercial sectors (O'Connor et al., 2019). These findings show widespread impact across society and tremendous economic growth over time. Another research study was completed by Gregory McLaughlin at the Air Command and Staff College (1997). In this, McLaughlin analyzes the features of GPS and how they have contributed to the development of GPS. These research studies provide details on the results of GPS that are useful in analyzing development consequences.

My analysis hinges upon looking at this process through the sociotechnical framework of diffusion of innovation. This framework was originally developed by Everett Rogers. Rogers' foundational work of this framework is the book, *Diffusion of Innovations* (1983). This book describes the main ideas of the framework, the key stages of the process, case studies, and methods for evaluating consequences of diffusion. Diffusion is defined as the “process by which an innovation is communicated through certain channels over time among the members of a social system” (Rogers, 1983). This process can be analyzed for ideas or technologies. Rogers claims that there are six key stages of the innovation development process: (1) recognizing a problem or need, (2) basic and applied research, (3) development, (4) commercialization, (5) diffusion and adoption, and (6) consequences (1983). By tracing technological development through these stages, the process and technology can be better understood. This process can also be iterative, as commercialization and diffusion can lead back to additional research and development. Elihu Katz, Martin Levin, and Herbert Hamilton build on Rogers’ research in *Traditions of Research on the Diffusion of Innovation* (1963). They state that diffusion of technologies relies on its related groups of people who are linked to specific communication channels, social structure, and values (Katz et al., 1963). These social groups and communication channels have a direct correlation on the ability and rate of diffusion.

I use these sources and this framework to trace the development of GPS. In my analysis, I trace GPS development through Rogers’ key stages to show how critical events and interactions broadened the scope of GPS technology. Using this framework, I show how diffusion across societal groups has caused GPS to evolve from the original intentions of the technology.

Analysis

Viewing the development of the Global Positioning System through the diffusion of innovation framework reveals the key interactions between the military, government, and civilian engineers and users. The direct impact of commercialization on the evolution of GPS is seen throughout the six stages of the innovation development process.

The first three stages of GPS innovation development show the sole influence of military-funded development. The first stage, recognizing a problem or need, spawned from the U.S. military as they realized the need for a more precise locating system to improve weapon locating precision and expand navigation systems (Sturdevant, 2015). The original plans for GPS were detailed in the 1966 United States Department of Defense (DoD) Secret Woodford-Nakamura Report (GPS World, 2010). The classified nature of these plans indicates that GPS was at first solely an issue of national security.

The second stage, basic and applied research, continued the military monopoly on development. The Navy's TRANSIT locating system for submarines planned a satellite constellation with four equally spaced satellite orbit planes, which would allow for global access to the satellite network. As TRANSIT evolved, errors with the system caused gaps to form in the satellite network (Danchik, 1984, p. 324). This lesson informed the later development of GPS. Air Force Project 621B accomplished a similar purpose as TRANSIT in relation to GPS, providing key analysis on the best aspects of a satellite locating system. These military research programs made key strides in determining the best technical features for GPS.

The third stage of innovation development, original technological development, was geared specifically to military applications. After the original findings of TRANSIT and Project 621B, military officials saw an opportunity to create a joint service project to restructure satellite locating. This project, GPS, promoted cost savings by streamlining the different programs into one synchronized locating system, combining the best aspects of each program (McLaughlin, 1997). This seemingly small decision that was intended for military efficiency had a large impact on the system. By incorporating the lessons learned from different programs into a common system, a technology with the capability of global access for all military programs and future commercial opportunities was created.

The commercialization of GPS, the fourth stage of the innovation development process, was characterized by a meaningful design decision that controlled the way GPS was used, denying civilian users the same access as their military counterparts. Commercialization is defined as “the production, manufacturing, packaging, marketing, and distribution of a product that embodies an innovation” (Rogers, 1983, p. 143). There were important details of the distribution of GPS that embodied its original intentions. In the development of GPS, the DoD recognized the potential usefulness of the technology to civilian users but had public safety concerns. To “withhold full accuracy from enemies but provide GPS service to civilian users, the [military] designed the system with a protective feature called ‘selective availability’” (Sturdevant, 2015, p. 332). With selective availability (SA), two sets of signals were emitted: one precise signal encrypted for military use, and one open, less precise signal for civilian use (Ruttan, 2006, p. 152). This was a key decision in the commercialization of GPS, giving favor to the original militaristic intentions of GPS but beginning the evolution of commercial GPS applications.

The diffusion and adoption of the Global Positioning System, stage five of the innovation development process, was characterized by critical interactions between the U.S. military, federal government, and civilians. The diffusion of GPS was a direct result of choices and communication between important groups. These important groups function “as [variables] to facilitate or block the flow of acceptance of innovation” (Katz et al., 1963, p. 245). At different times, the federal government acted as a blocker and facilitator to the diffusion of GPS.

An important event occurred when Korean Airlines Flight 007, flying from Alaska to Seoul, was shot down in Russian Airspace in 1983. The plane strayed off course due to an error by its Inertial Navigation System. In the aftermath, realizing that this was a navigation issue, President Ronald Reagan "approved the use of GPS in commercial aircraft" (Braunschvig et al., 2003, p. 158), starting the public realization that military-grade GPS signals would be important for safety in commercial use.

At this point, GPS receivers were not common in society. E.M. Rogers characterizes diffusion as a decision to diffuse the technology to its adopters (1983, p. 144). In 1984, the Department of Commerce's National Oceanic and Atmospheric Administration chose to publish the first standards of GPS, allowing the first civilian use of GPS in the surveying industry. This allowed for commercial GPS equipment to be manufactured and used while GPS was still under development, providing surveyors productivity benefits. This commercial use enabled manufacturers to invest in research and development. This "helped accelerate the development of GPS applications faster than would have been possible had the DoD been left to carry out this task on its own" (Pace et al., 1995. p. 249). This choice of diffusion began an evolution of efficiency on the civilian side of GPS that could not be replicated by the government.

When the Persian Gulf War broke out in 1990, GPS military applications were brought to the forefront because of the vast, feature-deficient desert terrain. Due to a lack of inventory of military receivers, the DoD elected to purchase thousands of commercially developed receivers (Pace et al., 1995, p. 250). In order to increase the accuracy of these receivers, the DoD turned off the feature that reduced commercial signal accuracy, selective availability (SA). This event plunged more funding into commercial development, proved the ability of commercial receivers, and showed the ability of SA to be disabled for greater benefit. In this event, commercial use began to win out over a desire for secrecy, due to military desperation in a time of need. It proved the capability and importance of commercial GPS, paving the way for further commercial development.

Using this development boom, civilians started to use GPS technology more, augmenting the system for their benefit, altering the course of development. By the early 1990's, civilian users of GPS had ten times as many receivers as their military counterparts (Sturdevant, 2015, p. 332). Civilians found the technology useful for their applications and pushed for more access to the limited SA system. Civilian users found ways to augment GPS receivers to navigate around SA (Sturdevant, 2015, p. 333). These methods included using pseudolites and differential GPS which each use ground technology to enhance the accuracy of signals, while circumventing the effect of SA (Pace et al., 1995). Surveyors and engineers in other industries who began to use GPS learned to leverage differential GPS methods to accomplish their needs around the SA system. These actions increased commercial applications and capabilities.

After this success, the federal government made actions to recognize and examine the importance of civil GPS usage. In 1993, a DoD and Department of Transportation Joint Task Force was created to examine the increased use of civilian GPS. Due to their recommendation, the National Defense Authorization Act for Fiscal Year 1994 mandated an independent study on the future of GPS (H.R. Rep. No. 2401, 1993). The findings of this study demonstrated the need for the removal of SA. It found that SA "undercuts GPS satellite improvements and inhibits foreign willingness to rely on the system," and the continued use of SA denies civilians the benefits of future improvements to GPS (NAPA & NRC, 1995, p. vii). It found that by continuing to selectively degrade signals, the U.S. would encourage the proliferation of differential GPS systems, and fuel speculation about the development of other positioning systems which undermine GPS. Users' ability to use differential GPS systems caused the effectiveness of SA to erode (NAPA & NRC, 1995, p. vii). The study recommends that SA be discontinued for the U.S. to retain its technological superiority. In this government-commissioned study, the input of independent organizations and civilians informed government decisions.

The U.S. Government responded to this recommendation by issuing a plan of action. In 1996, President Clinton issued a Presidential Decision Directive (PDD) announcing the intention to discontinue SA within a decade. This was to allow the military time to prepare for operations without SA. Clinton cited the ability to "enhance our economic competitiveness and productivity while protecting U.S. national security" as the reason for the decision (Clinton, 1996). Clinton mentions the economic benefits of encouraging innovation in the commercial sector, showing the decision is in response to the study. The PDD also starts an official government commitment to ensuring "an appropriate balance between the requirements of international civil, commercial, and scientific users and international security interests" (Clinton, 1996). The government makes this promise to retain its position of superiority at a time when it was in question. The communication and exchange of information between users, researchers, and the government resulted in this decision.

After only four years, President Clinton directed immediate discontinuation of Selective Availability in 2000, increasing GPS signal accuracy for civilians significantly, and stimulating a burst in consumer demand (Ruttan, 2006). The increased precision and availability of the system led to a dramatic decrease in receiver cost. These events had a compounding impact on commercial use. The cheaper access to the technology led to more innovation, which led to further driving down of barriers to getting receivers. These events led to "exponential growth in

GPS usage for in-car navigation, location-based services, personal technology and usage in shipping, sailing and other industries" (Aerospace Corporation, 2021). Civilian users push for access to GPS technology after the military decision to diffuse the technology changed the course of its development.

The consequences of this process, stage six of the innovation development process, show the expansion of GPS from a military technology to a widely used tool. Military applications of GPS are still very important and are subject to immense federal spending. In the twenty-first century, large investments are being poured into improving airborne weapons development (Sturdevant, 2015). The push for development outside of military applications has benefitted the military by decreasing the price of GPS receivers and increasing their availability. GPS now has many applications in diverse industries. Civilians have incorporated GPS into all facets of society. GPS facilitates everyday activities such as banking, locating, and power grid control, as well as scientific applications in studying animal movement habits and settling property disputes (Abulude et al., 2015). These applications of GPS were not seen as related to the original usage of GPS but came about as a result of the diffusion process. Newer generation GPS satellites beginning in the 1980's and onward include different configurations with varied capabilities to accommodate the breadth of GPS applications (Aerospace Corporation, 2021).

Civilians have been able to evolve the reach of GPS to all industries. This evolution has created enormous benefits in many sectors. According to research from the Research Triangle Institute, GPS development has generated $1.4 trillion in economic benefits for the private sector (O'Connor et al., 2019). This benefit is found in nine specific industry sectors that have a particular need for GPS's precise locating abilities. These sectors benefit from the expansion of GPS beyond military purposes. The study estimates that an outage of GPS service would cause a loss of one billion dollars per day. The evolution of GPS technology has resulted in far-reaching benefits that were unforeseen at the dawn of development.

Conclusion

The explosion of applications and transformation of GPS into a prominent tool from a solely military technology occurred as a direct result of choices and interactions between the U.S. military, government, and civilian engineers and users. GPS has conformed to accommodate the needs of all its users, military and civilian. Commercial diffusion has changed the breadth of GPS applications, and GPS has in turn provided immense benefits for private industries. This process is evidence of how military innovation spending can create widespread benefits for the civilian public.

Through this learning, the impact of government spending on military innovation is better understood. The importance and benefit of commercial and military collaboration in research is also illuminated. By combining commercial development flexibility and military funding, great strides can be made in technological innovation. Further research should build off this project by studying the diffusion of other military technologies that have expanded to large commercial products, and by comparing these technologies to those that remain solely military-focused.

As shown by the Global Positioning System, the development of military technologies can bring about new innovations and technological applications that were previously unimagined. GPS has evolved from a focused military technology to a preeminent tool for daily life as a result of interactions between the military, federal government, and commercial users. Decades from now, there will be new technological opportunities that are nonexistent today.

Military research should continue to compound benefits with the creativity of civilian engineers and users to impact the development of the technology of the future for good.

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