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International Competition for Satellite-Based Navigation System Services

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INTERNATIONAL COMPETITION FOR SATELLITE-BASED

NAVIGATION SYSTEM SERVICES

by

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ABSTRACT

INTERNATIONAL COMPETITION FOR SATELLITE-BASED NAVIGATION SYSTEM SERVICES

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The goal of this work is to review the current state of Global Navigation Satellite System (GNSS) development and its potential impact on the social, economic, and political dynamics of the various states fielding the systems. The most recognizable GNSS is the US GPS. It is the only operational system functioning at the time of this writing and has become part of the global commons. GPS, by virtue of its uniqueness, is considered the 'gold standard' of satellite based positioning, navigation, and timing systems. This uniqueness has also enabled the US to fully capitalize on the sizable economic dividends gained by the US technology sector from the development and sales of GPS user equipment and services.

This work argues that the emergence of three global peer competitors to GPS is going to usher in a changed international relations environment for those new players. The economic implications go beyond a simple return on investment and could represent the continued space science and technical competitiveness of these states or not. The international political ramifications of the success or failure of the particular GNSSs could have a greater impact on the current international order than has been previously considered.

The European Union, Russia, and China have become inexorably locked in a contest of domestic political will to field the next generation of GNSS in order to free

themselves from US GPS domination and at the same time gain economic advantage over the other in space system technologies. Concurrently, the US is endeavoring to field the next generation of GPS and maintain its dominance in the associated technologies linked to GPS.

ACKNOWLEDGEMENTS

It has been a long and convoluted journey to this point of my project. Deployments to Iraq and Afghanistan both interrupted my efforts to finish what I had started in any timely fashion. But finish I did with many lessons learned along the way; the most important being that I now recognize that there is rarely one right answer for anything. That was a lesson learned late in life for me.

The original genesis for this work came from Dr. Regina Karp, Department Chairman and my Advisor. Therefore, I would like to begin by thanking her. Dr. Karp spent more time than was necessary reviewing the work as it progressed in her capacity as Committee Chair. I appreciate that she was tough when she needed to be and was almost singlehandedly responsible for me finishing this work. She is a true professional and a great credit to herself and to ODU.

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I could not continue without acknowledging some of the supporting players who have offered a hand when necessary to keep me focused. First, I thank my wife, Amanda, who made sure I stayed on top of the papers over the years and urged me to finish the project.

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CHAPTER I

INTRODUCTION

A. PURPOSE

A popular TV show from the 1960's used to call space the 'final frontier' and then went on to tickle viewer's imaginations with the possibilities of using outer space as a place for commerce and settlement. Now, fifty years later, mankind has a semi-permanent settlement in the International Space Station and we the people are increasingly using satellites for global commerce. Part of the significance of this research project is to look at how a global increase in space-based commerce is affecting international relations.

We can only guess if the current trend of global states seeking space power status will mimic the race of states to colonize during the 19th Century with its corresponding levels of competition and conflict. There are no traditional boundaries in space and so far space has not been weaponized but it is being commercialized. One of the manifestations of space exploration is that we now have thousands of space vehicles and their detritus traveling around in Earth orbit while the various space states continue to build and launch new systems into those same orbits.

Part of that expansion of space vehicles will come from a significant expansion of Global Navigation Satellite Systems (GNSS) being deployed into space over the next ten years or so. This growth is going to mean hundreds of additional satellites launched into space over the life of these systems. This growth also represents tens of thousands of high tech jobs for participating states, the possibility of increases in state prestige and power, and the specter of future competition or conflict.

What is a GNSS and why is it an important topic of research? A GNSS is a collection of satellites in space orbit, a series of ground control and monitoring stations, and user receiver equipment that are designed to work together and provide accurate positioning, navigation, and timing (PNT) information to a user. At the base level, each satellite is programmed to send out a continuous stream of signals from space that will provide location information to a receiving device that has the ability to process the signals. System operation is, of course, exponentially more complex than that but for the purposes of this study it is no more than signals emanating from space and being processed on the ground to provide a specific location outcome. A navigation system installed in a motor vehicle is probably the most well-known application for a GNSS.

However, that is only one of a great many applications for these systems that also include mining, agriculture, oil drilling, surveying, mapping, cell phone, banking, military, and a host of others. It is so ubiquitous that it is now considered part of the global commons. Why then, if it is so common across the globe, do we study it from an international relations perspective?

The purpose of this research is to examine the current state of GNSS development and determine why various states have decided to build new and independent systems when there are other systems freely available for use. Will states uses their GNSS as a foreign policy tool offensively to increase its prestige and power or will they use it solely as an instrument of peace to the betterment of mankind? GNSSs have become so intertwined in the everyday life of people and states all over the globe that the interruption of these services could spark global chaos or worse.

The paper will examine the US GPS, the European Union's Galileo system, Russia's GLONASS, and China's COMPASS that makes up what will be the four global systems that are projected to be operational by 2020. Additionally, India and Japan are deploying regional navigation systems that are also reviewed in this study because they are directly related to, and fully support other global systems. The examination will also include a review of the internal and external politics that drive the policy decisions as well as the impact of the economic component associated with that decision making process.

Over the years there have been a number of GNSS augmentations designed and built to improve specific PNT capabilities. For instance, the European Geostationary Navigation Overlay Service (EGNOS) was designed and built to support the US GPS in the northern latitudes of the EU to specifically improve the accuracy and reliability of GPS relative to the civil aviation industry thereby improving the safety of air travel in Europe. Several other augmentation systems have been built for particular applications across the globe but none of these systems will be investigated within this work unless there is an aspect that pertains directly to the standing up of a GNSS as none of these augmentations can operate independently of a global system.

While the domestic political and economic impact that a GNSS has on the state is important to this work there is another critical impact that also warrants examination. The GNSS has become a crucial component of each state's military capacity and is a major element in support of their national security strategies. What cannot be overstated is the GNSS impact on the military. It represents the primary enabler for precision targeting of 'smart' weapons on land, at sea, and in the air. It is also the primary system used by commanders to track forces and logistical supplies as well as maintaining their situational awareness within their operating environment. GNSS is the system of choice for the remote command and control of Unmanned Aerial Vehicles (UAV) that have become an integral part of the military intelligence, surveillance, and reconnaissance gathering capability of most developed states.

However, at the same time, such reliance on a single space system injects vulnerability into the equation as well. If the military capabilities of a state depend on a series of radio signals emanating from satellites then the interruption of those signals could have a deleterious effect on the capabilities of those forces and jeopardize the national security of the state.

An example of the vulnerability and its potential impact relates to the US loss of a UAV that crashed into Iran in December of 2011. One report by the Christian Science Monitor said that the drone, a model RQ-170, had been spoofed by the Iranians and was forced to land in Iran. According to the article, "the 'spoofing' technique that the Iranians used – which took into account precise landing altitudes, as well as latitudinal and longitudinal data – made the drone 'land on its own where we wanted it to without having to crack the remote-control signals and communications from the US control center."[1] Although verification of this story from US government or other official sources has been elusive it serves as an example to underline the potential for international conflict based on GNSS operations.

Having the ability to defend against such space and cyber attack has become a hot issue for several major states and much of the discussion has a GNSS component. To

[1] http://www.csmonitor.com/World/Middle-East/2011/1215/Exclusive-Iran-hijacked-US-drone-says-Iranian-engineer-Video

suggest that a state's national security is based solely on its military prowess is, of course, a vacuous statement. There is no doubt about the importance of GNSS to a major state's military but the importance of the GNSS to a state's internal infrastructure security is often overlooked and that is just as critical to national security as any military capability.

Take for example that the world's civil aviation and maritime fleets depend on GNSS services to operate safely and to a large and growing extent the domestic rail and road systems of every developed nation. Global commerce is tracked and verified via GNSS services. The international banking and finance industry relies on GNSS time stamps in order to keep the world's books straight. And every developed state uses or plans to use GNSS as a major control component of their national energy grid. That means that signal interruptions could possibly trigger massive chain reaction outages across the state(s).

For one system to be so intertwined in the operations of any state with little or no system redundancy means that potential interruptions of service have become a serious concern for those states that could be impacted. What is truly amazing is that the GNSS that is globally responsible for most of these applications today is the United State's NAVSTAR Global Positioning System or GPS.

B. LITERATURE REVIEW

Political scholars have, for the most part, chosen not to recognize the incredible significance that the GNSS have had on the global population over the past several decades. While the US GPS is the only functioning GNSS currently in existence, there are three other systems being built and waiting to be deployed in the near future.

Considering the impact that just one system has had on global state interactions it is probable that the introduction of three more global system competitors will have a much more significant impact on the way states interact with one another and may introduce additional and unforeseen stress into those interactions.

GPS was created specifically to support the US military and has become an integral part of nearly every US military system that has been deployed over the past several decades or is currently in development. At the same time, GPS as a civil instrument has become so ubiquitous that it is now an assumed global asset available to anyone who has a receiver. In fact, GPS has further 'flattened' the earth and enabled increasing interdependence among and between states.

While the existing bank of literature on the scientific aspects of GNSSs is substantial, there is a paucity of literature extent on the political, social, and economic impact of GNSS on states and their behaviors especially those states involved in the fielding of new systems. There are several works that have been recently published that provide comprehensive overviews of a GNSS. Three of them are Kaplan's "Understanding GPS: principles and applications"[2]; El-Rabbany's "Introduction to GPS: the Global Positioning System"[3]; and Hofmann-Wellenhof's GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more"[4]. Each work is an excellent primer on a GNSS that includes system components and design parameters along with an in-depth review of the mathematical and scientific underpinnings of the system. All three

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[2]Elliot Kaplan, *Understanding GPS: principles and applications* (Boston: Artech House, 2006).

[3] Ahmed El-Rabbany, *Introduction to GPS, The Global Positioning System* (Boston: Artech House, 2002).

[4] Bernhard Hofmann-Wellenhof, *GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more* (New York: Springer Wien, 2008).

focus on empirical data and, for the most part, ignore the political and social implications associated with the systems.

From a strictly scientific perspective, there is an absolute plethora of works available describing and analyzing every technical or scientific facet of a GNSS. The list of technical topics is incredibly long and, for the purposes of this work, mostly irrelevant due to the absence of the political and economic facets that drove the development of the system in the first place. Finding sources pertaining to the international relations aspects specifically related to GNSSs have proven difficult to locate.

There are a small number of works available that address the international relations implications of outer space exploration and commercialization with Bormann's "Securing Outer Space: International Relations Theory and the Politics of Space"[5] appearing to be most comprehensive from a global perspective. This work tangentially addresses navigation systems but only in the context of a larger view of the whole of outer space.

After two decades of operations there are a fair number of sources available that trace the development and growth of GPS from a domestic political and economic perspective. Most of the primary source information pertaining to GPS resides in US Government documents. The US Air Force is the executive agent for GPS and has available a large and comprehensive archive on GPS on various Air Force web sites. The US DoD and DoT also have copious amounts of information available to the public on websites dedicated to GPS. The House and Senate Armed Services Committees have, over the years, commissioned various studies and reports on GPS that provide insights

[5] Natalie Bormann, *Securing Outer Space: International Relations Theory and the Politics of Space* (London: Routledge Critical Security Studies, 2009).

into the development and application of GPS from a US national security perspective. Finally, links to the criticality of GPS to US national security has been clearly enumerated by the White House in past and present National Security Strategies, National Defense Strategies, National Military Strategies, and National Space Policies.

While GPS was conceived and built as a secret project hidden within the depths of DoD, the EU's Galileo has been in the public eye since its inception. Interestingly, Galileo's long and torturous path to reality has been, at times, a public spectacle and yet it has failed to generate a great deal of academic interest from a social science perspective. The European Parliament, the European Commission, The European Space Agency, and the various committees have published hundreds of reports on proceedings regarding Galileo over the years with most of them narrowly focused on Galileo specifically. What is missing from much of this literature are efforts to put Galileo in the context of the larger European space sector itself rather than the internal focus on the cooperation or lack thereof among the various EU member states. As the size and scope of the Galileo project has grown it seems that the European political science community has generally failed to focus on the emerging space leadership role that Galileo will bring to the EU.

Another issue for the literature is the lack of any real academic review and analysis exploring the future impact on EU foreign policy from the deployment of Galileo. The European Space Agency has published several reports on Galileo that speak to the domestic political, economic, security, technological, or social underpinnings of the system. One report published recently by the European Commission in 2011 called "Why We Need Galileo" describes in detail why Galileo is going to be good for Europe. It talks about how the system will benefit the EU generally and improve the welfare of the population; how it will free the EU from US domination in the positioning, navigation, and timing arena; how it will generate tens of thousands of new high paying technical jobs; and how it will increase the national security of the EU as a whole.[6] The report focuses on the internal machinations of the EU and avoids linkages to the global arena.

There have been other EU government reports and studies conducted much earlier in the development of the project that could have provided additional amplification on the negotiations among the various departments and committees but have been lost to posterity because the documents are no longer available to researchers. It was disconcerting at times to realize how many Parliament or Commission documents from the late 1990's and 2000's found as references or citations during the research were no longer available for review having been deleted for whatever reasons.

Johan Lembke's "Competition for Technological Leadership: EU Policy for High Technology"[7] was published in 2002 and is a very detailed and comprehensive look at Galileo from the EU organizational and policy perspective. One third of the book is dedicated to Galileo. It provides valuable insights into the decision making process and the integration of both public and private concerns that were in play during the first several years of the largest, pan-European Union project in history. This work provides the critical links necessary to understand how the organizational model for Galileo was established. Unfortunately, it was also written several years before the project began

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[6] "*Why We Need Galileo*, 2011.
http://ec.europa.eu/enterprise/policies/satnav/galileo/files/brochures-leaflets/why-we-need-galileo_en.pdf

[7] Johan Lembke, *Competition for Technological Leadership*, (Northampton, MA: Edward Elgar Publishers, 2002).

experiencing significant cost overruns and timeline delays thereby denying later researchers the benefits of Lembke's superior capabilities.

Although Galileo was originally proposed to the European Commission as a critical link to solving current and future EU transportation problems it quickly grew into a system that would allow the EU to gain a greater degree of independence from the US while at the same time offering significant economic opportunity to European industry. This notion was clearly enumerated by Scott Beidleman in his 2005 article "GPS vs Galileo: Balancing for Position in Space."[8] This article provides a concise account of the reasoning and justifications that formed the basis for the Commission decision to go forward with the project.

Another scholar, Kazuto Suzuki, provided additional nuance to the international relations or foreign policy impact of Galileo in his book "Policy Logics and Institutions of European Space Collaboration"[9] published in 2003. Suzuki argued that Galileo was designed, in part, to be used as a foil against a perceived inflexibility on the part of the US regarding the availability and accuracy of GPS to EU member states. The book provides an interesting view how the Galileo program expanded in scope to the point of almost being too large to fail. The US did respond favorably to EU concerns but the EU chose to continue with the project in spite of US concessions.

Many of the best works on Galileo were published in the early 2000's before the project really found a solid footing among EU member states. The early works are important as they detail just how difficult it was to find common ground among member

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[8] Scott Beidleman, "GPS vs Galileo: Balancing for Position in Space", *Astropolitics: The International Journal of Space Politics & Policy* 3, no. 2 (2005).

[9] Kazuto Suzuki, *Policy Logics and Institutions of European Space Collaboration,* (London: Ashgate Press, 2003).

states and still maintain focus on the larger picture of getting Galileo deployed. More recently, the focus has shifted somewhat with the emphasis more on the technical and scientific details of the project and away from state behavior or global economic impact. It may be that the focus will shift again as Galileo gets closer to full operational capabilities.

Russia's GLONASS is similar to GPS in the sense that it was designed as a secret Ministry of Defense project back in the 1970's to counter US GPS military capabilities. Even though the system did achieve full operational capability for a couple of months in 1995, the system was left to decay on its own as funding and political will became scarce by the mid to late 1990's.

President Vladimir Putin informed the world through a 2001 Presidential decree that he was allocating sufficient new funding to bring GLONASS back to full operating capability by 2009. There is very little literature available from the early days of GLONASS as it was shrouded in secrecy. Today there is much more information available on GLONASS than ever before. Russia's Federal Space Agency[10] is perhaps the largest repository of available empirical and scientific data on the system. Another excellent source of current GLONASS data is available from Navigation-Information Systems (NIS)[11]. NIS is Russia's National Navigation Services Provider. NIS also offers a relatively detailed history of GLONASS as well. What is missing from nearly every Russian source is a solid analysis of the impact of a rejuvenated GLONASS on Russia's civil society, domestic politics, economy, or its foreign policy.

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[10] http://www.federalspace.ru/?lang=en
[11] http://www.nis-glonass.ru/en/about_eng

There is a dearth of data available on China's COMPASS compared to GLONASS. While China has established itself as a major space player, it has elected to keep much of the information related to space systems and space technology unavailable for casual consumption. As members of the United Nations International Committee on Global Navigation Satellite Systems, both Russia and China have released sufficient scientific and technical data to satisfy the basic requirements of membership. China has been somewhat opaque on releasing financial or economic data regarding COMPASS and has been slow to release information on the expected impact COMPASS may have on the global political situation or how it might affect China's foreign policy initiatives.

Locating information on COMPASS from official Chinese sources has proven difficult. China Today[12] is one semi-official site that does offer information on BeiDou and COMPASS for the asking. However, information is mostly empirical and what is not follows a state party line. The Xinhua News Agency[13] and the People's Daily[14] are two other media sources for official state information on China's GNSS projects.

Fortunately for researchers, there are several global web sources dedicated to the proliferation of GNSSs and whose depth of information allows the researcher to develop a better working picture of the GNSS world. Two sites in particular are noteworthy for their in-depth reporting on all things related to GNSS. The first, Insidegnss[15], is a multi-faceted instrument that makes available a wealth of information on all aspects of GNSS including regular analysis on the social and political dimensions of the systems. It is also

[12] http://www.chinatoday.com.cn/ctenglish/
[13] http://www.chinaview.cn
[14] http://english.peopledaily.com.cn
[15] http://www.insidegnss.com/

an excellent source of background information on development issues as the organization covers all global scientific and political conferences or summits involving GNSS states.

The second site is called GPS World[16] and although its purpose is to provide timely and accurate information on GPS it can be counted on to highlight the peer competitors on a regular basis for the purpose of educating its readers on new and emerging GNSS technologies and industry trends. This site also offers analysis on the impact that these systems might have on state behaviors or how it might influence US decision making. These are not the only sources for GNSS information outside of governments or academic works. The journal Space Policy has, over the years, published a number of articles on GNSSs and how these systems are affecting outer space governance and exploration. The Journal of Navigation is dedicated to GNSSs with a primary focus on the technical or scientific aspects of the systems. Aviation Week and Space Technology is another excellent source of data on any GNSS. This source is good for mapping out a global picture of launch schedules, payload nomenclatures, orbit information, and contracting information on system components.

When GPS's three peer competitors come on line sometime within the next 6-10 years relations among states will change. Each state will have new options, both military and civil, and with these new options will come new opportunities for scholars and researchers to write about how the advent of GNSSs has changed the social fabric of the global community. This is one aspect of space policy that touches nearly everyone and has yet to be thoroughly investigated. One thing is for certain, there will be winners and losers and it is only a matter of time until the results are tabulated.

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[16] http://www.gpsworld.com/

C. UNITED STATES

An examination of GPS from its inception during the 1970's through its present configuration is the focus of Chapter II. GPS became fully operational in 1995 and is designed around a 24-31 satellite constellation orbiting in Medium Earth Orbit (MEO). GPS was conceived as a system that would improve the precision targeting of ballistic missiles during the Cold War by the Department of Defense (DoD). Although it continues to exist as a DoD funded program, it does get additional funding from other US government departments depending on their particular user requirements.

GPS is a service that is offered free to the world and is part of the global commons. Every President since Ronald Reagan has reaffirmed that GPS will remain a free service for the good of the global population. However, the single caveat to service is the fact that DoD can, if the threat to the national security of the Nation is deemed serious enough, deny service on a regional basis to those who represent the threat. As an example, the US did exercise that right of signal degradation through selective availability to some areas of central Europe during the Bosnia crisis in the late 1990's.

The US statement of intent to deny service is the single largest issue facing global users of GPS and is one motivator cited by all other states as a major reason for the design and deployment of other captive systems. GPS offers two basic services to its users. One is called the Standard Positioning Service or SPS that is used for civil applications. It has an advertised 8-10 meter accuracy range and is available to anyone with a receiver programmed to process the signals. The second service is called the Precision Positioning Service or PPS that is an encrypted signal reserved for US military use only. PPS has an accuracy rate down to one or two meters. It was first used extensively during Gulf War I as a regional system with amazing effect.

The US has been a benevolent provider of global services since 1995 and has used GPS as a component of its foreign policy in several positive ways. It has encouraged international cooperation through its participation in a number of GNSS related international organizations that include the International Civil Aviation Organization, International Maritime Organization, International Telecommunication Union, U.N. Committee on the Peaceful Uses of Outer Space, Asia-Pacific Economic Cooperation, NATO, and the World Trade Organization. The US has also established GNSS cooperative bodies with Australia, China, Russia, the European Union, Japan, and India on the peaceful use, interoperability, and compatibility of the various GNSSs.

Currently, the US is in the process of modernizing its system. The launch of the first satellite of the next generation GPS III series is scheduled for 2014 and will provide new and improved global services including higher accuracy, better anti-jamming and anti-spoofing systems, and longer service life of the individual satellites. The US government has spent about $17 billion on the development and deployment of GPS through 2012 and the Obama Administration has requested $1.26 billion to support it in 2013. The projected cost to modernize the system to GPS III through 2025 currently exceeds $22 billion.[17]

However, there is extreme pressure to cut DoD spending and the Air Force is reviewing ways to reduce the cost of GPS modernization just as it is doing on all of its

[17] "The Global Positioning System for Military Users: Current Modernization Plans and Alternatives", Congressional Budget Office, (Washington, D.C.: October 2011), Appendix B, Table 2-1, 10.

current programs. The US pioneered the use of GPS and has provided a significant service to the global commons. It remains to be seen if GPS remains the gold standard of GNSSs into the future.

D. THE EUROPEAN UNION

There have been voices from within the European Parliament calling for the elimination of EU's dependency on GPS since the mid 1990's. There were concerns about the reliability of the system due to the possibility of service denial and other concerns that reliance on GPS introduced a vulnerability to the national security of EU member states.

The Transport Committee of the European Commission (EC) was the point of genesis for the EU's version of GPS that was named Galileo. There was a clear recognition of the improvements in safety and efficiencies that could be gotten from the extensive application of PNT services to EU transportation networks beyond the civil aviation and maritime realms. The two most obvious areas were the EU wide rail and truck transport networks. However, committee members were reluctant to subordinate Europe's transportation networks to a system that was controlled by a third party, the US, and therefore proposed that the Union design and build its own GNSS to meet these basic needs.

The challenge that faced the EU as it struggled to build the largest trans-European project ever attempted is the crux of Chapter III. The project nearly floundered on several occasions as its costs and timelines continued to grow well beyond projections. The chapter will begin by looking at the original intent of the Transportation Committee through the establishment of the various governing bodies and experiments with the public-private partnership through to a complete reinvigoration of the project as it exists today.

Member state involvement and interference played a significant role in the evolution of Galileo as the various states vied for economic or political advantage over the course of its development. Another interesting element of the project is the involvement of the US in EU politics and NATO. Early on in the project there was an effort by the US to derail Galileo as unnecessary due to the close relationship between the EU and the US.

The EU also launched a concerted effort to engage international partners in Galileo in an effort to offer the system to the global commons with true international control, shared costs, and shared economic remuneration. Although these efforts generally failed it was not surprising that the proposals to reach out, to promote cooperation and collaboration with an expectation of greater economic interdependence were extended because of the social democratic norms that govern EU member states.

In the end, it appears Galileo's most tangible attraction for most member states was the promise of economic return on their investments. This 'selling feature' was reiterated over and over in nearly all of the EP and EC official documents pertaining to Galileo. Some projections put the potential for economic return in the billions of Euros and that European industry could reap this windfall if Galileo was built fast enough. It is still too early to ascertain if Galileo will prove to be as economically viable as hoped or not. What seems to be certain is that Galileo will be built and at this point it may be too large to fail no matter what.

E. RUSSIA AND CHINA WITH MENTION OF JAPAN AND INDIA

Chapter IV examines the other navigation systems that exist east of the EU. Russia and China are each deploying operational GNSSs while Japan and India are deploying regional systems in order to satisfy their individual requirements. These states, less Japan, are grouped together because they each represent non-Western developing states whose infrastructure is growing rapidly and who represent the greatest growth markets for GNSS services in the world.

While each state has pledged that their system will be used for peaceful purposes it is also no secret that each of those states will ensure that their systems are fully integrated into their military forces in order to improve those capabilities as well. Having GNSS enablers for military forces represents a significant leap in overall capabilities especially in rocket and missile operations and could be a source of regional or global tension or conflict in the future.

Chapter IV also looks at the potential for economic return associated with GNSS services in these markets and how it might affect the US or the EU. The Asian market for user equipment is growing exponentially and is the single largest GNSS user equipment market in the world. It may be that China would like to capture that market for its industrial sector to the exclusion of US or EU manufacturers. The Indian sub-continent is the second largest growth market for user equipment and this chapter will explore what is being done by the various actors to make inroads into these markets as well.

The former Soviet Union built the GLObalnaya NAvigatsionnaya Sputnikovaya Sistema or GLObal NAvigation Satellite System (GLONASS), during the Cold War as a foil to the US GPS. The Soviets discovered how difficult it was to design, build, and deploy a space system as complex as a GNSS and then they failed in their attempts to operationally maintain the system after the breakup of the Soviet Union because of declining resources and lack of political will.

The system did reach full operational capability for a short time in 1995 but operations quickly decayed until the system was left with a handful of barely operational satellites by 2000. President Vladimir Putin's election and rising energy prices have proven to be the catalysts for the resurgence of GLONASS. Russia is moving rapidly forward in order to get the system back to full operational capability and has initiated a significant modernization program in order to improve system lifecycle costs and accuracy.

GLONASS satellites were originally burdened with exceedingly short life spans and that design flaw required a very aggressive launch program to maintain the space constellation. This may be the primary reason that the system fell into disrepair at the turn of the century. It also resulted in the introduction of a large number of space vehicles into orbit that added to the space clutter that exists today. Soviet GLONASS launches have totaled 130 satellites (through November 2011) in an effort to maintain the satellite array at 24 satellites. As a comparison, the US has launched a total of 60 satellites between 1978 and 2011 and had 31 satellites of them operating normally at the end of 2011.

Newer generations of Russia's navigation satellites are designed for much longer service lives and should significantly enhance the reliability of the system. The chapter will look at Russia's efforts to increase its level of international cooperation on space systems by bringing partner states into the GLONASS program and encouraging partner state design and production of GLONASS user equipment.

Although GLONASS was designed to support military operations the system has become much more than that over the past ten years. President Putin, while recognizing that GLONASS modernization will help his military forces, sees GLONASS more as an enabler of economic growth, national pride, and Russian resurgence over the next decade and more.

Chapter IV also examines China's decision to build and deploy its own captive GNSS called COMPASS or BeiDou-2. What makes this study more interesting is the fact that China actually has two navigation systems on the books. The first, called BeiDou-1 is a regional system that has been used extensively to support disaster relief efforts across the state because of its inherent two-way communication capability.

BeiDou-1 coverage ranges out beyond mainland China to include all of the South China Sea and much of Oceania and encompasses much of what could be considered China's traditional 'Middle Kingdom' boundaries. This regional system provides positioning and navigation services to a user base that includes the People's Liberation Army (PLA) and Navy (PLAN) as well as China's huge commercial fishing fleet.

What is interesting and not completely understood is China's decision to build a global system named COMPASS. China's foreign policy is based primarily on its regional interests and it has expressed a desire to be a major actor within its regional sphere of influence. However, building a GNSS like COMPASS will be one more enabler allowing China to project power globally.

China's stated reasons for building the system are varied with not wanting to be dependent on GPS being a major reason. The chapter will explore other reasons for China's behavior and how it might affect its foreign policy. Additionally, the economic potential for user equipment when this system comes on line could be fantastic as China carefully navigates the international negotiations revolving around interoperability and compatibility issues, frequency conflicts, and system transparency with other GNSS actors.

China is not particularly known for transparency and candor when engaged in international negotiations of any kind. Therefore much of the research for this work did not come from official government documents but comes from newspaper accounts, industry meeting notes, blogs, analysis conducted by other governments or think tanks and the like.

It may be that China sees COMPASS as being another engine of economic performance for the state and an instrument of increasing regional economic interdependence between China and its neighbors. Its true aims for COMPASS are currently clouded in mystery.

Chapter IV ends with an examination of the regional systems being built by India and Japan. They have been included because they are important to the future modernization plans of GPS and GLONASS. Japan's system, called QZSS, is being built to the same specifications as the GPS III series but in this case, Japan has an ulterior motive. Japan's geography challenges any space based navigation system because of its high mountains, narrow valleys, and the nature of its urban areas. Those tall mountains, narrow populated valleys, and crowded urban areas with a plethora of tall buildings crowded together are areas not suited to standard GNSS operations that rely on line of sight signal relay. QZSS was designed and built specifically to address these obstacles and will provide accurate and reliable service to the whole of Japan for the first time.

There is also an examination of how QZSS could provide Japan's Defense Force with additional missile defense capabilities in the event Japan chooses to pursue an expansion of these capabilities.

Lastly, the chapter will look at India's efforts to improve its infrastructure and its military by building its own regional navigation system called IRNSS and secondly by partnering with Russia to gain full access to GLONASS' military signals. India has traditionally been internationally non-aligned and it appears its current efforts to gain military advantage from the Russian system and, at the same time, build its own system that is fully interoperable with all other GNSSs will put India in a strong position to remain non-aligned and take advantage of the economic opportunities presented if it partners with every GNSS state through the design and manufacture of user equipment.

Besides looking for military advantage, it is clear that India's infrastructure is in desperate need of upgrading. The transportation sector in particular will gain significant efficiencies with the addition of PNT capabilities.

Chapter V will include the analysis and conclusions derived from the research in order to answer to main arguments. It will highlight the major findings of each chapter and attempt to describe what went wrong and what went right with each state's decision making process to build and deploy a captive GNSS. The chapter will also include some speculation on the future of GNSS from both the civil and the military perspectives.

Finally, the primary thesis of the work, namely the examination of the current state of GNSS development and why various states decide to build new and independent systems when there are other systems freely available for use and then take a look at whether or not states will use their GNSS as a foreign policy tool offensively to increase its prestige and power or will they use it solely as an instrument of peace to the betterment of mankind will be addressed.

CHAPTER II

NAVSTAR GPS

A. INTRODUCTION

GPS has become a primary enabler of modern technological devices and has done so in a relatively short period of time. Few could have predicted the absolute explosion of technology that relies on GPS for its operation. It has affected the way global citizens travel whether by air, rail, sea, automobile, or on foot. It facilitates the global banking and finance community with precision timekeeping for traders and nations alike. It is used as a primary tool for surveying land. GPS enables utility companies to draw more accurate maps of their utility lines to assist in maintenance and upkeep. It is now used extensively in the forestry industry by commercial tree farmers as well as the Forest Service and other Government agencies. It assists in mapping insect infestation, determining boundaries, aerial spraying and fire prevention and management. GPS is now being applied to the measurement of the structural integrity or deformation of large structures like dams, bridges, or TV towers where pinpoint accuracy is required. Disaster relief and emergency service organizations across the globe have come to rely on GPS to track emergency vehicles, find lost or injured people, and guide resources to areas of greatest need.

The United States pioneered the development and deployment of a Global Navigation Satellite System (GNSS) and continues to be the leading global purveyor of positioning, navigation, and timing (PNT) services. The system is based on a 24 or more satellite constellation operating from Medium Earth Orbit (MEO) or about 20,200 km in space. This GNSS is an amazingly complex system that has been updated and improved several times since its original inception in the 1970's.

The Navstar Global Positioning System or GPS for short is a dual-use system that was designed primarily to support the US military but has grown into a supremely important part of civil society and a critical element of, not only the Nation's economy, but that of the global economy as well.

GPS remains a crucial component of the US military's strategic capabilities. Loss of the system would impact every facet of military operations from logistics delivery to weapons system accuracy. Its importance cannot be overstated from a military perspective. The same could be said from a civil perspective and this dual-use system has become a highly visible United States Government asset that enjoys regular scrutiny from across the wide spectrum of Government and non-Government entities. There appears to be near unanimity on one thing about GPS from every stakeholder across the globe. The system cannot fail or the country and the world could suffer cataclysmic repercussions.

This chapter will provide a general overview of GPS. The idea is to present the reader with real sense of what GPS is all about and what it represents to the global community. It will begin with a description of the system itself, reviewing the components and their basic functions. Specific technological aspects of the components will not be fully enumerated, as they are not germane to the work. The chapter will, instead, discuss the system from a more international relations and national security perspective with the emphasis on the domestic political and economic pressures that drive security policies and statutes that regulate and govern GPS.

There will also be discussion of the history of the system beginning with the origins of positioning systems back in WWII and continuing through the present. There will be a non-technical review of the various generations of satellites that have populated the constellation over the years as well as a very brief review of the various electronic signals that are used by the system to operate.

A look at efforts by the United States to collaborate, negotiate, or coordinate with other international actors, primarily the European Union (EU), will also be discussed. Finally, the chapter will conclude with a look at GPS today and its direction over the next 20 years or so.

B. OVERVIEW GPS

Anyone wishing to write a history of global space-based global navigation systems would start with a history of the NAVSTAR GPS. The first version of GPS was launched into space by the United States between 1978 and 1985. But just writing that history would not put the development of GPS into any meaningful context with regard to conflict and cooperation between the US, the former Soviet Union, Europe or other international actors on space systems or space science born during the Cold War. The evolution and growth of GNSS technologies has been nothing short of phenomenal over the past four or five decades. The Cold War arms race pitted the Western Alliance with a qualitative advantage against the Soviet Empire's quantitative advantage of soldiers and war fighting material. The development and fielding of GPS eventually had a striking impact on the outcome of the Cold War.

It has since moved away from being primarily a military application and has been incorporated into new generations of civilian applications that have literally changed the way people live their lives and do business in the 21st Century. The scope of civil usage of GPS is huge. It is estimated that civilian users currently outnumber military users by a factor of 100:1.

What is GPS? It is a space-based dual-use system or network of satellites that facilitates the determination of position, navigation, and time at some point on Earth 24 hours per day in any kind of weather and on a global basis. It is based on microwave radio signals generated from the satellite in space, the time it takes the signal to travel to the receiver[1], and the location of the satellite in space. It requires three satellites to triangulate the location and a fourth satellite to compensate for the receiver clock offset from the atomic clock on the satellite. Each satellite is equipped with at least two atomic clocks that are designed to keep super accurate, in billionths of seconds, time. The more accurate the atomic clock on the satellite generating the signal the more accurate is the location on earth, assuming at least four-satellite coordination.

GPS is considered a descendent of ground-based radio navigation systems such as LORAN-C and Omega that were developed for maritime applications aboard ships and boats during WWII. These early systems were slow, sometimes taking up to three minutes to calculate a position and had a minimum error of 500 feet.[2] These early systems did not use space based signaling technology but instead were ground based.

But the times were changing and technology was advancing by leaps and bounds just after WWII. The Cold War was raging. And then came Sputnik and it changed the world of radio-navigation forever. By knowing the orbit of the satellite a station could

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[1]Distance = speed x time. Radio navigation signals travel at the speed of the light, which is constant, approximately 300,000 Km/s. Multiplying this constant with the time a signal has been traveling until the user received it, we calculate the distance from the satellite to the user.

[2] John Alvin Pierce, "An introduction to LORAN-C", *Aerospace and Electronic Systems Magazine* 5, no. 10 (1990): 16-33.

track radio signals emanating from the satellite and determine its location in space and or on the ground. Sputnik truly was the birth of space-based radio-navigation and with it, the space race between the US and the USSR. Scientists in the United States found that they could track the location and velocity of Sputnik as it orbited the Earth by plotting the change in the strength of radio signals that Sputnik was broadcasting as it moved closer to or away from the signal receiver. The scientists saw the advantages of this new avenue for determining velocity and location and it fostered the early work on using it to fix a location on Earth.

The US Department of Defense (DoD) funded several projects during the late 1950's and early 1960's to design a new and more efficient radio-navigation system. Several disparate research efforts in this new field were finally combined into a single project in 1973. The combined project was eventually called NAVSTAR GPS (Navigation Signal Timing and Ranging Global Positioning System). The United States Air Force became the lead service although the project staff had and still has representatives from the Army, Navy, Marine Corps, Defense Mapping Agency, Coast Guard, Air Logistics Command and NATO.

Initially, GPS was clearly a project focused solely on military applications and was deployed in response to Cold War threats to US and Allied national security interests from the Soviet Union. At the time, there was a pressing need to improve the accuracy of ICBM targeting capabilities from silo based missile launchers in the United States and submarine launched ballistic missiles at sea. It was a question of qualitative superiority of US nuclear delivery systems and the quantitative superiority of less accurate Soviet systems. GPS is what provided the US with the ability to precisely target its weapons on specific Soviet objectives.

Ten GPS test or validation satellites were launched between 1978 and 1985 and were used to prove the system components and concepts. After system validation, the first of twenty seven (including three spares) operational satellites was launched in 1989 and the last of the series was launched in 1996 with full operational capability of the system being declared by the Air Force on April 27, 1995.[3]

1. BASICS OF GPS?

Greatly simplified and without any technical jargon, GPS is a space-based system of satellites arrayed in a constellation above the earth that are equipped to send and receive designated microwave signals on specific frequencies. These signals capabilities enables an electronic device, called a receiver, located anywhere on earth or in space to quickly process the input signals from a grouping of visible satellites and accurately display that receiver's location to within a few feet of exactitude. The next sections will elaborate on the operation of the system.

2. SATELLITE ARRAY

Any GNSS has three major components and each is critical to the operation of the system. There must be a satellite array in space, there must be a ground component of some sort used to monitor the health of and control the satellites in space, and there must be a user segment that is gaining information from the satellite broadcasts. Each of these

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[3] NAVSTAR GPS Operations, USNO NAVSTAR Global Positioning System (Springfield, VA: US Naval Observatory). http://tycho.usno.navy.mil/gpsinfo.html

components is mutually dependent. The first component, the satellites, are designed and built with limited life cycles and operating systems. Space is a harsh environment and space vehicles are carefully monitored to ensure they remain operating within certain design parameters. The ground-based control stations adjust the position and the outputs of the satellites as they orbit the Earth. The Government has consistently maintained an attitude of constant research and development in order to keep GPS fully operational and allow it to improve and modernize its capabilities to keep up with military and civilian requirements.

Scientists designed the system to operate on a global basis with an array of 24 satellites working in concert with one another as required. None of the original satellites are still in operation as newer and better units have replaced all of the originals.[4] Each satellite has two major elements that facilitate the entire system. Each has at least two super-accurate atomic clocks and each has several transmitters to relay the various signals back to a ground station or to receivers on Earth.

The first generation of satellites called Block I was built by Rockwell International. There was one launch failure among the first eleven deployment missions between 1978 and 1983. These satellites were designed to test and validate the space-based PNT system concept. This series of satellites had a design life of 4.5 years. However, the average life of Block I satellites were just less than nine years of service with the last Block I satellite retired in November of 1995.

Rockwell International was also contracted to build the next generation Block II and Block IIA satellites. 28 satellites were deployed between 1989 and 1997. This

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[4] "Current GPS Constellation", USNO NAVSTAR Global Positioning System, (Springfield, VA: US Naval Observatory). http://www.usno.navy.mil/USNO/time/gps/current-gps-constellation

iteration of satellites had an expected lifespan of about 7.5 years. The key upgrade to the Block II was an increase in the amount of time the individual satellites could operate independently in space without inputs from the Master Control Station (MCS) on Earth. The IIA could operate out to 180 days without ground support and represented a significant improvement over previous iterations. The Block I satellites did not have the system capacity to monitor internal components and maintain signal outputs within design tolerances without regular corrections from the ground stations.

The Block II satellites had sufficient capabilities to self correct its orbit relative to other satellites and the Earth and to make atomic clock adjustments as required for up to 180 days before needing ground station inputs. This was a major upgrade to the system and improved the accuracy and availability of GPS to the user community. The cost to launch and deploy each Block IIA satellite was in the neighborhood of $50 million.

DoD awarded the contract for the third generation of satellites called Block IIR to Lockheed Martin. The first launch of a Block IIR satellite in 1997 resulted in a launch failure and two satellites were destroyed. The first successful deployment of a Block IIR satellite then occurred later in that same year. The original plan called for the Space Shuttle to deploy three satellites per Shuttle Mission as required to populate the constellation. However, the Challenger disaster of 1986 forced a change in the plan and GPS satellites reverted back to being launched in pairs on Delta rockets. There were 21 planned Block IIR satellites in this iteration. The lifespan was increased to at least 10 years and these models can also operate independently of ground support for up to 180 days at a time.

Ground support is a critical element of maintaining a functioning array and involves, among other things, the monitoring of the atomic clock and the actual orbit trajectory of the satellite. The ground support element will upload inputs to the satellite to make corrections to the orbit or to the atomic clock as necessary to maintain the array and the accuracy of the overall system. In other words, the ground support element synchronizes satellites with each other and with the various ground elements.

Another feature of the Block IIR satellites that is unique to this iteration is a secondary payload consisting of sensors to detect nuclear explosions anywhere on Earth or in space with the capacity to relay time, velocity, and location information back to the primary control center nearly instantaneously of the detection.

Some of the Block IIR satellites were upgraded to become Block IIR-M units. This upgrade included the availability of a military only code or signal called the M-Code that would be broadcast on the L1 and L2 channels that would significantly enhance the security of the signal against jamming. The first of eight Block IIR-M satellites was launched in September 2005 and the last on August 17, 2009.

The fourth and current generation of satellite contract called Block IIF was once again awarded to Rockwell International. There were 33 satellites in the original procurement phase as well as funding for a new GPS operational control segment (OCS) or ground segment.[5] However, the Air Force only ordered 12 Block IIF satellites to complete the run. The initial contract called for the delivery of the first units by 2001 with an expected first launch sometime in 2002.[6] The first launch of the Block IIF

[5] Robert A. Nelson, *The Global Positioning System*, (1999). http://www.aticourses.com/global_positioning_system.htm

[6] "First GPS Block IIF Satellite Moves to Cape Canaveral", *InsideGNSS*, February 11, 2010. http://www.insidegnss.com/node/1910

satellite occurred on May 28, 2010, nearly eight years behind schedule. This iteration of GPS satellite experienced significant cost overruns and scheduling delays as a result of lax testing and record keeping by the contractor. There were also a number of issues with the Government changing or adding specifications to the original design that resulted in lengthy delays and added cost.[7]

The Government did withhold payment of award fees to the contractor for lack of performance on this project. There were also problems with the on-time delivery of satellite hardware from subcontractors that exacerbated the issue and may have been caused by changing specifications or late awarding of sub-contracts. The Block IIF units are designed with a lifespan of not less than 15 years.

SATELLITE BLOCK	LAUNCH PERIOD	SUCCESSFUL LAUNCHES	DESIGN LIFE YEARS	LAUNCH MASS (KG)	DIMENSIONS H X W X L (CM)
I	1978 - 1985	10	5	759	
II	1989 - 1990	9	7.5	1660	
IIA	1990 - 1997	19	7.5	1816	
IIR	1997 - 2004	12	10	2032	152 x 193 x 191
IIR-M	2005 - 2009	8			
IIF	2010 - 2011	1 (11 in prep)	15		244 x 197 x 197
IIIA	2014 onwards	12 planned			

Table 1 GPS Satellite Block Launch Cycles to 2011

[7] http://www.globalsecurity.org/space/systems/gps_2f.htm

The microwave radio signal emanating from the satellite is the critical link between the satellite and the ground receiver. Not really a single entity of any sort, the signal is made up of several components including a minimum of two carrier frequencies, digital codes, and a navigation message. The two primary carrier frequencies, the L1 and L2, generate signals on different frequencies. Having the two signals on different frequencies allows the receiver to compensate for distortion of the signal from ionosphere interference. Additional signals were added over the years to account for an increase in service demand and to tailor GPS to specific user requirements whether it is military or civilian generated.

The digital codes are streams of digits, 0's and 1's, which are modulated at different speeds on the carrier frequencies that are unique to each satellite and are used to, among other things, identify individual satellites and provide the raw data for receivers to process. Finally, the navigation message is another stream of data moving along the carrier frequency. It contains "along with other information, the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac, and atmospheric data. Each satellite transmits its own navigation message with information on other satellites, such as approximate location and health status."[8]

First and second generation GPS satellites provided two signals to ground stations. One signal called C/A (Course/Acquisition) Code or SPS (Standard Positioning Service) eventually became available to anyone anywhere on earth with a receiver at no charge. The other signal was the P-Code or Precise Positioning Service (PPS) that was and remains encrypted and is now used solely by the US military, selected government

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[8] El-Rabbany, *Introduction to GPS, The Global Positioning System*, 14-15.

agencies and a very few, select, states. The P-Code was originally available to anyone with a receiver but with the proliferation of cheaper receivers the Government encrypted this signal in 1994 to ensure the signal's operational security for US military use. The Block I and II units allowed for the C/A signal to be broadcast on the L1 carrier while the P Code was broadcast on both the L1 and L2 to increase the robustness of the signal for military purposes and make it more difficult to jam or interrupt. Prior to 1996, the error factor for the SPS was in the 10-30 meter range and the PPS was about 5 meters.

Interestingly, President Ronald Reagan ordered the release of the SPS to the public as a free service in 1983 after Korean Airline Flight 007 got 'lost' in Soviet restricted airspace over the Sea of Japan and was shot down with the loss of all 269 passengers and crew. President Reagan believed releasing GPS free to the global civil aviation industry could help prevent such catastrophes in the future. It appears that neither the President nor his staff imagined what the effect of this action would have on the future lives and tempo of the global community. At the time of the release in 1983, an average GPS receiver cost about $100,000 and was not at all portable. A Litton Macrometer V-1000 receiver for example, introduced in 1982 for the civil aviation market, was somewhat typical. It was 22.8"x22"x25" in size and weighed 161 lbs. In order to become operational it was firmly fixed and hardwired into the aircraft. This is the market that President Reagan had in mind when he issued his directive offering SPS to the public.

Over the years, deploying and maintaining the GPS array has not really been that expensive. It is estimated by the US Army GPS Global Support Center that the annual maintenance costs for GPS in 2008 were around $1 billion per annum and that the total cost of the system to that date have exceeded $32 billion.[9] Considering the impact that GPS has had on the global society and the technological advances that have been enabled by its operation it can be argued that GPS has been a real shining star of US Government efforts. It can also be argued that GPS is now a part of the global commons and that the United States now has a responsibility to ensure system operation at no cost to the user community.

In any event, maintenance is required to keep the system working properly. One of the major reasons for satellite system failure is the gradual loss of electrical power on the satellite. The effects of space on the solar arrays that generate the power to keep the satellite operating tend to degrade over time until they become unable to produce sufficient electricity to operate at all. One of the ways that the Air Force has managed to extend the life of GPS satellites beyond their design life is to carefully control the use of electricity on board. One way to control usage is to shut down certain components when not needed or to limit their outputs. Replacing solar power panels is not a maintenance issue and failure renders the satellite permanently non-mission capable and it then becomes another piece of space junk.

Congress was warned that there was a potential for future problems in the maintenance of the GPS satellite array in a 2006 DoD report to the Congress. It recommended that Congress needed to recognize the danger of future failure of the system and act to ensure the future reliability with additional funding and resourcing of the system. When that report was released in October of 2006, there were 30 operational satellites in the array. However, the gross number of 30 satellites meant that the array was clearly sufficient for operations at the time but it did not necessarily reflect the

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[9] US Army GPS Global Support Center. https://gps.army.mil/gps/customcontent/gps/faq.htm#Q5

potential for future problems facing the Air Force over worn out or degraded components. Of those 30 satellites in 2006, 16 were past their design life and 19 lacked redundancy of crucial on-board subsystems. Lack of redundancy meant that component failures had occurred on those 19 satellites and one or more subsystems was operating without a backup subsystem.

While only 24 satellites are required for complete system availability the US has always had more than 24 in orbit at any one time. There are several reasons for this. The first and most important is the requirement to have a safety margin in the event a satellite experiences an unanticipated failure of any sort. With several spares in orbit transferring responsibility from the loss of one satellite to another is a relatively simple task and does not have a great impact on the user community. The other main reason for having more satellites in space than are required is the fact that some satellites perform well beyond their design life and remain operational. Therefore any new satellites that would be deployed would be put in a sleep mode until such time as it is necessary to assume an active position in the constellation.

The situation from a maintenance and reliability perspective had not changed much from 2006 to 2008. Another DoD report to Congress on GPS listed the constellation as having 13 Block IIA, 12 Block IIR and six Block IIR-M satellites in orbit with two Block IIR-M awaiting launch in late 2008. However, 20 of those were operating beyond the end of their design life and 19 were without sufficient subsystem redundancy. As of mid-2011, thirty-one satellites are in orbit supporting the GPS mission. The current 2011 array is composed of 15 Block IIA; 12 Block IIR; 7 Block IIR-M and 1 Block IIF satellites. Twenty-two of the current GPS satellites in orbit are currently operating beyond the end of their design life. Fortunately, the United States has been able to keep sufficient spare satellites in orbit to compensate for any satellite failures that have occurred thus minimizing the overall risk of system degradation or failure. But minimizing the risk also means that new generations of satellites are deployed in a reasonable timeframe to allow for anticipated system failures in the future. This aspect of maintaining the array has been called into question.

Full deployment of the most current generation, Block IIF satellites, has been delayed for a number of technical and resourcing issues and DoD warned Congress in 2006 that "sustainment of the GPS constellation will be difficult, and the Government could fail to meet published performance standards"[10] if new units were not deployed in a reasonable timeframe. DoD, however, had embarked on a process to extend the lifespan and add whatever upgrades were possible of the deployed satellites in an effort to mitigate the effects of the delayed deployment of new units. The first IIF satellite launch was delayed nearly eight years and finally took place in May 2010. The second was launched in July 2011 and there is one Block IIF scheduled for launch late in 2012.

The GAO put the blame for acquisition problems related to the fielding of the Block IIF satellites with the Air Force. Acquisition reforms did create some problems and those reforms included the Air Force adoption of a new program called the Total System Performance Responsibility (TSPR). Many responsibilities for producing weapons systems were moved from the service, in this case the Air Force, and moved completely to the contractor. This meant that the contractor was responsible for meeting all DoD specifications and fully integrating new products into the entire system. TSPR

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[10] "Report to Congress on Global Positioning System (GPS) 2006", Department of Defense (Washington, D.C.: October 2006), ES1.

was designed to streamline the acquisition process and help get new systems operational quicker and to leverage civilian expertise in production and management. It did not work according to the Government Accounting Office (GAO).

It was later determined that the new process actually slowed the system "because it was implemented in a manner that enabled requirements creep and poor contractor performance. For GPS IIF, the TSPR approach resulted in relaxed specifications and inspections by the contractor, loss of quality control in the manufacturing process, and poor-quality parts that caused test failures, unexpected redesigns, and the late delivery of parts."[11] Another issue that must be considered in the failure of the contractor, Boeing, to deliver the IIF units on time and on budget is the fact that the Government authorized a modernization program for the IIF satellites even before the first one was built. This occurred after the contract was let and coupled with the TSPR approach led to organizational failure. Boeing, on the other hand, had designed and built nearly 40 earlier model satellites and was no stranger to the space vehicle business or to the Government space acquisition process. The Air Force has subsequently abandoned TSPR due to multiple programmatic failures and instead, has increased acquisition training and staffing in an effort to provide the oversight and expertise required to conduct inherently government business with the contracting community.

3. GROUND SEGMENT

The second component of GPS is the Ground Segment or the Operational Control Segment (OCS). As originally designed and executed, this component consists of the

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[11] "Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities", Government Accounting Office (GAO) (Washington D.C.: April 2009), 11.

Master Control Station (MCS) located at Schriever Air Force Base (AFB), CO; Backup Master Control Station (BMCS) at Gaithersburg, MD (disestablished in 2007), Alternate Master Control Station (AMCS) at Vandenberg AFB, CA; four Ground Antennas, and six Monitoring Stations located across the globe.

Conceptually, it was a relatively simple system. Monitoring stations collect data from the satellites and pass the data to the master control station located in Colorado. The information is processed and the orbits of the satellites are tracked and controlled. The key to the system is the accuracy of the onboard atomic clocks, as the signal times from four satellites are required to accurately plot a location. For example, a three-nanosecond clock error at the satellite can result in a one-meter or greater error on the ground.

After the data is analyzed and the OCS makes system corrections, the corrected data is uploaded through the Ground Antennas back to the satellites. This is basically how the OCS controls the satellite array in space. The Ground Antennas are located at Ascension Island, Diego Garcia, Cape Canaveral, and Kwajalein Island. The ground Monitor Stations are currently located on Hawaii, Colorado Springs, Ascension Island, Diego Garcia and Kwajalein Island.[12]

The OCS infrastructure has been tweaked several times since it was originally stood up in order to keep OCS technology current with newer generations of satellite technology. The problem is that DoD has been having difficulty keeping the Ground Segment, especially the control centers, technologically current with the space array. The contractors who have the contracts to build the satellites are not necessarily the same

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[12] "GPS System Segments", USNO NAVSTAR Global Positioning System. http://tycho.usno.navy.mil/gpsinfo.html

contractors who have the contracts to update the control centers to ensure that the control centers and the satellites are in sync and fully interoperable.

One of the issues is the way that DoD funds GPS. When contracts are let for the next generation of satellites the contracts do not always include the control station upgrades that are required to keep pace with the new satellite technology. What this means is that there are satellites in space that have capabilities that are hidden from the user community, be they military or civilian, because the control stations cannot process the new satellite outputs. This disparity has not gone unnoticed by the Government although little has been done to bring the two components closer together in terms of interoperability.

For example, the OCS had not been upgraded sufficiently to fully support the capabilities of the Block IIR and IIR-M satellites by 2006 in time for the first Block IIR-M satellite that deployed in September of 2005 nor by the time the second unit was launched in September 2006. It wasn't until mid 2007 before the OCS was finally upgraded to a more modern distributed processing environment to fully support Block IIR and IIR-M families of satellites. There is widespread recognition within the Government and the Air Force that the OCS is not keeping pace with new space-based systems. In fact, there is a movement under way to try to make new satellites 'backward' interoperable with the current GPS as a way of minimizing the seeming lack of synchronization between the space segment and the ground segment. Planning is ongoing by the Government in order to replace hardware and software in the ground control segments so as to take advantage of the modernized satellites and their subsystems.

As it stands currently, planning has been underway for the next generation of ground station upgrades to support the Block IIF satellites and offer a baseline of support for the Block III modernization efforts scheduled to begin sometime in 2012.

Procurement began on this upgrade in 2007 and is not complete. However, even with the 2007 upgrades that have been completed by 2011, the OCS cannot support all system capabilities of the newest Block IIR-M satellites. Keeping all three components of the GPS synchronized and mutually supportive has proven to be extremely complex and expensive. It is critical that the Government budget for simultaneous upgrades to the ground segment in order to maximize the new technology being sent into space aboard GPS satellites. As new ways are developed to further inculcate GPS into the global community necessitates improved hardware and software for the ground stations and in space. If the two components do not keep technologically abreast then the user segment will not have complete access to GPS capabilities.

Another related area is the upgrading of monitoring stations. Historically, receivers get the very best reception for GPS signals when they are closer to the equator with coverage beginning to thin out as they move more into the northern or southern latitudes. Reception is at its worst near the poles. The reason for this shortcoming is the orientation of the satellites relative to the face of the Earth. GPS satellites are in orbit with a 55-degree inclination to earth. This inclination makes for a very stable constellation and allows for satellite visibility over the whole planet. However, the satellites are lower on the horizon the closer they get to the poles and this can, at times, make reception problematic.

Recognizing this shortcoming as being a serious impediment for maritime and civil aviation applications, the Government, in 2004, directed six National Geospatial-Intelligence Agency (NGA) monitoring stations to incorporate into the OCS by 2005 in order to improve accuracy to all users, civilian and military. The proposed addition of the NGA stations would, for the first time, provide 100% global monitoring of GPS thereby minimizing the need for other interfacing augmentations. The number of NGA monitoring stations was subsequently raised to eight stations and they were fully incorporated into GPS by 2006, and then expanded again to 10 stations by 2008. These additional monitoring stations have indeed provided true global coverage from GPS for ships and planes regardless of their location on the Earth.

4. USER SEGMENT

The third component of GPS is the user segment. It is made up of receivers and antennas that provide PNT information to users. The market for GPS equipment is huge. This is not a one-size fits all industry and the industry must be flexible enough to update technology to keep pace with the new generations of satellites. Some receivers cost as little as $100 or less and others will sell for tens of thousands of dollars depending on the requirements and the application. The Government and the private sector have been estimating the potential revenues from GPS user equipment for quite some time and have found this industry sector difficult to accurately predict.

Looking back at the first decade of the 21^{st} Century provides a view of the disparate attempts to quantify the potential sales value of global GPS equipment. A 2002 DoD report to Congress on GPS provides a snapshot of the user segment at the end of the

20th Century. It reported that global sales of GPS equipment in 2000 was around $9.34 billion with an increase to $9.5 billion anticipated by 2002 and then double digit growth through 2008. About 4 million GPS commercial units of one kind or another were sold globally in 2000 with about 35% going to the automobile navigation market and 22% for consumer use.

US manufacturers of GPS equipment accounted for 52% of global sales in 2000 and that percentage was projected to decline to 50% by 2002 as new manufacturers came on line. At that same time, US users represented only about 31% of the manufacturers' customer base meaning that US manufacturers of receiver equipment enjoyed a disproportionate share of the market relative the US per capita usage of GPS. The report concluded by warning that "maintaining GPS at the forefront of the world's satellite positioning and navigation technology can only be achieved through a national commitment accompanied by adequate and stable funding throughout the life of the system."[13]

According to a 2010 report by industry analyst Frost & Sullivan, there were some 15 million people who subscribed to some form of service that incorporates GPS by 2010. That figure is up from about 100,000 in 2004. Those figures did not include the millions of people across the world that uses GPS at no charge through their cell phones.[14]

The economic impact of GPS related products and services have been freely debated within industry and Government ever since the first satellites were launched into

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[13] "Report to Congress on Global Positioning System (GPS) 2002", Department of Defense, (Washington: D.C.: October 2002), 13-14.

[14] W.J. Henningan, "GPS is getting an $8-billion upgrade", *Los Angeles Times*, May 23, 2010. http://articles.latimes.com/2010/may/23/business/la-fi-gps-20100523

space. The 2004 DoD report to Congress, for example, cites 2001 studies by the Department of Commerce that suggests sales of GPS related products would be in the $10 billion range by 2008. Another commercially produced industry wide study pegs the global sales at $22 billion by 2008. The report identified the automobile and transportation tracking businesses as representing about 50% of worldwide sales in 2004. ABIresearch, another GPS industry organization, reported in 2009 that global sales of GPS equipment for calendar year 2008 exceeded $36 billion with 39% going to automotive applications and 33% going to marine applications. The report also projected 2010 sales of GPS equipment to exceed $39 billion.[15] Predicting GPS equipment sales is obviously not an exact science. The only thing for certain is that it has huge global potential and is clearly an issue that should be closely monitored and supported by the whole of government.

C. NATIONAL SECURITY INTERESTS

President Bill Clinton was the first President to issue specific policy with regard to GPS. He did so with the issuance of Presidential Decision Directive (PDD) NSTC-6 in March of 1996. In it, the President established the Interagency GPS Executive Board (IGEB) as a policy-making organization chartered to manage and operate GPS with the following goals:

- Strengthen and maintain our national security.
- Encourage acceptance and integration of GPS into peaceful civil, commercial and scientific applications worldwide.
- Encourage private sector investment in and use of US GPS technologies and services.

[15] Dominique Bone and Stuart Carlaw, "Global Navigation Satellite Positioning Solutions", ABIResearch (2009). https://www.abiresearch.com/research/1003224-Global+Navigation+Satellite+Positioning+Solutions?ll&viewtable=1000741~RR-GPS-09.xls-Table1-2.csv

- Promote safety and efficiency in transportation and other fields.
- Promote international cooperation in using GPS for peaceful purposes.
- Advance US scientific and technical capabilities.[16]

NSTC-6 provided policy guidance and responsibilities to various departments across Government in an attempt to promote a unity of effort to support the President's strategic vision for the future of GPS. This policy paper was the first to promulgate the notion that the US should provide GPS services to the world at no charge. It was also important to President Clinton that his policy on GPS was that it would be used for peaceful purposes supporting civil and scientific use and would be known to all inside and outside of Government through this NSTC. He also directed those in his administration to cooperate with other entities, states and non-Governmental organizations alike, to ensure there was a balance between the needs of the global civil community and the Nation's national security interests. In other words, President Clinton recognized the military importance of GPS and the national security implications of a GPS failure but at the same time, the need to ensure GPS be made available to the global user community. So there was a requirement to find a 'balance' between the two competing interests and for the Government to do whatever was necessary to support both parties' continued use of GPS.

Title 10, Section 2281 of the United States Code (USC) directs DoD to provide whatever is necessary to sustain the capabilities of GPS and its services to support the national security interests of the country. Specifically the code directs the Secretary of Defense (SECDEF) to "develop appropriate measures for preventing hostile use of the GPS so as to make it unnecessary for the Secretary to use the selective availability feature

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[16]"US Global Positioning System Policy", PRESIDENTIAL DECISION DIRECTIVE NSTC-6, (Washington D.C.: The White House, March 28, 1996), Policy Goals.

of the system continuously while not hindering the use of the GPS by the US and its allies for military purposes." Simultaneously, the Secretary will also sustain the capabilities of the GPS for peaceful purposes on a global basis without charge to users "in order to meet the performance requirements of the Federal Radio-navigation Plan (FRP) prepared jointly by the Secretary of Defense and the Secretary of Transportation."[17]

This same law, Chapter 136, Section 2281, calls GPS "vital to the effectiveness of the United States and Allied military forces and to the protection of the national security interests of the United States."[18]

The US Congress directed DoD to submit a biennial report beginning in 1998 on the status of the GPS. The reports covered all aspects of the system from both a military and a civil perspective and have provided a clear history of US Government policies and behaviors regarding the system. The first report recognized the growth of GPS applications globally and the need to recognize the challenges resulting from increasing global usage of the system specifically as they related to issues of national defense and national security interests. From the beginning, GPS was designed and deployed as a military system and the state of the system in 1998 was once again focused on its ability to support the Nation from a military perspective.

The 2004 DoD report to the Congress closely considered international interest in GPS and stated that 37 different nations had made GPS their standard for military

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[17] United States Government, Title 10, USC, Subtitle A, Part IV, Chapter 136, Sec 2281, (Washington D.C.: February 1, 2010).

[18] United States Government, Title 10, USC, Subtitle A, Part IV, Chapter 136, Sec 1074 (a), 2, (Washington D.C.: February 1, 2010).

positioning, navigation, and timing (PNT) information. This is an important metric and demonstrates how pervasive GPS dependency had become by this time.

However, the United States does not export PPS encrypted equipment or licenses to manufacture encrypted equipment without a Memorandum of Agreement (MOA) with foreign nations covering the sales or exportation of sensitive military equipment to third party nations. Most of the countries whose military had adopted GPS were European. However, other Allies and treaty partners also signed the MOA and adopted GPS as their standard. These countries have included Japan, South Korea, Australia, Canada and Israel. NATO, as a military command, has also followed suit and made GPS its standard as well. In most cases the foreign militaries did not have a lot of choice in this matter because in order to train with US forces a foreign military must have the capacity for basic electronic interoperability to include the extensive use of GPS. The importance of this international military cooperation for the US military is that "these agreements will significantly contribute to improved interoperability and situational awareness as these nations join with US forces in future coalition military operations."[19]

The importance and reliance on the military side of GPS was accentuated in 2003 with the execution of Operation Iraqi Freedom. 57% of the nearly 20,000 precision munitions used by the US during the march to Baghdad relied on GPS to meet guidance and targeting requirements. Allied forces were able to advance in mass across Iraq that took Iraqi Republican Guard forces by surprise using GPS as their primary navigation instrument. Operation Iraqi Freedom also became the first instance where a foreign government, Iraq in this case, initiated a jamming campaign in an attempt to interfere

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[19] "Report to Congress on Global Positioning System (GPS) 2004", Department of Defense, (Washington D.C.: October 2004), 8.

with GPS signals and degrade the performance of the system. Fortunately for the US, the Iraqi jamming attempts were not sufficiently sophisticated to cause any real degradation of the system but it highlighted the absolute need to have interference counter-measures fully developed and available to protect the system from attack.

1. SECOND ORDER EFFECTS OR INCREASING CIVILIAN APPLICATIONS

Every Presidential Administration since Bill Clinton has lobbied the Government and industry to continue to work toward maintaining US dominance in space technology, specifically GPS. A second order effect of this Government policy to ensure that GPS remains at the forefront of all global PNT systems by encouraging the creation of new applications was the generation of a large number of requests from other Government agencies as well as industrial concerns for additional capabilities to support these new and emerging applications. DoD recognized that with the proliferation and rapid growth of GPS civil applications across the globe that some safeguards had to be emplaced to protect the US military's access to a secure system.

It is not surprising that successive Administrations continued to champion the system after recognizing the economic advantages of being the lead nation in space technology. DoD also saw the burgeoning growth of GPS applications and by 2006 was warning the Bush Administration that the number of new GPS application requests were creating real challenges for the DoD scientific community because they were requiring larger and heavier satellite components which in turn were changing the launch and lift parameters and increasing the costs and lead times to get new satellites deployed into space and that this could jeopardize system operation and availability for the military.

The vast majority of the requests for new services were coming from domestic players catering to the civil community, especially in the transportation sector that includes the Nation's highways and railways. Industry and Government alike were finding more and more ways to improve efficiencies with the integration of GPS into their systems.

2. VOLPE COMMISSION AND PDD-63

GPS had become a fully integrated component of the American economy by the time Bill Clinton took office. He was fully aware of the positive impact that GPS and its equipment requirements were having on job creation and space science growth. But he also knew how important GPS had become to the Nation's infrastructure, particularly to the Nation's transportation sector. So much so that he commissioned a landmark study into the effects of a GPS failure on the United States and was the first President to look specifically at GPS as a major component of the Nation's national security. President Clinton signed PDD-63 in May of 1998. In it, he ordered that DOT "in consultation with DoD, shall undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on the Global Positioning System. The evaluation shall include sponsoring an independent, integrated assessment of risks to civilian users of GPS-based systems."[20]

The resultant evaluation was called the Volpe Commission's 'Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System' that was published August 29, 2001. John A. Volpe, former Secretary of Transportation in the Nixon Administration, chaired the Commission. In it, several

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[20] "Critical Infrastructure Protection", PRESIDENTIAL DECISION DIRECTIVE PDD-63, (Washington D.C.: The White House, May 22, 1998), 11-12.

different deliberate threats to GPS were illuminated including the possibility of jamming satellite signals, provoking the satellites to provide erroneous data or the loss of satellites or ground station elements to attack or sabotage.

With these various scenarios in mind, the report recommended, "public policy must ensure, primarily, that safety is maintained even in the event of loss of GPS. This may not necessarily require a backup navigation system for every application. Of secondary but immediate importance is the need to blunt adverse environmental or economic impacts.. The focus should not be on determining the nature of the backup systems and procedures, but on which critical applications require protection."[21]

It was also noted that America's adversaries could jam or spoof[22] the system to disrupt operations. To counter this threat, the report encouraged DoD to make available anti-jamming and anti-spoofing technology to the civil sector in order to further harden GPS capabilities.

The Volpe Report also addressed the possibility of GPS being compromised unintentionally through atmospheric disturbances, signal blockage due to the 'urban-canyon' effect, or interference from other radio sources. The 'urban-canyon effect occurs in densely crowded urban areas with high concentrations of tall buildings. Signal receivers need four satellites to gain an accurate location plot and being in an 'urban-canyon' environment surrounded by tall buildings sometimes obscures the satellites and signals do not penetrate to the surface. In response to these threats, the report

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[21] "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System", John A. Volpe National Transportation System Center, (Washington, D.C.: August 29, 2001), ES4.

[22] Spoofing is the intentional generation of fake GPS signals. Spoofing can take place directly against a satellite or can be directed against ground support stations so that the user computes incorrect position solutions.

recommended continuing to modernize the array, make available three civilian signals as opposed to a single signal on existing units, and a corresponding increase in signal strength to mitigate the effects of atmospheric interruptions.

Adding additional signal generation capability to the satellite array is difficult and takes a lot of time to implement. New signal generators need to be installed on the ground during the manufacturing process; therefore, additional signal capability is not available for satellites already in orbit. More signal availability at greater strength tends to mitigate ionosphere interference and gives the signal a more robust signature that is less easily jammed or spoofed. Adding signal capability and increasing the strength of each signal is considered a major upgrade to existing technology.

Scientists took on the challenge of adding new signals to next generation satellites and they have struggled to succeed over the years. In a 2002 report to the Congress, DoD highlighted its objective of adding one additional military and one additional civilian signal to the next generation of satellites, the Block IIR-M, that were then scheduled to begin deploying in 2004 and then a third civilian signal to Block IIF units that were then scheduled to deploy beginning in 2006 in order to increase outputs to keep up with anticipated increases in civil demand. However, a 2006 DoD report to the Congress showed the Block IIF modernized satellite initial deployment date had slipped to sometime in 2010 due to technical issues in the design of the signals upgrades.

The newly designed signals capabilities of the Block IIF satellites that were proving troublesome were intended to be a limited access capability. The third signal would be dedicated specifically to safety of life applications and would be utilized by emergency service or first responder personnel. This third signal would also be available to the civil aviation industry as an emergency channel to support search and rescue efforts. The Block IIF would introduce, for the first time, triple frequency GPS that would eventually improve the overall robustness of the system, reduce atmospheric interference, and offer new opportunities for much greater accuracy.[23] Currently, only two of the proposed twelve Block IIF satellites have been launched into space. They are years behind schedule and millions of dollars over budget due to the technological challenges facing the contractors and scientists designing and building the units.

The Volpe Report did not stop at recommending upgrades to compensate for possible vulnerabilities in the system. It also recommended that DOT "create awareness among members of the domestic and global transportation community of the need for GPS backup systems or operational procedures, and of the need for operator and user training in transitions from primary to backup systems, and in incident reporting, so that safety can be maintained in the event of loss of GPS, in applications that cannot tolerate that loss."[24]

The report recognized the single greatest vulnerability was a system failure. It argued that GPS should not be the single point of failure within the Nation's transportation sector and that redundancy was a requirement from a national security perspective in order to prevent a catastrophic disruption of the transportation infrastructure in the event of gross disruptions of the GPS. The Nation has grown to depend on GPS and a system failure would create significant domestic havoc.

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[23] "Report to Congress on Global Positioning System (GPS) 2008", Department of Defense (Washington, D.C.: October 2008), 13.

[24] "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System", John A. Volpe National Transportation System Center, (Washington, D.C.: August 29, 2001), ES6.

GPS is the primary location device for containers of goods moving from ports to distribution centers. It is the primary tracker of rail shipments and passenger trains. It allows the Government to track sensitive shipments across the United States and it allows the Federal Highway Department to monitor road conditions, accidents, and location of law enforcement personnel. And today the traveling public uses GPS instead of paper maps to travel from one place to another. A shutdown of the system, even for a few hours, would have a significant impact on the Nation's transportation system.

It is easy to see how this ubiquitous system has grown and become fully institutionalized in the American culture because it literally touches all people nearly every single day. But it is important that the public remember why it was originally designed. Going back again to the 1998 DoD report to the Congress. It states explicitly that "information dominance achieved through greater precision of positioning, velocity, and timing information will be key to maintaining superior tempo and surprise...it clearly delineates GPS as the centerpiece of DoD's positioning, navigation, and timing system architecture for the foreseeable future."[25] The report also recognized a need for DoD to develop some means to prevent the Nation's adversaries from being enabled by using GPS against the US while still maintaining free and unfettered access to signals by the military and by civil users outside the envelope of hostile activities.

This is the single biggest issue facing DoD and the Government as they work to provide GPS to the civil community but also protect GPS from those bad elements that would do the United States harm.

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[25] "Biennial Report to Congress on the Global Positioning System", National Executive Committee, (Washington, D.C.: 1998), 1. http://www.pnt.gov/public/docs/1998/biennial1998.shtml

The 2004 DoD report to Congress saw the growing importance of GPS to the economy and defined one of the major challenges facing any modernization efforts then being considered by DoD. The report stated that there was a need "to develop and acquire effective capabilities to protect US and Allied forces' ability to operate with the system and at the same time deny adversarial use of GPS without disrupting civil use outside an area of military operations."[26] This is truly dual-use technology that has, in many respects, become a global entitlement program. DoD responded to this need by establishing an activity called Navigation Warfare (NAVWAR) in order to study the issue in detail and to include NAVWAR in the program modernization process as necessary in order to ensure GPS remained a viable and integral facet of future military planning and operations in spite of increasing emphasis on civilian applications. What NAVWAR was supposed to do is protect the vital interests of the United States where GPS is concerned. New civil applications and emerging technology that is capable of attacking the system is war-gamed and analyzed hoping that this effort will allow DoD to stay ahead of the competition and still maintain GPS as a dedicated asset in the defense of the Nation.

3. A RAND STUDY

The Air Force commissioned a RAND Corporation study in 2005 to study the incongruous nature of providing a system such as GPS that is so absolutely critical to the military in support of national security interests of the Nation and offering it at no charge to anyone with a receiver anywhere on Earth. The obvious problem is operational

[26] "Report to Congress on Global Positioning System (GPS) 2004", Department of Defense, (Washington, D.C.: October 2004), 3.

security. How does the Nation maintain operational security of the system and still offer almost complete transparency of intellectual property to anyone in the global community? There is no easy answer to this question. GPS has become a part of the global commons while still having to be a dedicated system designed to protect the sovereignty of the United States. There have been attempts to hack the system and interfere with the military PSP and fortunately for the United States, these attempts have mostly failed. The US works diligently to protect the carrier frequencies used for military signals. The Government also uses state of the art receivers that are not readily available on the open market making the signals more difficult to jam or hack. However, there has been a general consensus that because of its widespread use, GPS is no longer secure enough to be used as a primary PNT instrument for the Nations' most sensitive weapons systems. The Government has developed alternate guidance systems that do not rely on GPS for these specialized systems.

In order for the US to remain at the forefront of GPS technological development and modernization as Presidents have asked, the domestic manufacturing world has to have relatively unfettered access to standards and requirements in order for them to produce goods and services. In other words, GPS technology, including intellectual property, has to be unclassified for the most part to encourage manufacturers to apply scarce R&D dollars to modernization efforts. This commercialization of the system is in serious conflict with DoD mission to support the Nation's national security.

The RAND study offered one interesting recommendation to the Air Force that was not immediately accepted by the Government but could enable DoD to safeguard its encrypted share of GPS and at the same time give US industry an opportunity to participate to some lesser degree in space system modernizations. The report recommended, "GPS is and will remain a dual-use system, but a potential opportunity exists to improve the civilian service in ways the United States can do only if it shares the burden. Should the United States seek to formally share the responsibility of satisfying civilian user needs with the EU?"[27] It is an interesting question because it may run counter to Presidential policy as expressed in PDD-63 and the later NSPD-39 where both the Clinton and Bush administrations directed the Government to maintain GPS dominance globally and to ensure US corporations remain the preeminent repositories of space technology and development. Sharing the stage with the EU or any other international actor was not envisioned although both administrations were interested in cooperating with others to ensure some degree of interoperability was achieved although the interoperability should be based on US standards.

The 2006 DoD report to Congress is most parsimonious in its description of Government efforts to maintain US preeminence in space-based PNT services. The report states flatly that "while GPS currently enjoys unprecedented acceptance throughout the world, new threats to GPS are emerging and foreign satellite navigation systems are on the horizon. Threats must be understood and dealt with, and foreign PNT systems must be made compatible or interoperable with GPS."[28]

The DoD threat references to other satellite systems are primarily focused on EU efforts to get their version of GPS, the Galileo Project, operational and there had been a number of concerns in the US about the effects of a new competitor to GPS. Of course

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[27] Rosalind Lewis et al, *Building a Multinational Global Navigation Satellite System*, (Arlington: RAND Corporation (2005), 69.

[28] "Report to Congress on Global Positioning System (GPS) 2006", Department of Defense, (Washington, D.C.: October 2006), ES3.

there was no real way to ascertain for certain what the effect on US market share of the global GPS market would be or if Galileo would be a true competitor but the Government needed to recognize and be aware of the Galileo potential. Since the launch of the first GPS satellite in 1989 until the present time there has been no peer competitor to GPS and it remains to be seen if Galileo's coming on line sometime in the next decade will foster a sharing of global applications as individual systems or if Galileo and GPS become truly interoperable and the synthesis of two systems working together provides something greater than the sum of both systems individually for the betterment of the global community.

In concert with the concerns about the design of Galileo is the fact that there are other nations whose military forces use the civil signals of GPS as their primary military signal. So what does all this mean to the Nation and its national security? The Volpe Report clearly recognized the potential dangers to the Nation and its Allies when numbers of other states began relying on GPS for its military operations. Warning the Government of the dangers of foreign military interference the Report warned that "the accelerating worldwide military dependence on GPS makes mechanisms to disrupt the signals potent weapons that many militarily sophisticated countries are actively developing...it is possible that adversaries could create the capability to deny the GPS signal to civil applications over wide geographic areas and for long periods of time."[29]

What this means is that foreign or non-state actors could target GPS as a military objective and inflict significant damage to the American Homeland without having to

[29] "Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System", Volpe, App A, A.2.2, 70.

engage in combat with American troops. A successful attack on the civil side of GPS would, in short order, wreak havoc on the US infrastructure and the economy.

The whole notion that bad actors could co-opt GPS and somehow use it against the United States has been a running theme from DoD since the beginning. As will be seen in Chapter III, preservation of the right to inherent self-defense in the case of GPS was quite a contentious issue during negotiations between the US and the EU on Galileo interoperability with GPS. An agreement between these two entities was finally signed in 2004 but not before specific language was inserted into the Galileo Agreement to ensure all Parties had the opportunity to protect their national interests.

Article 11 of that agreement states in part that "the Parties intend to prevent hostile use of satellite-based navigation and timing services while simultaneously preserving services outside areas of hostilities."[30] This paragraph alludes to GPS capabilities that would allow the US to restrict signal generation on a regional basis in the case of military requirements. What is not written into the agreement is whether or not there would be a simultaneous restriction of Galileo signals in the event of a US military necessity.

4. LONG TERM VIABILITY

The GAO released a study in 2005 that sounded additional warnings to the Government regarding the long-term viability of GPS and questioned the ability of the Nation to maintain its preeminence in GPS services. The report clearly recognized the importance of GPS to the Nation's infrastructure and to its national security while also

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[30] EU/USA Agreement: Promotion, provision and use of GALILEO and GPS satellite-based navigation systems and related applications, (County Clare, Ireland, 2004): Art 11, Para 2. http://www.pnt.gov/public/docs/2004/gpsgalileoagreement.pdf

stating that more needs to be done to stay ahead of the field. GPS as a program has been plagued by cost overruns, component development problems, and deployment delays, so much so that the constellation is at risk of falling below the minimum requirement for serviceable satellites within the next several years. The GAO study recommends that "focused attention and oversight are needed to ensure the program stays on track and is adequately resourced, that unanticipated problems are quickly discovered and resolved, and that all communities involved with GPS are aware of and positioned to address potential gaps in service."[31]

But there is more to it than being aware of deficiencies in the system. From a national security perspective the fact that ground station and user equipment technology is not keeping pace with satellite technology leaves the military in a position where some of the satellites may have capabilities that cannot be tapped by the Nation's military forces. The GAO report mentions a diffuse leadership organization and decentralized acquisition as two areas that are not working in the best interests of the program.

The report states flatly that "without more concentrated leadership attention, such disconnects could worsen, particularly since (1) both the ground control and user equipment programs have been subject to funding shifts to pay for problems affecting the satellite segment, and (2) user equipment programs are executed by separate entities over which no one single person has authority."[32]

The Government has made some changes to the GPS program since the GAO study was released. DoD did assign the Assistant Secretary of Defense for Networks and Information Integration (ASD NII) as the single focal point within the department for

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[31] "Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities", Government Accounting Office, GAO-09-325, (Washington, D.C.: April 2009), 40.

[32] Ibid.

GPS and gave that office the responsibility and the authority for all aspects of the program. Problems still persist however since the complexity of the system and the disparate requirements of service from the various departments across Government make it exceedingly difficult to streamline and improve the specification and acquisition aspects leaving this part of the system open to additional criticism from Government watchdogs like the GAO. Perhaps raising the responsibility of oversight from the department level to the executive level in the National Security Council could increase the visibility of issues and concerns and serve to improve bureaucratic efficiencies in regard to GPS?

D. DOMESTIC POLITICAL AND ECONOMIC IMPACT

There has been a growing recognition within the Government of the need for better Federal oversight of the civil applications associated with GPS. As mentioned earlier, the growth of civil applications for service has been nothing short of phenomenal and DoD, although a fine steward of military applications for GPS, was not the most sympathetic steward for the burgeoning civil market. The Clinton Administration made the first effort to streamline the system and give the civil community a seat at the table. A Memorandum of Agreement (MOA) was signed in January of 1993 between the Department of Defense and the Department of Transportation (DOT) that pertained to the civil use of GPS. This MOA was updated in December of 2004 to further delineate the responsibilities of each department specifically related to space-based positioning, navigation, and timing (PNT) issues.

Besides being responsible for protecting the operational security of GPS and to use the system in defense of the Nation's national interests, the MOA calls for DoD to continue to finance, through its budget, whatever is necessary to operate the entire GPS system including its maintenance and upkeep. Additionally, it directs DoD to provide the necessary information from the system to DOT that allows DOT to disseminate that information to the global user community, among other responsibilities. The release of GPS intellectual property to the global community was a watershed moment in the growth of GPS applications across the globe. Having access to this information simply by request allowed scientists and manufacturers everywhere to design equipment that would somehow interface with GPS and would further enhance the importance of the system in the everyday lives of the global community.

1. DOT

DOT is responsible for representing Government interests in anything related to the use of or requirements for civil GPS services. Importantly, both departments have the joint responsibility of controlling GPS augmentations in a national emergency, among other responsibilities.[33] Augmentations, in this case, represent other land or space based PNT systems that are not stand-alone but are used with GPS in order to improve its performance, accuracy, and/or reliability in specific applications. By focusing additional resources and visibility on GPS and its augmentations it is not surprising that by 2004 GPS had become the single standard radio-navigation aid for civil aviation on all global oceanic routes. This civil aviation application, where there is a requirement for

[33] "MOA between DOD and DOT, Civil Use of the Global Positioning System", (Washington, D.C.: Government Printing Office, November 3, 2008), 5.1, 5.2, 6.1, 7.1.

redundancy of all systems and there exists a strong expectation of safety is a good example of the need for an augmentation.

GPS was not designed to provide the level of confidence required for civil aircraft operations in the vicinity of airports or on domestic routes. GPS, as it stands alone, has not possessed the required accuracy, availability, and integrity for primary use in these applications. Therefore, the Wide Area Augmentation System (WAAS) was commissioned by the Federal Aviation Administration (FAA) in 2003 as an augmentation system to bolster GPS integrity, availability, and accuracy that meets or exceeds all FAA requirements for NAS and Category I[34] approaches and is currently in use. Research has been ongoing for GPS augmentation solutions to FAA requirements for Category II[35] and III[36] approaches as well.

Augmentations like WAAS and their specific functions and capabilities are covered under the Federal Radio Navigation Plan (FRP) originally published by the Government in 2001 and updated biannually. It is a critical piece of the Federal infrastructure governing GPS. In it, the plan provides the roadmap for Government departments to follow with regard to PNT generally and to GPS specifically. The Government and DOT in particular, has recognized that the various iterations of GPS constellations have not totally met the requirements of every user group and it has offered specific augmentation guidance to those user groups that have needed additional capabilities such as the civil aviation or maritime communities. When published in 2001

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[34] An instrument landing approach procedure that provides for approach to a height above touchdown of not less than 200 feet.

[35] An instrument landing approach procedure that provides for approach to a height above touchdown of not less than 100 feet.

[36] An instrument landing approach procedure that provides for approach without a minimum height above touchdown.

the FRP was mostly focused on those two major applications but over the years the FRP has incorporated numerous other major applications as they mature including surveying; global mapping; weather prediction; critical timing applications; and other space applications.

2. NSPD-39

President George W. Bush signed into law National Security Presidential Directive (NSPD)-39 in December of 2004 that established for the first time an overarching cabinet-level committee to ensure that GPS remained the preeminent global PNT system and that it was to be interoperable and as compatible as possible with other systems being deployed across the globe. The National Positioning, Navigation, and Timing Executive Committee (NPEC) was established and would, among other things, work to ensure all Government agencies involved with GPS work in concert as much as possible to "ensure that national security, homeland security, and civil requirements receive full and appropriate consideration in the decision-making process"[37] thus charting a strong course to maintain a balance between the civil and economic aspects of the system with the military requirements of keeping the Nation safe from its enemies in recognition of the importance of GPS to the Nation's infrastructure.

NSPD-39 clearly recognized the growing importance of GPS to the global community and how important the system was to the US economy. As such, the NSPD charged the NPEC with the specific responsibility to "ensure that the utility of civil services exceeds, or at least equivalent to, those routinely provided by foreign space-

[37] "NSPD-39 U.S. Space-Based Position, Navigation, and Timing Policy", (Washington, D.C.: The White House, December 15, 2004), 4.

based positioning, navigation, and timing services."[38] It was clear that in 2004 the President indicated a willingness of the US to do whatever was required to remain competitive with any systems on the drawing boards or being deployed in order to maintain the US scientific and manufacturing advantage in the PNT world.

In his coordinating instructions to the Cabinet, the President provided additional strategic guidance on how the US was going to maintain its global advantage. NSPD-39 specifically directed the Secretary of Transportation, in cooperation with the Secretaries of State and Commerce, to "facilitate foreign development of civil positioning, navigation, and timing services and systems based on the Global Positioning System; and international participation in the development of civil applications for US space-based positioning, navigation, and timing services."[39] This NSPD makes clear that the Government should apply whatever resources are available to it in order to ensure that GPS remains the world standard in PNT and that emerging PNT applications be tethered directly to GPS and the United States.

3. eLORAN AND NDGPS

GPS has continued to show itself to be a reliable and stable platform for enhancing the performance of systems through the use of augmentations. However, due to the fact that GPS and the augmentation that are intended to be used with GPS are Government financed getting the augmentations into operation can sometimes be difficult and time consuming. The Department of Homeland Security (DHS), for example, made the policy decision in early 2008 to designate an enhanced version of Loran-C called

[38] Ibid.
[39] Ibid, 8.

eLoran as the official backup system to GPS because of persistent concerns about critical infrastructure protection responsible to DHS with NPEC approving the decision in March 2008. However, President Obama later identified Loran as a system that could be terminated and directed the Coast Guard to cancel Loran. About the same time that the President was cancelling the system the Congress, specifically the Senate Committee on Commerce, Science, and Transportation, inserted language into SB-1194 that authorized the appropriation of $37 million for FY 2010 and 2011 to modernize and upgrade the Loran infrastructure to provide eLoran services specifically as a back-up system to GPS. The bill is currently awaiting action in the House of Representatives.[40] This is a good example of how politicized GPS can become and sometimes, why it takes so long to bring new systems on line. It can also be an example of why systems are sometimes put into operation that do not perform to expectations.

LORAN has been around for decades and has become a very well recognized and trusted system for the seafaring community. The United States Coast Guard operated LORAN-C first as the primary location fixing maritime system and, with the growth of GPS both in accuracy and availability, as a quasi-backup to GPS until 2010. President Barak Obama announced that the LORAN-C system was obsolete in 2009 and the system was unfunded by the Congress in 2010. The Congress had also gotten reports stating that GPS could be the single point of failure for the global maritime industry without a redundant system as a safety backup. Therefore, the Congress convened a series of debates considering the efficacy of maintaining and upgrading LORAN-C to become an actual backup system to GPS.

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[40] Glen Gibbons, "eLoran: The Never-Ending Story?", *Inside GNSS*, June 15, 2009. http://www.insidegnss.com/node/1571

The Coast Guard Authorization Act of 2010, as amended, removed mention of LORAN-C and effectively deleted the system from the inventory per the President's edict. Even so, the Congress then inserted a directive in the 2009 Defense Appropriations Act (DAA) that directed DHS to conduct an assessment on the value or requirement for the Nation to have a separate backup maritime navigation system to GPS. Scientists were able to upgrade the LORAN system and improve the strength of the LORAN signals sufficiently to quell many of the criticisms surrounding the system. The upgraded system was rebadged eLORAN, or enhanced LORAN. Research continues on the system but it has lacked budget support and has not been designated as the primary backup to GPS for the maritime industry although it is not yet dead.

Another example of an earlier augmentation that has gone relatively smoothly and is on track is NDGPS. On October 27, 1997, the Department of Transportation was directed under Title 49, Section 301, of the USC to "establish a nationwide system to be known as the 'Nationwide Differential Global Positioning System (NDGPS)'.... and to ensure that the service of the NDGPS is provided without the assessment of any user fee; and in cooperation with the SECDEF, ensure that the use of the NDGPS is denied to any enemy of the United States...and develop standards for the NDGPS."[41]

Research began on the standards for accuracy of location during the early 2000's on an upgraded High-Accuracy NDGPS that would provide navigation data to within 10 centimeters that would represent unprecedented accuracy for a space-based system.

The NDGPS augmentation was programmed to be fully operational by 2007 and to provide predictable accuracies in the 1-3 meter range that were anticipated to meet most requirements within the maritime community. A 2004 DoD report to Congress

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[41] United States Government, Title 49, USC, Sec 301, (Washington, D.C.: February 1, 2010), 61.

addressed maritime issues and describes the NDGPS as an operational Coast Guard augmentation that meets all Harbor Entrance and Approach phase requirements to include integrity broadcasts when the system should not be used for navigation.[42] The report also projected NDGPS upgrades would enable it to meet most requirements for all land-based transportation systems including rail, transit, and emergency response by year 2008. NDGPS and LORAN are complimentary systems for the maritime trade with LORAN used mostly in an open ocean environment and NDGPS being used in littoral areas to include harbors and bays.

By 2004, over 40 different countries, increasing to over 50 by 2008 had made the Coast Guard's DGPS their single standard for maritime PNT requirements and the US and Canadian Coast Guards have merged their two systems to form a cross-border DGPS system that provides a seamless service across North America.

The FY2010 DAA allocated $14.0 million for NDGPS operations conducted for inland transportation requirements through DOT and on the Nation's waterways through the Coast Guard. The FY2011 DAA increased the funding of the program to $23.0 million but the requested funding for FY2012 has dropped to $17.3 million as passed by the House of Representatives and is awaiting action by the Senate.

4. INTERFERENCE

In the early 2000s, with the Government recognizing the growing importance of GPS to the civil community and its potential impact on the overall economy with more and more segments of the economy relying on the system, it began to consider the impact and ramifications of GPS blackouts. Although there was the realization that the GPS had

[42] Report to Congress on Global Positioning System (GPS) 2004, 5.

been designed to support the US military, it was also apparent that applications directed to the global population writ large were increasing at a very rapid rate. This increase in applications was causing a cascading effect in that disparate systems across the economy were becoming dependent on GPS in order to perform according to design.

The overall effect of a long-term denial of service would mean that major sectors of the National infrastructure could fail simultaneously creating serious consequences at the national level. Scientists and experts also differed on what was considered long-term. What was apparent was that some applications such as time stamping confirmations covering global banking transactions would begin to affect the global economy much faster than the a container tracking program associated with the transportation infrastructure with the loss of GPS inputs. With such dependency on GPS it is no small wonder that the Government was so focused on finding the ways and means to mitigate the effects of potential interferences to the system.

The 2002 DoD report to the Congress made several recommendations for mitigating the potential effects of deliberate or non-deliberate interference with GPS operations. The key concern of DOT was the integrity of the Nation's transportation system and the national effect on that system if GPS was interdicted in any significant fashion. Therefore, in addition to having functioning back-up systems in all major modalities, the report recommended that the Government maintain the viability of the transportation infrastructure by:

- Ensuring that adequate backup systems are maintained.
- Maintaining the partnership with the Department of Defense to continue modernizing GPS with the implementation of new civil signals.
- Facilitating transfer of appropriate anti-jam technology from the military for civil use.
- Conduct industry outreach to develop receiver performance standards.

- Emphasize and promote education programs with state and local departments of transportation that advise users about GPS vulnerabilities.
- Complete an assessment of radio-navigation capabilities across all the modes of transportation to identify the most appropriate mix of systems, from both a capabilities and cost perspective, for the next 10 years and beyond. This will include completing the evaluation of the long-term need for the continuation of the LORAN-C.[43]

The President's Commission on Critical Infrastructure Protection had cited, in an earlier report from October of 1997, GPS as having the potential to be one of the two most vulnerable components of America's critical infrastructure. It stated that the "most significant projected vulnerabilities are those associated with the modernization of the National Airspace System (NAS) and the plan to adopt the Global Positioning System (GPS) as the sole basis for radio-navigation in the US by 2010."[44] At issue was the lack of scientific research and understanding of potential threats of interference from external sources. The contention was that there were no systems in existence that could be guaranteed to be available 100% of the time and operating at 100% of design capacity. Therefore, there existed a strong possibility that GPS could become a single point of failure within the NAS if all other land-based instruments of radio-navigation were withdrawn from service prematurely.

The report recommended that assessments be completed on the vulnerability of the national transportation network that would rely on GPS and that research be conducted to find ways to mitigate the effects of external interference of GPS operations.

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[43] Report to Congress on Global Positioning System (GPS) 2002, 10-11.

[44] "Critical Foundations: Protecting America's Infrastructures", Report of the President's Commission on Critical Infrastructure Protection, (Washington, D.C.: October 13, 1997), Chap 3, 13.

5. TRADE ISSUES WITH EU OVER GALILEO

The Government concerns about system interference carried over into the negotiations with the EU over the Galileo program as well. One major and contested aspect of the Galileo Agreement between the US and the EU that was signed in 2004 pertained to the need to ensure that there was no trade discrimination built into the system that would favor one national industry over another as the various manufacturers invest resources in the development of equipment using or supporting GPS. In order to ensure all Parties were gravitating in the direction of trade equity the US Congress directed the Office of the US Trade Representative (USTR) to query the US equipment industry for comments on the transparency of the EU Galileo program for US access to Galileo technical specifications.

In response to this query, the US GPS Industry Council replied that the US GPS was truly an open and available system that offered all technical civil specifications free to the global market. It also stated that the overall effect of the integration of Galileo into satellite radio-navigation would be most beneficial if the EU reciprocates with the same level of access and transparency. However, in May of 2009, the EU was requiring licenses for manufacturers to sell products supporting Galileo and the actual receiver test beds necessary to conduct R&D on new products were not exportable from Europe.

Thus, according to the report, "US user equipment manufacturers would need to consider relocating their US R&D engineering facilities to Europe for proximity to these test beds if the Galileo signal modulation component is not commercially authorized for export in the near term. Most importantly, access to the same kind of information for GPS signals has been long available to European manufacturers."[45]

A 2009 GAO report seemed to support the assertions on non-discriminatory licensing procedures highlighted in the USTR report. The GAO report detailed assertions from the Department of Commerce that seemed to be a lack of information coming from the European Commission about the whole licensing process to include availability of licenses, procedures for application, and requirements for receiving a license to sell Galileo equipment. The report also stated that because it normally takes 18-24 months to have new products ready for the market, US manufacturers were "hesitant to invest in technology that is not officially licensed and that could possibly be banned from sale. US firms are concerned they will not have their products ready and will lose their market share to European companies with inside access to technology and/or licensing information."[46]

Under pressure from the Government and US manufacturers of GPS equipment, the EU announced in the Galileo OS Signal In-Space Interface Control Document (ICD) late in 2010 that any entity would have access to all Galileo data for the purposes of commercial activity of nearly any sort. The caveat was that each entity had to apply for a license to use the Intellectual Property Rights (IPR) of Galileo that are solely owned by the EU. The document states definitively "the use of information contained in the OS SIS ICD, including the spreading codes which are subject to IPR, is hereby allowed for

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[45] US GPS Industry Council Docket No, USTR-2009-0010, (Washington, D.C.: May 13, 2009), http://www.regulations.gov/#!documentDetail;D=USTR-2009-0010-0002

[46] Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities, GAO-09-325, 39.

manufacturing, distribution, commercialization, sale of electronic devices and supply of Value Added Services according to the terms and conditions of the license agreement."[47]

It is still too early to determine if the licensing process instituted by the EC is sufficiently streamlined to allay criticisms lodged against the program for its seeming lack of transparency in regard to non-European manufacturers. It does appear, however, that the EC is making a determined effort to reduce the roadblocks and provide Galileo data to the all who request it. This would lend itself to improvements in cooperation and eventual total interoperability between GPS and Galileo in respect to the transmission of standard signals.

6. NATIONAL SPACE POLICY

President Barak Obama's 2010 National Space Policy has provided additional guidance to Governmental departments and domestic manufacturers on the subject of GNSS. The policy diverges from NSPD-39 in the sense that the 2010 Policy is not nearly as strident in its language to maintain US dominance in the PNT world. Where President Bush's direction was to have Government departments endeavor to have international players design and build their systems to work with GPS, President Obama has softened the language and redirected US policy. According to the 2010 document, US space policy now includes the need to continue to operate and maintain GPS according to

[47] "Galileo OS SIS ICD", Committee on Enterprise and Industry, Issue 1, Rev 1, (Brussels: European Commission, September 1, 2010), http://ec.europa.eu/enterprise/policies/satnav/galileo/open-service/index_en.htm

specifications but that "foreign positioning, navigation, and timing (PNT) services may be used to augment and strengthen the resiliency of GPS."[48]

The policy goes on to recognize the need to provide resources for increased emphasis on detecting and combating intentional or unintentional attacks from any sources on GPS. This should involve domestic and international efforts to protect the GNSS. The policy also continues to call for appropriate and reliable back-up systems to GPS to protect the Nation's critical infrastructure.

E. TRANSATLANTIC IMPACT

There has been significant cooperation between the US and Europe over the years since the end of WWII. The trans-Atlantic partnership has, by most metrics, been very successful. Consider the bi- or tri-lateral space projects between US and the UK on the Ariel Project in 1967; the US and the Federal Republic of Germany on the Helios Project in 1974; the US and UK and the Netherlands with the Infrared Astronomical Satellite Project of 1983; or the International Ultraviolet Explorer Project of 1978 built by the US, the UK, and the European Space Agency (ESA). Each of these cases demonstrated willingness of the United States and of Europe to work together in the design, build, and deployment phases of space systems. Additionally, each of these projects was designed for the peaceful exploration of space and was conducted under the auspices of NASA in cooperation with other stakeholders.

As the world moves into the 21st Century that cooperative spirit between the US and the EU may not be as vigorous as it once was. There are a variety of reasons for

[48] President Barak Obama," National Space Policy of the United States of America", (Washington, D.C.: The White House, June 28, 2010), 5.

more degrees of separation between these entities. It could be that the European experiences with the Spacelab project during the Apollo Mission days was one reason that Europe determined to focus more on pan-European space projects and move away from working cooperatively with the US.

1. EUROPE GOES IT ALONE

The first flight of Spacelab took place in 1983 and was designed and built in Europe. Its purpose was to be used in concert with the US Space Shuttle and represents the high point of combined US-European space exploration efforts although it is viewed by some Europeans as being conducted under unfavorable conditions. At issue was the US military's reluctance to approve multinational projects that had dual-use purposes because of the potential for illegal or unwanted technology transfers that might reduce the US advantage in space technology or threaten US national security interests. The specter of dual-use technology being transferred to other state players remains into the 21st Century as a major stumbling block to international cooperation in space exploration between the US and other international actors including the EU.

By the end of the 20th Century Europe had fielded its own space delivery system, the Ariane rocket, and had had a major success with the Spacelab. As European states continued to integrate so did the European space industry and there was increased confidence in European capabilities to 'go it alone' on larger and more complex projects.

The United States has held numerous rounds of negotiations with the EU and the Government of Japan on the establishment of a global standard for GPS. According to an early 1998 report, these negotiations are a prelude to agreements covering the following shared objectives:

- The global use of GPS as a world positioning, navigation, and timing standard;
- Expanded civil GPS use within the context of mutual national/regional security interests;
- Harmonization of standards and acceptance procedures for GPS technologies, equipment, and services;
- Adequate frequency allocation and protection from encroachment for GPS signals;
- Elimination of potential barriers to the growth of commercial GPS applications; and
- Development of information infrastructure in the transatlantic region by facilitating growth in trade and investment in GPS equipment and services.[49]

The Volpe Report of 2001 addressed other Global Navigation Satellite Systems as potential backups to GPS. Commenting on Galileo specifically, the report found several issues with the design of that system that was still in the definition stage of development at that time. The report raised issues with the proposed range of frequencies being proposed by Galileo designers. "Should these frequencies be chosen," according to the report, "it would appear that interference/jamming of GPS might well affect Galileo as well, thereby greatly reducing its ability to serve as a backup to GPS. In addition, Galileo's satellite signals will be about as powerful as GPS, making them also easy to jam."[50]

2. SELECTIVE AVAILABILITY

One of the primary justifications for the EU undertaking such a massive project to design, build and deploy the independent Galileo system was because of the potential

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[49]"Biennial Report to Congress on the Global Positioning System", National Executive Committee, (Washington, D.C.: 1998), 4. http://www.pnt.gov/public/docs/1998/biennial1998.shtml

[50] Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System, Volpe, 6.2.2, 53.

unreliability of the GPS signal and resultant location fixing capability. Early GPS satellites that broadcast SPS on a single carrier, the L1, were supposed to be less accurate than the PSP military signals broadcast from both the L1 and L2. In practice however, both signals were nearly equal. This prompted DoD to initiate something called selective availability or SA on the Block II satellite SPS signals.

What that means basically is that a receiver cannot accurately determine its exact position as is normally possible because the transmitter is purposely transmitting a decayed or erroneous signal. This SA feature was controlled by DoD and was used to ensure that Threat forces could not use GPS signals as an enabler against the US. However, it also meant that the accuracy of the signals were less than optimal for all civil applications as well.

President Bill Clinton, after close consultation with DoD, announced that SA would be switched off altogether in May 2000. That action significantly improved the accuracy of the SPS signals on a global basis. In September of 2007, President George W. Bush ordered the SA capability of GPS to be permanently deleted from the menu of options offered by the next generation of GPS Block III satellites thus eliminating one of the most contentious issues promulgated by global users against the US GPS.

3. GALILEO AGREEMENT

Negotiations on the design and selection of the carrier frequencies identified in the 2001 Volpe Report as a major point of contention between Galileo and GPS carried on for several years until agreement was reached that satisfied both entities. With the major differences and objections mitigated by negotiation, US Secretary of State Colin

Powell and EU Vice President Loyola de Palacio signed the Galileo Agreement at Shannon, Ireland, on June 26, 2004. This agreement between the US and the EU guaranteed interoperability of standard systems between GPS and Galileo. In her remarks, EU Vice President de Palacio said that both signatories had pledged to "set the world standards in the market through the use of the same open signal. This will allow all users to use in a complementary way both systems with the same receiver."[51]

During the same ceremony, Secretary Powell agreed with the Vice President's remarks and added that Vice President de Palacio "understood the importance of protecting allied security interests and ensuring that Galileo was compatible with the US Global Positioning System."[52] Secretary Powell reinforced the notion that the US position considers security issues to be of paramount importance and that the EU position is focused on the civilian and commercial aspects of the competing systems.

The agreement's objective was to provide for substantive cooperation amongst the signatories in the application of GPS and Galileo signals and services to support peaceful, commercial and scientific purposes without losing sight of the need to ensure all mutual security interests.

The RAND Corporation study on GNSS for the US Air Force in 2005 suggested that the cooperative spirit of the Galileo Agreement of 2004 was not as straightforward as it was written into the agreement. RAND cited the specified goals of the Department of State's Office of Space and Advanced Technology to ensure current US space policy was congruent with national security strategy, national economic policies, preservation of US

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[51] "Remarks at the Signing of the Galileo Treaty", (US Department of State: Shannon, Ireland, 2004).

[52] Ibid.

outer space leadership, and to ensure US manufacturers remain competitive in space related products. That being said, RAND proffers the following analysis writing that:

> "the goal of enhancing US space leadership and aerospace industry competitiveness appears to be incompatible with efforts to foster greater cooperation with the EU, which has its own goals of leadership and competitiveness for the EU countries. The State Department has expressed concerns about (1) European regulations and standards that may effectively mandate use of Galileo, and (2) opportunities to provide navigation products not being made equally available to all manufacturers, and (3) Galileo's strategic and military implications."[53]

Language was inserted into the agreement to bolster spirit of cooperation "to further ensure radio frequency compatibility and non-military service interoperability, the Parties shall ensure that their augmentations meet the requirements of ICAO, IMO and the ITU to which such Parties are bound and such other requirements as the Parties may find mutually acceptable."[54]

In this case the Agreement was referencing the International Civil Aviation Organization or ICAO. The ICAO sets standards and recommends practices for the safe and orderly development of international civil aviation. Its ongoing mission is to foster a global civil aviation system that consistently and uniformly operates at peak efficiency and provides optimum safety, security, and sustainability.[55]

IMO is the International Maritime Organization. It is the United Nations specialized agency with responsibility for the safety and security of shipping and, among other things, the prevention of marine pollution by ships.

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[53] Rosalind Lewis et al, *Global Navigation Satellite System: An Initial Look*, (Arlington: RAND Corporation, 2005), 31.

[54] EU/USA Agreement: Promotion, provision and use of GALILEO and GPS satellite-based navigation systems and related applications, (County Clare, Ireland, 2004), Art 4, Para 2. http://www.pnt.gov/public/docs/2004/gpsgalileoagreement.pdf

[55] http://www.icao.int/icao/en/strategic_objectives.htm

The US Government had previously offered GPS to ICAO and the IMO in anticipation of having GPS established as a core component of any future space-based PNT system recognizing that it will take a number of years to reach the goal of a cooperative and interoperable global system. Both organizations have accepted the offer and have made GPS their organizational standard for PNT services.

The third major regulating body referenced by the Agreement is the ITU or the International Telecommunication Union headquartered in Switzerland. The ITU establishes a binding, global framework for international telecommunications and sets forth the structure of the Union as well as its diverse and far-reaching activities promoting telecommunications. It will "effect allocation of bands of the radio-frequency spectrum, the allotment of radio frequencies and the registration of radio-frequency assignments and, for space services, of any associated orbital position in the geostationary-satellite orbit or of any associated characteristics of satellites in other orbits, in order to avoid harmful interference between radio stations of different countries."[56] In other words, the ITU is the global assignment and adjudicating agency that monitors and polices the radio waves and ensures that there is some semblance of global order with regard to radio frequency usage and ownership.

F. FUTURE CONSIDERATIONS

The 2004 DoD report to Congress updated the pace of future program modernization efforts and detailed the rebranding of the eight remaining Block IIR satellites to Block IIR-M with the inclusion of one new military signal and a second civil

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[56] International Telecommunications Union, *Constitution of ITU,* (Geneva: ITU, 2011), Chapter I, 2.a, 98. http://www.itu.int/net/about/basic-texts/constitution/chapteri.aspx

signal. The report offers a strong warning to the Congress that "should GPS IIF launches be delayed, sustainment of the GPS constellation will be difficult, and the Government could fail to meet performance levels prescribed in published federal plans and standards"[57] Block IIF deployments remain nearly eight years behind original projections. The final phase of the current modernization plan is the deployment of GPS III. Originally scheduled for deployment sometime after 2012, and then to 2014, this block of satellites will improve accuracy, integrity, anti-jamming capabilities, and availability as well as meet the projected requirements of all current civil and military needs. The Joint Requirements Oversight Council (JROC) of the Joint Chiefs of Staff validated the initial capability development documents for the Block III modernization on August 4, 2005.

The first contract was awarded for Block III units in May of 2008 with an expected first launch date slipping again from 2013 to 2014. The Block III effort is projected to cost American taxpayers about $8 billion dollars. The Boeing Company is contracted to build 12 satellites and Lockheed Martin is contracted to build an additional 18 as a full replacement of the current constellation. When operational, it is expected that the new Block III units will provide location information down to a couple of feet and will have atomic clocks accurate to a fraction of a billionth of a second.[58]

The proposed modernization effort, from a DoD perspective, remains complex and challenging. The Block III system should have "effective space, control, and user segment capabilities to protect US and allied ability to utilize GPS in combat, and enable

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[57] "Report to Congress on Global Positioning System (GPS) 2008", Department of Defense, (Washington, D.C.: October 2008), 1.

[58] W.J. Henningan, "GPS is getting an $8-billion upgrade", *Los Angeles Times*, May 23, 2010. http://articles.latimes.com/2010/may/23/business/la-fi-gps-20100523/2

denial of hostile use of space-based PNT without unduly disrupting peaceful use outside an area of military operations."[59]

1. ACQUISITION CHANGES

In 2004, NSPD-39 made one significant change to the evolution of future generations of GPS satellites, specifically to the Block III modernization. NSPD-39 changed the acquisition procedures for Government development and deployment of GPS satellites. It directed that "Global Positioning System civil signal performance monitoring, augmentations, and other unique positioning, navigation, and time capabilities will be funded by the agency or agencies requiring those services or capabilities." This directive greatly decentralized control of satellite content away from DoD and layered it across other interested Government stakeholders. Deconfliction of content disputes was pushed to the Executive Committee (NPEC) for resolution or action.[60]

This policy change was first implemented with the FY08 Department of Transportation budget. DOT set aside $7.2 million as its part of the Block III modernization effort and the upgrades to the modernized ground control segment (OCX). DOT set aside another $20.7 million for the FY 09 budget and has an expected five-year civil set aside of more than $200 million for FY 09-13. The FY08 allocation comes from the Federal Aviation Administration (FAA) and the Federal Highway Administration (FHwA) individual budgets.

[59] "Report to Congress on Global Positioning System (GPS) 2006", 5.

[60] "NSPD-39 U.S. Space-Based Position, Navigation, and Timing Policy", (Washington, D.C.: The White House, December 15, 2004), 5.

One of the challenges facing any Government that supports satellite operations is the cost of maintaining them in orbit and being prepared to replace them in a timely fashion as their lifespan ends in space and they become another piece of space junk. In spite of US leadership in space technology there still exists significant problems in the research, design, build, and deployment of new satellites. An argument could be made that the basic issue is risk mitigation due to the potential for mission failure. Not only does a failure to deploy, for whatever reason, represent the loss of a significant amount of money but it also means that a replacement mission will take a significant amount of time to build and launch.

The RAND study back in 2005 foresaw the difficulties in keeping pace with technology growth in applications for GPS. As previously discussed, GPS is and will continue to be a military asset designed to support the national security of the United States. The question of civilian advances and loss of operational security presents great challenges to scientists and the Government. The RAND study opined that closer cooperation with the EU could lessen the burden on the US and still provides the global services required by the civil community. The study stated that "both the GPS and the planned Galileo system are trying to provide a level of robustness and service that is difficult to meet individually but may be more easily achieved jointly. A combined system may allow both the United States and the EU to provide high performance and robustness without maintaining the current 24+ satellite constellation at all times."[61]

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[61] Lewis et al, 69-70.

2. CURRENT DIFFICULTIES

GPS was in bigger trouble by 2009 as the timetables for replacing older satellites with newer models was three years behind schedule and $870 million dollars over an original budget of $729 million. A GAO study, GAO-09-670T, found several disturbing issues with the deployment of the next generation of GPS satellites. In one finding the GAO discovered the Air Force had changed contractors and was having difficulty with the new contractor. Another finding shows the program was having difficulty keeping senior managers on the job and that this was causing stability problems within the program. Along those same lines the GAO criticizes Air Force acquisition as not having a single point of failure within the program and that "diffuse leadership has been a contributing factor, given that there is no single authority responsible for synchronizing all procurements and fielding related to GPS."[62] The report also identified challenges facing the program with potential compatibility problems inherent in the next generation of GPS with other global based systems.

Another area of great concern found by the GAO was the fact that the Air Force had not synchronized its effort in order to ensure that ground based support requirements were being modernized to meet the scheduled deployment of the next generation of satellite. What this means specifically is that there will be satellite capabilities that are available to the user segment that cannot be accessed because the ground segment has not been sufficiently upgraded. In one case a modernized signal is being made available to the military that is more resistant to jamming. However, upgrades to the OCS will not be completed for at least ten years therefore denying the military access to the new signal

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[62] GLOBAL POSITIONING SYSTEM: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities, GAO-09-670T, (Washington, D.C.: Government Accounting Office, 2009), 1.

until the user equipment is upgraded. This is partly the result of decentralization of the acquisition process and a failure to synchronize the efforts of every facet of the project.[63]

3. THE FUTURE IN SPACE FROM SPACE

Future developments in GPS capabilities being used in space were highlighted in the 2004 DoD report to Congress. The report discussed NASA's continuing research into the application of GPS systems to systems beyond or above the GPS array. Research was being conducted on the possibility of relying on GPS data to increase the density of satellites over certain portions of the globe that might have strategic national interests for the US. There were projects being implemented to study how GPS signals could be used in support of future manned missions back to the Moon and beyond to Mars.

NASA began installing GPS PPS receivers in Space Shuttles beginning in late 2006. It was first used in navigation as a back-up system with STS-115 Atlantis in September 2006 and was used as GPS-only navigation for STS-118 Endeavour in August 2007. The International Space Station has a four-antenna array deployed specifically to support Shuttle missions with orbit and attitude determination.

Another significant capability developed by NASA that became operational in October 2006 is the Global Differential GPS (GDGPS) augmentation. This application was designed to support NASA science projects and offers a phenomenal 10-20 centimeter positioning accuracy for authorized users with dual-use receivers anywhere on the ground, in the air, or in space.

The 2010 Space Policy of the US provides several of these directives to NASA. The current policy directs NASA to begin crewed missions beyond the moon, including a

[63] Ibid, 6.

manned visit to an asteroid and then follow-on manned missions to Mars and back in the 2030's.

4. SEARCH AND RESCUE

GPS has also supported the existing Search and Rescue Satellite Aided Tracking (SARSAT) system and its Russian equivalent, COSPAS, that is responsible for saving over 20,000 lives worldwide. The SARSAT/COSPAS system is projected to degrade as early as 2013 due to end of life cycles for its primary satellites. The 2008 DoD report to the Congress details a proposed US SARSAT replacement called DASS or Distress Alerting Satellite System. NASA has developed proof-of-concept demonstrations on deployed GPS satellites as well as a test ground station located at the Goddard Space Flight Center in Maryland. This proof-of-concept DASS has been installed on all Block IIR-M and IIF satellites. It has been identified as a strong candidate as a secondary payload on GPS III satellites.[64] There seems to be a commitment from the US government to ensure the uninterrupted continuation of SARSAT/COSPAS into the future.

G. CONCLUSION

GPS modernization is at a crossroad in 2012 and continues to receive attention at all levels of industry and government because of the ubiquitous nature of its mission. Funding levels are under pressure due to reduced budgets. The Obama Administration, perhaps recognizing the difficulty in maintaining GPS as the one and only world

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[64] "Report to Congress on Global Positioning System (GPS) 2008", 12.

standard, is looking outward to the international community to ensure the system is compatible and interoperable with emerging systems in recognition of a new order of GNSS players. If history is any gauge then getting GPS III fully deployed and operable within its budget and within a reasonable timeframe is going to be a herculean task for the Government and its contractors.

There are subtle signs out there that might indicate that some aspects of the DoD procurement system are reforming. Just recently, according to the Denver Post, the US government levied a multi-million dollar penalty on Lockheed-Martin, the prime contractor for GPS III satellites. The article reported that "Lockheed Martin will lose its entire fee of about $70 million to defray an 18 percent cost overrun on the first Global Positioning System satellites of a new design, according to the Air Force. Cost incentives on the contract caused Lockheed-Martin to lose the fee, although the government continues to bear the cost-risk for development and production of the first two satellites."[65]

The first two satellites are projected to cost in excess of $1.5 billion with the first of 32 scheduled to be launched sometime in 2014. The cost of succeeding satellites is projected to be about $119 million per copy. The larger issue is the fact that the program is years behind schedule and, if that delay is extended, it could cause significant problems for the Nation in several different areas.

There is no doubt that the government and the space industry would like to see GPS III maintain its preeminence in the global PNT business. The big question is whether or not the government, in concert with private industry, can deliver the goods in

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[65] Denver Post staff, "Lockheed takes $70 million hit over GPS III satellite overruns", *The Denver Post,* April 23, 2012. http://www.denverpost.com/business/ci_20411085/lockheed-takes-70-million-hitover-gps-iii-satellite

a timely fashion. There are voices in government that have doubts about the US capability to deliver this crucial capability.

Going back to a GAO report from 2009, page two lays out a stark reminder to the Congress on the problem. It says "it is uncertain whether the Air Force will be able to acquire new satellites in time to maintain current GPS service without interruption. If not, some military operations and some civilian users could be adversely affected."[66] What is unsaid in the report is the effect that any kind of preventable interruption would have on the reputation and perception of reliability of GPS across the globe in a time of increasing GNSS competition for services and user equipment. The GAO again points to problems in the acquisition process and suggests the deployment schedule for the GPS III vehicles is too optimistic. If true, and if the delays and cost overruns continue with the IIF models, it may be that the unthinkable will occur and the US will be left in the dark, so to speak, for PNT services.

As stated earlier in this chapter, a large percentage of the current GPS constellation is operating beyond its life expectancy. There is an expectation of perhaps 12 more GPS IIF satellite launches out to 2018 in an effort to maintain the minimum requirement of 24 operational satellites in orbit. Here is the rub; the Air Force does not use the engineered design life of each space vehicle and its components as a measure of its expected service. It now uses a computer model called GAP or Generalized Availability Program to predict the mean time failure of the various components of each satellite. The predictions are based on statistical computations of previous failures and

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[66] United States Government Accountability Office (GAO), *Report to the Subcommittee on National Security and Foreign Affairs, Committee on Oversight and Government Reform, House of Representatives: GLOBAL POSITIONING SYSTEM, Significant Challenges in Sustaining and Upgrading Widely Used Capabilities.* (Washington, D.C.: Government Accounting Office: April 2009), 2.

provide a confidence level the Air Force is willing to accept for the continued reliability and availability of the current GPS.

Acknowledging the computer model as a basis for its predicted future and the possibility of losing service, Steve Huybrechts, a director in the office of the assistant secretary of defense for network and information integration, testified in 2009 that "we shouldn't be sitting here thinking that all the GPS receivers are going to stop working. What you're going to get is a slight degradation in performance over small portions of the world over short periods of time compared to today."[67] This testimony is nothing short of a reiteration of the GAO study except that it comes from the office that has responsibility for the operation of the system. Does this mean that after 20 years of unequaled superiority, the government is accepting the fact that GPS may be moving into a period of decline?

Another issue that has yet to be resolved is the seeming disconnect between the design/development/deployment of the GPS III space vehicle and its required ground control segment upgrade. The Air Force admits the two system components are not synchronized. In the past, resources have been shifted from the user equipment and ground segment components to the space component in an effort to speed the development of that segment but at the expense of the other segments.

The major question is whether users are going to have the capacity to capitalize on the improved capabilities of GPSIII or not when those capabilities become available. The Air Force is still working to find resolution to this troubling issue. At stake are billions of dollars worth of user equipment sales and thousands of jobs all across the

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[67] Glen Gibbons, "GAO Report on GPS Satellite Constellation Status: The Pushback", *Inside GNSS*, May 25, 2009. http://www.insidegnss.com/node/1527

United States as China, Russia, and the EU attempt to acquire the mantel of GNSS 'gold standard'.

This part of the history of GPS is waiting to be written and its outcome is incredibly important to US national security and its economic vitality going into the 21st Century.

CHAPTER III

GALILEO

A. INTRODUCTION

It does not initially seem intuitive that the European Union (EU) would be interested in fielding an entirely new space-based positioning, navigation, and timing system that would compete with the American GPS on a head-to-head basis. Why? Because the American GPS is a free service offered globally to anyone who has a receiver capable of receiving and processing its signals. GPS is also a proven system with three decades of exceedingly dependable service. The EU has been relying on GPS for most of those three decades and much of the European civil and military equipment sets that rely on GNSS signals for operation are designed and built to work with GPS.

Another consideration against a European stand-alone system is the economic aspects of building a new space-based system from the ground up. It is tremendously expensive to build satellites and their launch vehicles in order to populate a satellite array that needs anywhere from 24 to 30 satellites in orbit at all times. European states, especially France, Germany, Italy, and Great Britain, are well aware of the costs and the risks associated with designing and building new space systems with cutting edge technology as they are the resident national leaders in designing and building European space systems.

On the flip side of this argument is the notion that designing and building a new space system with cutting edge technology will concurrently generate a huge number of high tech and high paying jobs for those nations and corporations actually doing the work and providing an eventual fair return on initial investment of public and private resources.

This chapter will look at the Galileo Project, Europe's alternative to America's GPS. The chapter will begin with an overview of the European policy making organizational bodies and how they intersect with Galileo. There will be a short history of Galileo going back to its genesis and its conceptual requirements. There will be discussion on the challenges facing the project and a detailing of the major stakeholders from the early days of the project through its multiple iterations and phases. Another section of the chapter will look at the national security interests of the EU as they apply to Galileo and then, more importantly, a look at the domestic and economic impact that Galileo has had on the EU over the course of its unfinished journey toward fruition. Finally there will be a tally of the overruns, both in cost and in delivery dates, which have flummoxed the European Commission (EC) and the European Parliament (EP) for years. The chapter will end with a look at the future of Galileo and whatever conclusions might be discerned from the research.

B. THE EUROPEAN SPACE AGENCY (ESA)

The ESA is the major governmental entity involved in European space policy and as such, it is important to understand its genesis and functions in the European Union context. The convention for the establishment of the ESA was approved in conference by the EP on May 30, 1975. The text of the convention optimistically addressed many of the issues that would prove challenging for Europe to deal with in the coming decades. At that time, the 15 member states agreed that developing a unified capacity in space was one of their major goals for the ESA. It was agreed that the ESA would work toward the peaceful uses of space only and would steer clear of national security issues facing member nations. It was also agreed that the Agency would place its emphasis on space research and development and allow industry to focus on the marketing, manufacturing, and business end of space projects. This organizational structure and policy put the ESA in stark contrast to NASA in the United States. NASA was clearly a dual-use agency that worked at once with DoD and with other civil and academic entities on space-based projects. NASA partnered with the private sector on the peaceful exploration of space and with DoD on its sensitive and classified national defense missions.

Although the then 15-member European Union had officially authorized Galileo in 1999, a case can be made that it was actually projected as a component of an autonomous space program envisioned by the board of the ESA back in the early 1980's. There was a clear recognition that there was a need to unify the efforts of the industrial base of Europe if Europe was to compete on the world stage in space technology and space-based systems. The ESA Council of Ministers adopted a large slate of successor projects in 1985. One area that was seen as crucial to attaining the autonomy that the EU was seeking was the development and expansion of "the uses of satellites for telecommunications, observation, navigation, and meteorology, and thereby strengthen its technological base and international competitiveness."[1]

The biggest difference between the ESA and NASA was that NASA was involved with nearly every aspect of US space projects and could be considered the central repository for America's collective knowledge of space systems. The ESA, on the other hand, was destined to work only on the peaceful uses of space while each EU member

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[1] Helen Wallace, "Building a European Space Policy", *Space Policy* 4, iss. 2 (1988): 118.

state or coalition of states could design and operate space systems as they considered necessary to support their specific national security purposes. This distinction put the ESA at a significant disadvantage insofar as its cumulative institutional knowledge of space and space-based systems was less than it should have been when it assumed sponsorship of Galileo.

During the 1980's the ESA executive board was looking ahead to future decades. They identified four major pillars necessary to support future proposals. First, they were confident that ESA should continue to function primarily as an R&D organization; second, the recognition that end users needed to be involved in every project from the beginning to culmination; third, that ESA and member state national projects must be complementary and to insure that they were not competitive with each other and wasting resources; and finally that the ESA remain a critical component in the development of European industrial capabilities and increasing its global competitiveness.

Initially, the ESA goal was to be considered a "qualified partner" with Japan and the US for major international space projects.[2] At this time the Cold War was providing its share of global tensions and cooperation with the Soviet Union on space projects was out of the question. As will be seen in the next chapter, a number of states besides Russia, including China, India, and Japan began investing significant resources in succeeding decades in space and space-based projects and with those investments came new opportunities for EU and ESA engagement.

Furthermore, in 1985 there was a redefinition of interests and the ESA adopted a multi-decade program to produce several future generations of space projects with the

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[2] John Krige and Arturo Russo and Lorenzo Sebesta, *A History of the European Space Agency 1958-1987, Volume II*, (The Netherlands: ESA Publications Division, 2000), 65.

object of insuring European autonomy in space. The ESA grappled with the fact that over the past thirty years the major states with space programs, UK, France, Germany and Italy, had applied huge amounts of financial and human resources to work bi- or multi-laterally in order to maximize their individual returns on investment and minimize their inputs to the ESA in the name of national security.

This had become a particular problem for the smaller states, as they were not on the receiving end of any real participation in the larger space projects. These smaller states were forced, by size, to work within the confines of the ESA charter. The bigger issue for the larger players is the "fair-return principle" policy of the ESA Convention that greatly affects the international competitiveness of ESA projects.[3] The general consensus among European member states regarding the 'fair-return principle' is that each state will receive a proportional return in corporate contracts or man-hours of labor against whatever resource contributions the state makes in the name of a project. This formula certainly preserves the status quo of manufacturing capabilities but makes it very difficult for smaller and poorer states to participate in current projects or to have an opportunity to grow their domestic industrial sectors.

Throughout the 1980's and 90's the larger member states continued to develop and protect their own industrial capabilities until eventually there came a recognition that the European space industry was in danger of losing its ability to operate in space autonomously if significant changes were not made. The recognition of the need for future change provided the impetus for Galileo's introduction as the possible engine for that change.

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[3] European Space Agency, *Convention for the Establishment of a European Space Agency*, (Paris: European Space Agency, 1975), Annex V, Art II.

EUROSPACE, the Association of the European Space Industry, had conducted an exhaustive study in 1998 that focused on what the impact of one global positioning system, controlled by the military of one nation, might have on the strategic independence of other technologically advanced states. The subject of the study was obviously the United States and its GPS. The report was a call to action for the European states to mobilize their resources and invest in a separate and independent system to guarantee their future industrial viability and national security. The report stated, "The existence of a world satellite navigation monopoly is liable to create a strategic dependence relationship in a substantial number of domains associated with national sovereignty."[4]

The study conclusions were hugely important to the future of the European Union generally as they pointed to the growing dependency of Europe on the largesse of the United States in areas that were of critical importance to European high tech industries and their future viability.

Potential strategic dependency existed on two levels according to the report. First, it directly invokes a dependency on the actual users of the system who have no other options. More importantly is the second level. This would be the impact of having to rely on a positioning system, controlled by others, as the basis for the design of new technologies and systems. Future innovations on land systems, civil air fleets and space technology will all rely to a large extent on consistent and reliable positioning, navigation, and timing signals. That means that in order for Europe to truly control its

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[4] EUROSPACE, "European Strategic Dependence as Related to Space Technology", *Navigation, Air & Space Europe* 1, no. 2, (1999): 45.

own destiny in industrial technology development and state security it was going to have to have a captive GNSS system.

From a state security perspective the report was strident in its comments. Regarding GPS generally, it states, "its direct applications which are liable to impose GPS progressively as a mandatory technical base for programmes which traditionally constitute the hard core of national sovereignty (military and civil/aerial)."[5] The meaning was clear, Europe was going to have to grow its own GNSS, regardless of cost, or it was going to be relegated to playing second fiddle to the United States in critical infrastructure and security areas. The EUROSPACE report was released just as the EU states and the ESA were negotiating approval of the Galileo Project. It seems reasonable to assume the report impacted favorably on the negotiations.

The 9/11 attack on the World Trade Center prompted the United States to attempt to force the EU to cancel its plans to build Galileo strictly for national security purposes. The US military was very concerned that enemies of the US could use Galileo services to launch further attacks and that the US would not be in a position to block Galileo signals thus rendering those enemy cells incapable of gaining positioning and navigation signals. Officials from the US and the EU met in conference several times between early 2001 and 2002 trying to iron out differences. At one point in the process, it appeared the US pressure would prevail causing EU press spokesman Gilles Gantelet to announce that "Galileo is almost dead." Shortly after that Jacques Chirac, President of France, was

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[5] Ibid., 50.

quoted as saying the failure of the Galileo project "would lead inevitably to a vassal status, first scientific and technical and then industrial and economic."[6]

This was a significant moment for the entire project. Complaints from the US centered on the actual signal frequencies proposed by Galileo's designers. The US maintained that the frequencies were too closely aligned with current GPS frequencies making it impossible for the US to block Galileo signals without blocking GPS signals as well. Everything revolved around US national security interests and the continued ability of the US to regionally block space navigation signals when required. This was a huge issue and was finally resolved when the ESA reconfigured its design parameters and increased separation of signals between Galileo and GPS thus acceding to US demands allowing the US, if it chooses, to block Galileo signals without degrading GPS military operations. Conversely, by moving to different frequency bands, the ESA created a situation where the EU also had the option of blocking GPS signals if it chose to do so.

The underlying need for a truly autonomous space program was to be a driving force for the ESA and the EU in general, into the 21st Century. With recognition of the need for an upgraded global positioning system, the ESA and its industrial partners came up with an outline of capabilities that they believed would provide Europe and Europeans with a new degree of space independence and, at the same time, provide the world with a system that would be a benefit to all peoples.

[6] Steve Kettman, "Europe GPS Plan Shelved", *Wired Magazine*, January 17, 2002. http://www.wired.com/politics/law/news/2002/01/49778

C. GALILEO COMES TO LIFE

The European Council officially proclaimed the launch of the European Civil Satellite Navigation Programme called GALILEO on March 26, 2002. With that announcement came the release of €1.1 billion in public funds by the EC and the ESA for the first phase of the project. This phase would be referred to as the Definition Phase. It is noteworthy that this project was the first of its kind in that it attempted to unite all EU member states and the ESA in a common space project. It had taken three years for all of the member states to agree to Galileo after negotiations began. There was a general consensus among states that there would be a significant economic boost from Galileo and that it would also have significant political and social ramifications in future years. It had been a long and difficult journey to get Galileo moving to the approval stage.

In order to understand how Galileo developed it is important to understand that it is a product of an increasing realization by the EU of the need for a captive stand-alone Global Navigation Satellite System (GNSS). The system was originally envisioned as consisting of two phases; GNSS 1 and GNSS 2.

GNSS 1 was the development and fielding of an intermediate system, referred to as an augmentation, designed to support and improve signals from the American GPS. The augmentation was called the European Geostationary Navigation Overlay Service or EGNOS and would consist of three satellites and a series of ground stations across Europe and would augment GPS coverage across all of the European landmass.

The purpose for this phase of the project was to improve the accuracy and reliability of GPS when applied specifically to the civil aviation industry in Europe. The system would not operate independently from GPS but in concert with GPS. EGNOS was approved by the EU in 1994 and reached full operating capability in 2005. It was never considered as anything beyond a civil aviation or maritime safety of life complement to the American GPS. One of the primary functions of EGNOS was to insure the reliability and the accuracy of the GPS signals and to notify users of signal errors in order to satisfy civil aviation and maritime safety requirements.

EGNOS was a European Space Agency (ESA) project from the start with financing from a variety of public and private bodies that had a vested interest in improving the safety and reliability of the European civil transportation industry.

One of the earliest official references to the need for a larger and more complete GNSS comes from an EC resolution in 1992 that states that the Council will "pursue its work with a view to setting up a radio-navigation plan which takes into account the development of satellite navigation systems, of existing terrestrial systems and of the radio-navigation plans of the Member States."[7] The first formal study on stand-alone satellite navigation options for Europe was funded by the European Commission Directorates-General of Transport and Science and Research and Development in December of 1992. The study was completed and circulated to all members of the Commission for consideration and future action. A couple of years later, in 1994, the Council of the European Union asked the Commission to begin the process of developing a stand-alone European GNSS.

The Council passed another resolution in 1994 asking member states and private industry to "define the requirements of all potential (GNSS) users and describe the

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[7]European Council, *COUNCIL DECISION of 25 February 1992 on radio-navigation systems for Europe (92/143/EEC)*. (Brussels: 1992). 1. http://eur-lex.europa.eu/Notice.do?mode=dbl&lng1=en,en&lang=&lng2=bg,cs,da,de,el,en,es,et,fi,fr,hu,it,lt,lv,mt,nl,pl,pt,ro,sk,sl,sv,&val=185659:cs&page=&hwords=null

resulting possibilities and to initiate and support the preparatory work needed for the design and organization of a global navigation satellite system for civil use."[8]

By 1998, the Council had put the issue of the European space industry's economic vitality clearly in focus by stating that "Europe's capacity to compete in the potentially lucrative market for services would be undermined if it did not have equal access to the technological developments in the system itself, and the US in particular shows every sign of using the strategic advantage provided by its military positioning system (GPS) to establish a dominant position in the world market for systems and services."[9]

GNSS 2 was to be the development and deployment of a stand-alone GNSS of up to 30 satellites in a three-plane medium earth orbit (MEO) array at about 23,000 km circling the globe and providing positioning, navigation, and timing information to a network of ground stations and to anyone with a receiver programmed to process the signals. This is the system that would eventually become Galileo. So where did Galileo come from and what will it do for Europe and the rest of the global commons?

The first time that Galileo as a named project was formally presented to the EU was in February 1999 when the EC asked the member states to move forward as quickly as possible to approve and develop the next generation of GNSS that they called Galileo. Neil Kinnock, Commissioner responsible for Transport Policy, said when addressing EC members:

> "As the Internet has revolutionised electronic communication so global satellite systems are revolutionising navigation. Europe must put itself in a position to

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[8]European Council, *Council Resolution of 19 December 1994 on the European contribution to the development of a Global Navigation Satellite System 94/C 379/02*, (Brussels: 1994). 2. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:1994:379:0002:0003:EN:PDF

[9] Communication From The Commission To The Council And The European Parliament, *Towards a Trans-European Positioning and Navigation Network,* (Brussels: 21 January 1998). 5. http://aei.pitt.edu/6801/1/6801.pdf

> capture a fair share of a world market that could be worth an estimated 40,000 million Euro within a few years and would offer the potential to generate quality jobs. Europe must also have control of the systems on which safe movement by air, land and water transport will increasingly depend. But that cannot happen without combined and consistent political action. Failure to act now would mean missing a huge and probably unrepeatable opportunity. The investment needed less than 3,000 million Euros is not unbearable since it would be spread between 15 Member States over ten years. The returns would be immense."[10]

1999 was a watershed year for the EU and the actual realization of a stand-alone European GNSS. One of the first important events that year was the issuance of Council Resolution of 19 July 1999[11] that authorized the initiation of the Definition Phase of the project that formally began the EU affair with Galileo.

Galileo's conceptual genesis was solidified in 1999 when engineering proposals from Great Britain, France, Italy and Germany were each compared and then distilled into one cogent proposal for a new generation of a stand-alone global navigation satellite system.

The Galileo satellite array design would differ significantly from the GPS array with GPS array having six orbital planes in MEO as opposed to the three orbital planes that were planned for Galileo (Figure 11). As originally proposed, another eight Galileo satellites would eventually be launched into geostationary earth orbits (GEO) in order to compensate for certain coverage shortfalls resulting from the adoption of a three plane orbit array. However, the GEO array was not anticipated to be deployed until well past the Operational Phase of the current Galileo project. EGNOS and Galileo would not be mutually dependent. EGNOS was designed to have the same affiliation with Galileo that it shares with GPS.

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[10] Europa Press Release RAPID, IP/99/102, (Brussels: October 2, 1999), http://europa.eu/rapid/pressReleasesAction.do?reference=IP/99/102&format=HTML&aged=1&language=EN&guiLanguage=en

[11] Official Journal of the European Communities, *COUNCIL RESOLUTION of 19 July 1999 on the involvement of Europe in a new generation of satellite navigation services-Galileo-Definition phase,* (Brussels: March 8, 1999). C221/1. http://www.etsi.org/WebSite/document/aboutETSI/EC_OJ_Council/Council_221_01.pdf

Galileo was presented to the EP as an opportunity to consider a new global positioning system independent of US or Russian military control that was being offered not only as a system for greater European autonomy but also as an economic engine for European workers and companies. Galileo was seen as being able to better respond to civil demand because it was designed with a civilian oriented infrastructure. It also possessed the innate design capability to enhance the security of one or all EU member states if the situation called for it without having to rely on US capabilities.

As envisioned in 2002, Galileo would consist of a constellation of 30 or more satellites providing significantly upgraded and more accurate positioning, navigation, and timing services to its customers than from GPS or Russia's GLONASS systems currently in play. The issue of accuracy cannot be overstated. In 2001 for example, GPS transmitted its signals on two levels. One for the military called the Precise Positioning Service or PPS that was encrypted and not available for civilian use and a second signal, called the Standard Positioning Service or SPS, was allocated specifically for civilian use. At the time, SPS was considered accurate to 36 meters horizontally and 77 meters vertically.[12] From a safety of life perspective relative to civil aircraft operations, these accuracy parameters were certainly less than optimal. EGNOS was created to address that issue and is one area that Galileo was offering significant upgrades in service. Galileo's developers were projecting accuracy in the one meter range horizontally and vertically. Coupled with this much greater accuracy would be a service guarantee from the operators that would provide timely alerts to the user if there were errors in the generated data.

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[12] Asst Sec of Defense, Global Positioning System Standard Positioning Service Performance Standard, (Washington, D.C., October 2001), 13.

Folks at the ESA knew that Europe had a great opportunity to take the lead in navigation, timing, and positioning services if it could get Galileo into service early enough. The US had already announced it was working on the next generation of GPS and Russia had announced a complete upgrade of its GLONASS array. Getting Galileo operational before the other systems came on line would be in the best interest of Europe both economically and politically. With that in mind, the ESA pushed the proposed schedule to the limit and projected full operational capability of Galileo by 2008. The system would be monitored and operated by two primary ground control stations; one near Munich, Germany and the other in Fucino, near Rome, Italy.

Galileo was developed to provide five distinct capabilities that its designers believed were needed by the global user community. ESA called Galileo's first capability Open Service or OS. It would be available to anyone with the appropriate receiver without user fees. OS could be considered something equal to the general signals available from GPS or GLONASS although the signals would come with enhanced accuracy and continuity based on the fact that the technology was newer and more advanced. OS was to be the mass-market service typically used in automobile navigation systems or cell phones.

Commercial Service or CS was the second design capability for Galileo. This would be a subscription service with user fees assessed and collected. Potential customers include those who need location guarantees due to liability issues, various telecommunications applications, and most banking interests or those whose business is directly related to specific locations or time stamps are targeted for CS. The CS guarantee of service and fidelity of signal is the primary differentiator between Galileo and GPS. If the system fails there may be compensation due back to the user depending on the extent of the service contract.

There is a significant linkage between the original ESA Convention preamble of "desiring to pursue and to strengthen European cooperation, for exclusively peaceful purposes, in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems"[13] and the next two capabilities. Its designers created Galileo as an instrument of peace and, as such, there is a corresponding responsibility to provide added value to the general global population as a public service.

That being said, the third capability of the system is called Safety-Of-Life Services or SoL. There is an apparent expectation of SoL generating future revenues but the exact details are still being worked out. SoL was designed to be a subscription service that offers enhancements to public transportation, marine systems and the civil air industry with much higher fidelity and continuity than has been available from GPS or GLONASS. This capability is designed specifically as an application requiring stringent performance parameters such as civil air fleets and rail systems where near absolute accuracy is required in order to protect and safeguard the lives of the population. The service will be certified accurate and will require certified receivers for operation.

The fourth element is a Search and Rescue or SAR capability. It will be contributory in nature and is focused solely on the global humanitarian search and rescue system called COSPAS-SARSAT that has been in use since 1982. This capability will enhance and complement COSPAS-SARSAT and will not be a stand-alone feature of

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[13] ESA, "Convention for the Establishment of a European Space Agency" (Paris: October 30, 1980), Preamble. http://www.esa.int/convention/

Galileo.[14] One of the important improvements to the system provided by SAR is the ability of Galileo to receive and transmit in near real-time distress messages from anywhere on the globe. This would reduce waiting time of emergency beacon recognition for those in emergency situations from an average of one hour to only a few seconds.

The final capability of Galileo is called the Public Regulated Service or PRS. Also a subscription service, PRS will be focused on security issues across Galileo's customer base. As originally proposed, PRS was to be offered to the European Council, the European Commission, member states, some security and governmental organizations like police and fire departments, intelligence agencies, customs, or other security services across the EU as well as designated third countries. PRS could also be used for European member state or alliance military applications if necessary and has the potential to impact the European Common Foreign and Security Policy or the European Security and Defense Policy. The PRS signal is fully encrypted and designed to resist unwanted jamming or spoofing.

From a design perspective, security of the entire system was identified as the critical vulnerability and the designers have incorporated certain appropriate interference mitigation technologies and encryption requirements in order to protect Galileo from those who threaten the system or the EU whether they are terrorists, hostile entities or simply hackers looking for a challenge. Guaranteeing Galileo's operational security is of paramount importance and all signals will be constantly monitored for safety and security purposes with action plans in place to counter threats.

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[14] According to the COSPAS-SARSAT website, the system is an international satellite system dedicated to search and rescue. It has been used in thousand of SAR events and has been instrumental in the rescue of over 24,000 lives worldwide.

Space projects have historically been burdened with significant risk and Galileo is no different. Reviewing the EC pronouncements on the launch of Galileo provides an interesting perspective on the optimism that surrounded the announcement by the various stakeholders. Mr. Olivier Onidi of the European Commission outlined the thinking behind the approval process for an audience at the Institute of Navigation in November of 2002. Mr. Onidi was the head of the EC unit responsible for Galileo and for intelligent transport within Directorate General for Energy and Transport at the European Commission. He remarked that the private side of the partnership was convinced that GPS users would be willing to pay for superior service from Galileo. He opined that there was the case for a huge burgeoning market in the world outside of the US and the EU in the developing world. And he suggested that there was a belief that the new technology being incorporated into Galileo would spur the development of new innovative and technologically superior products and applications for European industry's long-term benefit.[15]

1. PUBLIC AND PRIVATE PARTNERSHIP (PPP)

The next big question for the EC and the ESA was how to get Galileo built. One of the more important and interesting project design decisions was the fact that it was to be designed and built as a Public-Private Partnership (PPP) that promised complete civilian control as opposed to the single nation military control of GPS and GLONASS. The inference from the concept was that Galileo's service would never be purposely jammed except in the case of extreme trans-European defense security issues.

[15] Olivier Onidi, "GALILEO is launched", (Portland, OR: *In Proc. ION GPS 2002*, Sept. 24-27 2002. Institute of Navigation), 245–248.

A PPP type of organizational structure is not that common to Europe but is used in some form or another in most of the developed world depending on the scope and technological requirements of the project. It is a relatively common business association in the United States. The main reason it is not seen much in Europe is that the basic premise of a PPP runs counter to the generally accepted norm of public provision generally associated with the European style social democratic welfare state. There were a total of only 79 PPP projects across the EU for the year 2001 with a combined total value of €13,315 million with the United Kingdom accounting for nearly 67% of all of them.[16] It is not surprising that the UK was the primary champion for privately financing the project against the objections of other member states. The EC decision to enter into a PPP for a project of this scope moved the EC and the ESA into unchartered waters and would eventually prove to be a completely unworkable solution.

A PPP can be proposed by the public sector or by the private sector although most are initially proposed by the public sector. The theoretical purpose of this sort of partnership is to leverage the best efficiencies of both the public and private sectors in order to complete a project that will support societal environmental or infrastructure requirements such as roads, bridges, tunnels, healthcare, education or other large community type projects. It is generally undertaken because of insufficient public resources, an unwillingness to raise public debt, or lack of public expertise coupled with a desire to spread the risk and leverage the higher operating efficiencies of the private sector.

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[16] Andreas Kappeler and Mathieu Nemoz, *Public-Private Partnerships in Europe-Before and During the Recent Financial Crisis*, (Luxembourg: European Investment Bank, July 2010), 7. http://www.eib.org/epec/resources/efr_epec_ppp_report.pdf

When PPP's are commissioned, the private sector will generally pledge a certain level of resourcing and work with the public sector through to completion of the project in return for future concessions from direct payment, user fees or taxes. The public sector will likewise pledge some percentage of the total costs and will retain ownership and property rights of the finished project. The public sector will also provide official government oversight throughout the project and its association with the project should provide national and international legitimacy as well as confidence in the eventual outcome. There is an expectation that the finished project will meet the needs of the public for the least cost and the earliest delivery.

However, with Galileo there was a need for further refinement of the typical PPP organization because this project was to be the largest and most complex PPP ever proposed within the confines of the EU. There are five generally accepted PPP variants that are used for societal infrastructure projects. They are public leverage, contracting-out, franchising, joint ventures, and strategic partnering. Distinctions between each type sometimes are blurred creating PPP hybrids.

Galileo was an example of a joint venture where the EC and elements of the European space industry proposed to enter into a collaborative agreement to design, build, finance and operate Galileo. A DBFO (design, build, finance, operate) model is the most common example of a joint venture PPP and has been used as the organizational model for a number of infrastructure improvement projects in Europe even though the PPP is not particularly common throughout the EU. The Galileo model's final structure differed rather significantly from the standard DBFO model in that the private sector was expected to build, partly finance, and operate a very complex system that had been designed and partly financed by the public sector with little or no input from the private sector.

Previous DBFO models, especially in the US, almost always include private sector inputs into all phases of the project to minimize overall risk, mitigate cost increases, or delays in the project. This was the first time that the ESA had worked closely with the EC on this large of a project and it was also the first time that the EC itself agreed to be a part of a PPP. Galileo represented the first large civil project that was being undertaken at the greater EU level as opposed to previous single- or multi-state consortiums.[17]

Two well known PPP projects that were finalized around this same time include three separate 30 year contracts for upgrades and maintenance of the London Underground worth €6.5 billion (€700 million from private concerns) and a 20 year contract to build and operate the Skynet 5 defense satellite system for the UK valued at €1.4 billion (€375 million from private concerns). On the other hand there were two other PPP's that were completed but with significant shortcomings. The first was the Eurotunnel that was completed late, was grossly over budget, and was materially under-forecast (well short of projected revenues from users) and the other was the Iridium satellite phone and communication satellite system that was completed on-time and within budget but was materially under-forecast.[18] So the record of PPP performance across Europe was really mixed and turning to a PPP for Galileo was a huge risk for the EC to undertake.

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[17] Ibid., 13.

[18] Michael Dinham, *Galileo-Europe's satellite navigation system-Can a Public Private Partnership Work?*, Paper for Association for European Transport Conference 2003, (Strassbourg: 8-10 October 2003), 17. http://www.etcproceedings.org/paper/galileo-europe-s-own-satellite-navigation-system-can-a-public-private-partners

There is always some element of financial risk associated with any large public project and one of the primary responsibilities of public officials should be to work to mitigate risk wherever possible to lessen the possibility of public loss. In the case of Galileo the stakes were higher than ever before with an eventual projected exposure of €6.4 billion in public funds and over €2 billion in private sector funds. There were a number of concerns that should have been closely considered by the EC and the ESA regarding the Galileo project in order to increase the odds of success.

Even though multiple studies had been conducted that provided assessments on the potential market applications from Galileo, they were still only potential projections on a market that was new and unknown. It was also impossible to know with any degree of certainty whether potential users would pay for services that were currently available at no cost from GPS or just how large the market was for improved subscription services. Another major issue was the fact that there was no policy or statute in place to levy royalties for Galileo's services. Each of these assumptions were critical and their failure had the potential to jeopardize Galileo's future success.

Another critical design aspect of the Galileo model was the requirement for conceptual clarity, technical expertise and competence from all public and private stakeholders in-so-far as executing and operating within the PPP design parameters. As will be seen later in the chapter, the public sector's lack of conceptual clarity created significant difficulties for the private sector during the Development phase and would end up being a primary reason for the eventual failure of the PPP.

2. GALILEO JOINT UNDERTAKING (GJU)

EC Regulation No 876/2002 established the Galileo Joint Undertaking (GJU) as an agency or executive body on May 21, 2002 to oversee the public sector during the initial Definition and follow-on Development Phases of the project. It was established specifically to represent EU and ESA member states as the public sector component of the PPP. It was tasked to "successfully complete the development of the Galileo programme during its development phase by combining public and private sector funding. In addition, it should make it possible to ensure the management of major demonstration projects."[19]

Membership in the GJU was limited to the EU as represented by the EC and the ESA (Fig 12). The European Investment Bank was also listed as an entity that could, at some future time, become a sitting member. The charter for the GJU was set to expire in four years time in May 2006, to coincide with the projected conclusion of the Development phase. This was a critical decision because it injected a time-dependency on a project that should have been mission dependent thereby increasing risk. It was drafted under the assumption that the Development phase would end within the projected timeframe with no allowance for system delays. As will be seen later in the chapter, this crucial assumption proved to be another critical error in the planning and implementation of the PPP.

An Executive Director supported by an Executive Committee governed the GJU. The GJU Administrative Board was made up by an equal number of EU member states

[19] Official Journal of the European Communities, *Council Regulation (EC) No 876/2002, Setting up the Galileo Joint Undertaking,* (Brussels: May 21, 2002). 2, Sec 15. http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Regulation&an_doc=2002&nu_doc=876

and ESA member states at the Program Board on Satellite Navigation (ESA PB-Nav). The GJU Administrative Board controlled the GJU agenda and all decisions were made by qualified majority vote.

When the decision was made to have the GJU expire in May 2006, it was assumed that the EC would have created another agency called the GNSS Supervisory Authority or GSA to assume the project leadership mantle. It was expected to be up and running well before the GJU expired in order to allow for a smooth transition. The key mission of the new authority would be to seamlessly assume management responsibilities of the ongoing project just as the Deployment phase was beginning and provide official oversight of Galileo into the out years of operations. Galileo was to be a huge multinational undertaking with numerous member states and international partners working together through cooperative agreements and the organization of the oversight bodies seemed to assume the project would proceed from the start point with few, if any, issues that would delay the timeline. It was as if the EP, the EC, the ESA and much of the space industry were living in la-la land with regard to the potential problems that might face them from such a complex and expensive project.

The original governance structure for the Development phase was flawed from the beginning and was a major contributor to the dysfunction exhibited by the partnership. The primary tasking for the GJU was to be to insure a successful completion of the Development phase including the launching of a series of four validation satellites as it transparently managed public funds and provided competent oversight for all demonstration and test modules.

However, the GJU was chartered without input from the private sector. In fact, it was charged with the responsibility to establish a business plan that covered the entire project through completion based on information provided by the EC on allowable services, projected revenues and other measures as deemed important by the EC members but not necessarily important to or in sync with private industry. It was also designed as a bridge between the ESA and the EC with regards to Galileo except that its mission, functions, responsibilities, and authorities were not clearly delineated with buy-in from the ESA, the EC or private industry. All in all, the GJU did not really fit the needs of any one stakeholder much less all of the stakeholders.

Another major GJU responsibility was the management of the concession or contracting aspects of the project. It was incumbent on the GJU to manage the request for proposals, the review of proposals, and be responsible for the ultimate selection of a project consortium. As such, it was expected to enter into competitive negotiations with private industry on the financing of the final deployment and operating phases of the project and more importantly, enumerate the specific responsibilities, roles, and risks that were to be shared by both sectors throughout the process. Finally, the GJU was expected to make any necessary changes or modifications to the project as required based on current circumstances. The GJU was also set to be disestablished at the end of the Development phase with the assumption that the newly formed GSA would be capable of seamlessly moving into the oversight and management position beginning with the Deployment phase.[20]

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[20] Ibid., Annex Art 2, 7.

3. ECONOMIC

Negotiations amongst EU member states on the concept and initial need for this kind of European-only system were labored and extensive. The initial proposal for the new global positioning satellite array came primarily from the public sector that were based on commercial opportunity. A resolution passed by the European Commission in 1999 outlined the potential impact very clearly that "satellite-based positioning and navigation are increasingly gaining importance in nearly all fields of technology, being a key element for the setting-up of a multimodal infrastructure for all forms of aviation, water and land transport. Satellite navigation has the potential to make a major contribution to an effective use of transport infrastructure, to an increase in safety, to a reduction of environmental pollution and to the setting-up of an integrated transport system with crucial importance for the Single Market."[21]

The Commission's 1999 final report on Galileo estimated the potential market for GPS services to be about €113 billion and the potential market for GPS hardware to be some €122 billion from 2005 to 2023. This was a huge market and the EC was suggesting that Galileo could provide upwards of 30% market penetration by European industry and support its quest to stay on the leading edge of technological innovation and applications.[22]

Commission interest in GNSS prompted a number of additional studies across Europe as public and private interests attempted to gauge the magnitude of overall economic effects that might result from a future European GNSS. However, fluctuations

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[21] European Council, *Council Resolution of 19 July 1999 on the involvement of Europe in a new generation of satellite navigation services,* (Brussels: 1999). 1. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999Y0803(01):EN:HTML

[22] European Commission, *Galileo-Involving Europe in a new generation of satellite navigation services COM (99)54 Final*. (Brussels: February 10, 1999). 3. http://aei.pitt.edu/4703/1/000784_1.pdf

in projected revenue streams and job creation became a real political football in the succeeding years as different agencies, commissions, member states, and industrial concerns lobbied for or against Galileo and presented wildly disparate projections.

A study conducted by PricewaterhouseCoopers in 2001 for the EC found markets across the range of sectors and put the potential operator revenue generation from fees for services at €66 million by 2010 and more than €500 million by 2020. Using these figures supported the study prediction of a return on investment ratio of 4.6 and that was shown to be the highest positive return on any public-private project in Europe. The report concluded that Galileo would begin showing a positive cash flow by 2011, a short three years after the expected full operational capabilities date.[23]

A 2004 EU industrial community estimate projected that the future economic opportunity included the creation of about 100,000 new jobs for the companies that launched this next generation of GNSS. In another case, the European Economic and Social Committee (EESC) issued an Opinion in February 2005 raising the number of new jobs to more than 150,000 jobs in Europe alone and a potential market of three billion receivers by 2010 and an annual return on investment of up to €250 billion.[24]

Other 2005 EC projections of revenues that might be derived from an independent GNSS suggested there was a €9 billion market that would become accessible to European concerns all for the investment equivalent of 250 km of high-speed rail track. The Commission advertised the project as so revolutionary that it would be compared to how

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[23] European Commission, Olivier Onidi, *GALILEO is launched*, (Luxemburg: 1999). 3, http://ec.europa.eu/dgs/energy_transport/galileo/doc/galileo_is_launched.pdf

[24] European Economic and Social Committee, on the Proposal for a Regulation of the European Parliament and the Council on the implementation of the deployment and commercial operating phases of the European programme of satellite radio-navigation, (Brussels: February 9, 2005), Sec 2.8. http://eur-law.eu/EN/Opinion-European-Economic-Social-Committee-Proposal-Regulation-European,168251,d

the cell phone has changed the lives of people or how low cost air travel has proved a boon to worldwide tourism.[25]

However, not everybody was buying into such huge potential future markets for Galileo. A fact sheet published by the EC's Committee on Industry, Research, and Energy in 2006 specifically targeted these numbers as possibly being too optimistic and suggested that the future numbers, as well as concerns about the unknowns surrounding the end costs of the project, as being major issues of controversy and may be contributing to missed deadlines.[26]

Then in 2010, the GSA modeled the economic impact from the launching of Galileo and projected that the market for Galileo would grow at a rate of 11 percent over the next decade, reaching some €165 billion for the core market. Figure 3 presents the findings of the GSA study according to market share and by region.

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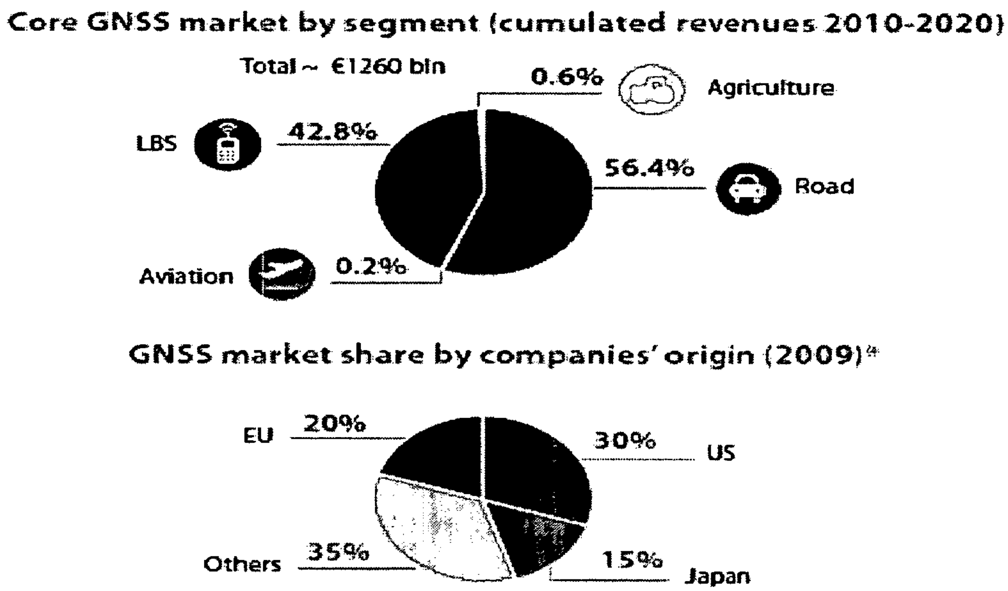
[25] European Commission, *White Paper: European transport policy for 2010: time to decide*, (Luxemburg: September 12, 2001), 101.
http://ec.europa.eu/transport/strategies/doc/2001_white_paper/lb_texte_complet_en.pdf

[26] Committee on Industry, Research, and Energy Fact Sheet FIS/2004/0156, *Satellite navigation programmes EGNOS and Galileo: implementation of the deployment and commercial operating phases 2008-2013*, (Brussels: December 20, 2006).



Graph 1 2010 Market Share per GSA[27]

One thing is for certain. Most of the estimates that have been made regarding the economic impact of Galileo on the European economy were based on Galileo reaching the market well before the US deployed its next generation of satellite called GPS III. As it appears now, most of the technological advantage that Galileo enjoyed has been lost to GPS III due to the extensive delays in deploying the satellites. What is even more troubling is the completion of Russia's upgrades to its GLONASS and the deployment of the Chinese COMPASS system both possibly occurring before Galileo reaches its final operational capability putting even more downward pressure on the economic viability of the system.

[27] European GNSS Agency, *GNSS Market Report Issue 1*, (Brussels: November 2010). 6. http://www.gsa.europa.eu/files/dmfile/GSAGNSSMarketreportIssue1.pdf

4. PROCUREMENT

Protectionist policies were alive and well in Europe around the turn of the 21st Century. There has been, until recently, a gross multiplicity of overlapping industries competing with one another from state to state in the EU defense and aerospace industry segments. This is not unusual in and of itself in the competitive global economy. However, there have also been differing procurement policies within the boundaries of each European state making any kind of unified systematic procurement effort across Europe very difficult to orchestrate. In other words, the game is played differently from state to state. With the lack of a unified EU wide procurement system and a tendency for states to subsidize their defense and aerospace industries at different rates, it is no wonder that the industries themselves would take the lead of space system development.

The Galileo procurement process was exceedingly difficult from the beginning. The original PPP design envisioned the EU providing some 50% of the funding for the project and a European industrial consortium providing the remaining 50%. The ESA and the EC would fund the initial R&D and Development phase of Galileo with public funds. More importantly, the ESA would be responsible for the concept and design of the project. The plan called for the private sector to come online after the design plans were complete and would then be expected to fund, build, and operate the system as was previously designed.

Funding streams would shift when the Deployment phase began with the EU providing 1/3 of the funding while the private sector assuming the remaining 2/3 of the cost including €200 million that had been previously pledged to the project by industry in 2001. This funding stream would underscore the notion that Galileo was a civilian run enterprise designed to support the civil community at large and at the same time provide a return on investment for its investors.[28]

5. PHASES OF IMPLEMENTATION

The original Commission proposals called for the Definition phase to run through the end of 2000 and the Development or Validation phase beginning in 2001 after an expected stamp of approval from the European Council of Ministers. This phase would continue through the end of 2004 and was to reach culmination with the launching of at least two test satellites into space orbit in order to validate the overall design concept, satellite subsystems, and the ground station design. Next, the Deployment phase would kick off featuring the launching of up to 30 production satellites into MEO by the end of 2008 with Galileo reaching full operational capability. The last and final stage of the project was the Operational phase that would continue out into the future and would include operations, maintenance, and satellite replacement missions.

However, the plan did not go exactly as anticipated by the EC. The Definition phase was supposed to be a time when the ESA and the EC would generate various technical studies on the system and initiate preliminary pre-developments on some of the new technologies that were anticipated to be required components of the project. The EC was also expected to create an effective governance structure that would encompass the coming partnership with the private sector. It was also expected to begin the process of lining up international partners and drafting international agreements in order to facilitate the follow-on Development phase.

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[28] European Union, "Statement of the Council of European Transport Ministers", *GPS World*, (May 2002), 14.

Finally this was the time when the ESA and the EC were expected to develop and publish all of the required business and legal feasibility studies for implementation and execution throughout the later phases of the project. The Development phase did begin on schedule in 2001 and was supposed to run for four years. This phase was overseen by the GJU beginning in May 2002 with its four year charter. It included significant technological inputs from the ESA and should have included €200 million in initial, good faith, funding from the private sector. It was anticipated that the GJU stakeholders would be capable of producing a nearly complete picture of the system to include its space, ground, and user components and would have the capacity to oversee the design and building of up to four prototype satellites with an accompanying ground element that could be launched into space as the system 'validation' element.

There were a number of other important tasks that needed to be completed during this phase including the EGNOS deployment and operation, and the negotiation and selection of a concession or contractor consortium from the private sector to actually deploy and operate Galileo for the long term. As it turns out, EGNOS was successfully launched but the selection of a private concession became a bridge too far for the GJU.

The Deployment phase could not commence without the selection of a consortium and the failure of the GJU to select a consortium set the project back on its heels. The forecast to be operationally ready by 2008 was predicated on meeting a strict time-line. The four year charter for the GJU (2002-06) and the anticipated standing up of the GSA in 2005 in anticipation of the beginning of the Development phase did not allow for programmatic adjustments. This phase was also particularly optimistic as it called for the industrial consortium to assemble and launch the entire satellite array and to install the supporting ground elements required supporting the 30-satellite array within a 36-month period.

It was also expected that the business plan would be executed during this same phase and that the consortium would be in a position to begin collecting user fees from Galileo's operations. The plan proved to be too difficult to implement and neither the EC nor the ESA had developed viable contingency plans to account for unanticipated problems that were likely to arise as the project moved forward.

The final phase of the ambitious plan was the Operational phase that would begin sometime in 2008 and continue through the out years of the project. By this time there was expected to be a revenue stream in-place that some said would allow the stakeholders to break even on their investments by 2011. The consortium would be heavily involved in the maintenance of the system and would be responsible for satellite replacement as required. It was expected that the ground stations would be fully operational and functioning by this phase. Unfortunately, this ambitious plan went awry almost from the start. As will be seen later in the chapter, the goals and outcome expectations of the original plans were grossly overstated and the EP was slow to act in recognizing the depth and extent of the problems and coming up with solutions to fix it.

D. DOMESTIC AND POLITICAL IMPACT

It has only been in the last couple of decades that the EU has acquired sufficient domestic economic and political power that it, as a body, has had the ability to sponsor large, cross-border, industrial projects that require significant R&D and pre-production resourcing in order to bring a project of this magnitude to fruition. The main issue has been getting the individual states to cede some degree of sovereignty in support of the collective EU. The state sovereignty issue has loomed large in all negotiations and cannot be exaggerated. It is one of the primary reasons for the continuation of large individual state industrial subsidies and makes it very difficult orchestrate trans-European projects on the magnitude of the Galileo project. For Galileo to succeed, some member states were probably going to be required to forego some existing industrial capability in order to improve industrial efficiencies and competitiveness across the EU as a whole.

The 2003 Framework Agreement between the EC and the ESA was an important beginning toward a closer cooperation between member states and the ESA in terms of cost and risk sharing in large space projects. The Framework addressed two important issues that were impacting the Galileo project. Article 1 described the purpose of cooperation as "optimizing the use of expertise and available resources and contributing to the consolidation of the close cooperation between the European Community and ESA, thereby linking the demand and supply of space systems within a strategic partnership." It then goes on to promote "achieving greater coherence and synergy of research and development in order to optimize the use of resources available in Europe, including the network of technical centres."[29]

The long-time goal of many policy makers has been the emergence of a stronger EU that will support a smoother and more transparent development of space based projects under a more centralized organizational structure. The Framework was recognition of a serious vulnerability in the EU organization and an attempt to bring most

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[29]Official Journal of the European Union, *FRAMEWORK AGREEMENT between the European Community and the European Space Agency,* (Brussels: June 8, 2004). Article 1, d,e. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:261:0064:0068:EN:PDF

of the parties closer together in order to promote trans-European unity of effort under some form of a unified leadership.

A report issued by the EC in July 2004 contained interesting language describing the ultimate impact that Galileo might have on the greater European society. It suggested that satellite navigation "had become part and parcel to the daily life of European citizens, featuring not only in their cars and portable telephones but also in their banking habits and the civil protection systems which look after their security; all of which confers on the Galileo programme an additional citizens' dimension."[30] The language of the Commission works to reinforce the notion of a trans-European view vis-à-vis Galileo. It should be important to all Europeans that this project is the largest of its kind ever attempted and that it is requiring the resources and expertise of all of Europe to complete. There was no single European state that would or could build a project of this magnitude.

One contentious issue that has made negotiations difficult has been the historical propensity of EU member states to allow their individual defense and aerospace industries to cooperate on civil space projects under the auspices of the ESA or the Western European Armaments Group (WEAG)[31] individually thereby bypassing the EU generally and adding to the fragmentation of overall trans-European cooperative efforts. Having been business as usual over several decades leading up to Galileo it is not surprising that politicians, civil servants, and corporate boardrooms found it difficult to change their cultures, their strategies, and their behaviors in order to come together with a

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[30] Commission Of The European Communities, proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND THE COUNCIL on the implementation of the deployment and commercial operating phases of the European programme of satellite radio-navigation, (Brussels: July 14, 2004), Sec 1.

[31] The WEAG was established in 1976 to promote armaments cooperation among EU member states. In 2000 it had a membership of 19 states. It was disestablished in 2005.

truly unified effort to build Galileo. It had almost become a zero sum game where states or corporations were expecting nearly one-for-one returns on their investments from a project making it nearly impossible to draft or implement any sort of meaningful or workable trans-European project outline.

Another issue that needed to be addressed was the parochial nature of the European industrial base. Seven years into the Galileo project most of the high tech assets like manufacturing plants were still located in and closely associated with individual member states with many of them being partially owned by that state. Additionally, defense and security assets like military equipment belonged to each state separately with each state formulating its own defense related policies, and being responsible for funding its own military forces. This is the basis of one of the major peculiarities of the way Europe conducts business.

EU member states have historically protected their space and defense related industrial base with subsidies and anti-competitive policies while maintaining them separately from the general economies. This allows individual members the option of forming unilateral, bi-lateral or multi-lateral member state partnerships for the development of space or military systems that are tied to their own security or national defense. France was perhaps the most radical in its resistance to member state collaboration. Jean-Daniel Levi, Director General of France's Centre National d'Etudes Spatiales (CNES), publicly stated at one point in 1994 that "it is easier to take decisions alone than with 13 others."[32] It appeared to Mr. Levi that European collaboration made attracting financing for new projects more difficult and the CNES began looking for bilateral or multilateral avenues for future project work.

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[32] Suzuki, 140

At issue during the late 1990's with the major space states was the increasing influence of the ESA in policy making mostly at state expense. Germany and Italy both had resident space agencies similar to France's CNES. Both Germany and Italy grumbled and complained about ESA mandates concerning fair returns, small member state veto authorities, and a growing chasm between national agency engineer salaries and those at the ESA. The larger states wanted more autonomy through ESA reform and many smaller states objected. Peter Creola, the Swiss Minister for Space, summed it up for the smaller states with this statement in 1999. Looking at ESA reform he said that the smaller states "will not participate in the slow erosion and ultimate destruction of what we have helped to build and are today proud of, to raise the status of national (space) centers to 'European' ones would mean facing again the conflict between larger and smaller countries."[33] And there were other issues with the ESA as well.

In the case of commercial space related projects, several of them have been funded by civil consortiums or PPPs between government and private industry and subsequently executed by the ESA. This is the rub. The ESA charter requires it to work on peaceful space projects that work for the good of the European people thus creating legal difficulties for the ESA and its projects as in the case of dual-use technology for example.[34] Historically, most space projects have had some military application that has limited the exposure of the ESA to the greater EU industrial base for space based projects. It was only with great difficulty that EC ministers were able to develop language that redefined 'peaceful only' to include the notion of 'non-aggressive' military applications in the ESA charter.

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[33] Ibid., 141.

[34] Marco Pisano, "Moving Europe towards a more effective procurement of space-based assets", *Space Policy* 22, iss. 3 (2006): 177.

The ESA works primarily with industry on high-tech space projects outside of the defense sector. The Agency does not get involved at the production end. Nor does it exploit the economic opportunities available to the production entities. It works in the pre-competitive phases of product development. At issue for Galileo was the historical weakness of the links between Europe's member state national interests and the charter of the ESA that is focused on the development of civil space projects designed for peaceful purposes for the good of all Europeans by its original convention. With Galileo EU member states were going to have to reevaluate their business practices and learn to work together harmoniously in ways they had not done previously. There were several issues that needed to be sorted out before Galileo could be called a success.

The elephant in the room has most always been the presence of the United States in nearly every facet of European life. Concern with becoming an "equitable partner" with the United States has been a huge issue that has vexed European governing bodies for decades. One of the more well known examples on the subject of trans-Atlantic space system collaboration and the need for European autonomy was amply demonstrated during the negotiations to bring the European Columbus space program fully into sync with the Spacelab program in the 1980's.

There was a distinct impression by the European ministers that the US had an entirely different perception of the concept of collaboration than did the Europeans. At one point in 1985 during an ESA committee meeting, French Minister Curien reminded the other Ministers that the center of decision-making was and would remain with NASA. He stated that "(I) notice every time we refer to the US space station in draft Resolutions we discreetly call it the 'international space station'". He said that "(I) cannot help smiling at the label 'international' – I would be so much happier to meet this word in an American document. For the time being the station is a US civilian station that will probably be used by the military." He finished his statement by saying "What Europe must aim for is the point at which the Americans themselves call it international".[35] Having the French Minister making these kinds of comments is not surprising since France has actively pursued military independence from all other nations since Charles DeGaulle was president of France.

It is also the member state that has devoted the most resources to space systems and space development. France was also an early proponent for using Galileo in military operations that ran counter to Germany and the UK who strongly favored civil only operations. This particular issue ended up being one of the more contentious that faced the EC during the Development Phase.

In another instance regarding US dominance in space the EC issued a report in 1999 that directly addressed the political ramifications of Europe failing to have a captive GPS capability. "The challenge is to guarantee Europe's strategic needs without excessive cost or risk. By contrast, failure to act would strengthen the present US market dominance and leave Europe entirely dependent on the US for many security-related matters."[36] These 'security-related matters' had caused considerable consternation within the EC and the ESA as the project continued to slowly evolve.

The EC did not authorize the actual Development phase by the ESA to begin until early 2002, almost 15 months behind schedule. The largest unresolved issue for the EC was again, the potential for Galileo being used to support military operations. There was

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[35] Krige et al., 72.

[36] European Commission, "Galileo: The Challenge Facing Europe", *Air & Space Europe* 1, no. 2, (1999): 23.

significant concern over the fact that the project was being advertised as a commercial entity and that it was being built with private sector funds for peaceful purposes and how it could, at some point or under certain circumstances, be used directly to support military operations. Commission members had difficulty in reaching political consensus on this issue. Several Transport Ministers voiced the opinion that there were potential customers that would not pay for Galileo's services if they knew the system was being used by the military and therefore, could be turned off if necessary.

But it didn't end here. Even though the Development phase had been delayed 15 months Commission members refused to ratify the go-ahead from early 2002 because there were other lingering concerns over the perceived fairness of industrial contract awards across the various member states. These negotiations consumed another year until the EC finally approved the go-ahead for the Development phase in May of 2003. Over the years, German nationalism had been a major stumbling block with regard to consensus on contract awards. Germany is Galileo's major benefactor and it was insisting on fair returns for its commitments.

Germany wanted assurances that it would have a direct leadership role in Galileo operations and that its national industries, particularly its satellite industry led by EADS Astrium, would be building a large percentage of the space vehicles and ground support infrastructure. This kind of intransigence created significant churn within the EC, the GJU, and the ESA. An article from Aviation Week and Space Technology from 2007 captured the mood succinctly when it reported that "Galileo is in the hands of a monopoly industrial grouping...and not surprisingly, rivals such as EADS Astrium and Thales Alenia Space find it difficult to work together, while Spanish and German politicians are trying to increase their nations' role and influence in the consortium. After reinventing international collaboration and joint ventures and achieving considerable successes, major segments of Europe's aerospace industry are in a deadlock. Cooperation apparently has reached its limit."[37]

But neither the United States nor security related matters were the only issues facing the EC and Galileo. In early 2005 the European Economic and Social Committee (EESC) tendered an Opinion to the EC concerning citizens' right to privacy issues regarding the ability of Galileo to spy on the population. The Committee expressed real concern that there was the potential to violate the rights of citizens through the collection of personal data or other privacy issues. The Committee strongly recommended that the Parliament work directly with the European Fundamental Rights Agency and possibly set up a review body to prevent any sort of infringement on citizens' rights. The Committee voiced their concern by stating "the EESC considers that explicit guarantees for privacy and personal data protection are no less important than security considerations if the success of Galileo is to be secured through the full support of civil society."[38]

Building on this thread, the EESC also opined that Galileo was relatively unknown to most Europeans. So it would be in the best interests of the EU and the Parliament if the Parliament would undertake efforts to educate the population on the benefits of the project in order to insure the population would be willing to continue to support funding requirements in the future and to reassure them that their privacy was being safeguarded. This was in 2005, fully six years into the project and at least one

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[37] Pierre Sparaco, "European Blockage: Economic Nationalism Impeding Galileo Program", *Aviation Week & Space Technology* 166, no.17 (April 30, 2007): 60.

[38] European Economic and Social Committee, *on the Proposal for a Regulation of the European Parliament and the Council on the implementation of the deployment and commercial operating phases of the European programme of satellite radio-navigation.* (Brussels: February 9, 2005). Sec 4.5.6 and 4.5.7.

influential committee believed the public was generally unaware of such a significant and costly project looming on the horizon.

The negotiations between the five major EU member states with a history of space system development, Germany, France, UK, Spain, and Italy, on the processes and procedures for seeing the Galileo project become a reality had proven to be difficult at best. The notion of 'fair return' continued to vex to negotiators. This project was the first very large trans-European project and the learning curve was steep. Past precedent pertaining to returns on investment leaned toward the concept of a proportional return against investment by geographic region. Trying to apply that principle on this scale of project was proving to be not only inefficient but was very uncompetitive as well.

It was clear that in order to be globally successful the member states were going to have to develop a more unified approach to investments and returns that was not based on single member state benefits but on the benefits of the community writ large. This was unchartered territory for most of the stakeholders. In fact, during the negotiations to reform the ESA, Spain was the only member state to vote against any reform because it's small and largely uncompetitive industry had always been the recipient of 'fair return' and it was the most vulnerable member state if reforms of any kind were initiated to improve ESA organization and efficiencies.[39]

1. THE BUSINESS OF OVERRUNS

No one should have been surprised that there would be cost overruns and production delays with a project the size and scope of Galileo. The real issue for

[39] Suzuki, 132.

consideration is how the various governing bodies of the EU responded to them as they surfaced throughout the project. The ongoing and growing difficulties with the Galileo project early on during the Development phase had been reported to the European Parliament on more than one occasion. The Parliament, representing the political and macroeconomic interests of the EU, responded by issuing Resolutions in support of Galileo but took little direct action to address the problems. Almost from the beginning there were problems within the PPP. Financing the project was one of the early issues.

Private funding commitments from industry were a problem during the Development phase and this contentious issue was never fully resolved. Fifteen private sector corporations had signed a Memorandum of Understanding (MOU) with the EC in the spring of 2001, including Astrium, Alcatel, Alenia Spazio and Thales, indicating their readiness to participate in the project and to encourage the EU Transport Council's speedy approval of the PPP. The MOU anticipated a €200 million contribution from the private sector to help support the Development phase running out to 2005.

For reasons not fully elucidated, this contribution was never forthcoming although from the start, industry was never satisfied with the level of public sector insurance or details on future budgets that had been provided by the EC and the GJU. Another reason for the delay in the transfer of private funding to the project was the lack of detail provided to industry on the design and performance requirements for the two proposed validation satellites. Taken together, it appears that private industry was hesitant to commit the initial €200 million upfront to a project that was perceived to be lacking in planning and clarity. This was the first instance where obvious cracks had developed between the governing bodies of the EU and the private sector that were supposedly supporting the PPP.

In a 2004 Resolution, the Parliament obliquely addressed some of the issues that were causing the project to fall behind its proposed time schedules and to be over budget. The Resolution states that it "Commends the role played by the Joint Undertaking (GJU) as the driving force behind the project and calls for its powers with regard to the signing of the agreement with the future concessionaire to be clarified; stresses the need for it to operate with transparency and budgetary discipline."[40] Parliament also reminded those entities associated with Galileo that it expected accurate and timely inputs regarding issues with cost overruns or private funding issues so that the Parliament could address these issues deliberatively during appropriate budget venues.

These comments were remarkably prescient considering that the project was still relatively early in its development. The lack of clarity with the GJU's role and responsibilities within the overall scheme proved to be cumbersome and debilitating. The necessary expertise required administering a PPP of this magnitude and complexity ended up being beyond the capabilities of the GJU and its members as originally chartered.

The EP, for its part, did ask to have an EP representative assigned to the future organizational overseer, the GSA, in order to insure the EP maintained situational awareness of the program's execution during the Deployment phase. On the downside however, not asking for an immediate seating of a representative deprived the EP of the

[40] Official Journal of the European Communities, *European Parliament resolution on the communication from the Commission to the European Parliament on the Council on the state of progress of the Galileo programme,* (COM(2002)528-C5-0075/2003/2041(INI)), Sec J9. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2004:096E:0128:0131:EN:PDF

necessary awareness it needed to stay abreast of what was going on during the Development phase. This edict eliminated the opportunity for close oversight of the early stages when the GJU most needed support and assistance in terms of organization and guidance.

In the same resolution, the Parliament reaffirmed the strategic importance of Galileo stating that it "stresses the enormous significance of Galileo for the European Union's industrial, transport, technological and environmental policy development, and hence at the same time for the achievement of the strategic goals set in Lisbon of making the Union the most competitive and dynamic economic area in the world."[41] While the Parliament recognized the strategic importance of the project it chose not to impart any sense of timeliness or urgency into its pronouncements leaving the EC, the ESA, and GJU to continue to lurch along from missed timeline to missed timeline.

The Development phase was not completed according to design for a variety of reasons but it seems as though the primary reason was the fact that the GJU did not possess sufficient capability to complete its assigned tasks and the European Parliament, the Commission, and the member states were slow to intervene.

E. EUROPEAN NATIONAL SECURITY

In spite of the more public difficulties that were percolating up through the partnership over Galileo's organization, funding, policy, and risk there were other areas of interest that also needed to be addressed that impacted the stakeholders. The gorilla in

[41] *European Parliament resolution on the communication from the Commission to the European Parliament on the Council on the state of progress of the Galileo programme,* Sec J2.

the midst was the application of Galileo capabilities to defense or military related missions.

The issue of using Galileo to support European defense strategy had been discussed at length among the various ministries of defense across the continent. It was generally recognized that Galileo represented a capability that could not be ignored militarily if the situation presented itself and left them no choice but to use it. However, Galileo was stood up under the auspices of the ESA and therefore was officially designated for peaceful uses only. This was a problem and by the end of the Definition phase the EP had yet to formulate any official policy regarding the use of Galileo in the national defense strategy of the greater EU. What is truly amazing considering the size and scope of the project is that the EC never queried member state ministries of defense, either individually or in concert, as to any possible military capabilities that might be or needed to be made available with Galileo. In essence, the EU military had been shut out of the concept and development of Galileo. This was a tremendous oversight and it led to additional delays in the project.

In this case, it was the UK that was waving the flag. It was fundamentally against the incorporation of an encrypted signal into Galileo. The issue was cost and the UK did not believe that an encrypted signal was worth the investment considering the fact that NATO used the GPS military channels and would continue to do so into the future. The UK was categorically against PRS because the project was advertised as civil only and should not have any military capabilities. The UK eventually gave up its opposition when it became clear that there was a qualified majority in favor of PRS. Still, the controversy resulted in more delays.

NATO and the EU had been using GPS for decades along with other US intelligence and military system capabilities to provide the level of performance fidelity required by European national defense systems. The Cold War had provided the backdrop for US involvement in Europe's defense and now that the Cold War was over the EU was going to have to formulate a new defense policy that included Galileo or not.

As it turns out, the development of Galileo was moving faster than the member state defense ministers had anticipated. It is important to understand the convoluted nature of the EU organization when it comes to space programs. Historically, sovereign defense has been the responsibility of each state with NATO having the primary responsibility of defending the continent. Galileo was an EU project that didn't come under the direct purview of NATO and therefore didn't show up on the radar of local ministries of defense. Why did that make a difference?

Because that meant the subject did not garner a significant amount of press or political discourse but it was something that Government defense officials on both sides of the Atlantic had been debating for several years in spite of peaceful use only policies. The on-going debates focused on both internal and external defense.

Galileo designers had originally proposed to lay their encrypted Public Regulated Service (PRS) signal frequency very close to the GPS M-code frequency that was and continues to be the exclusive realm of the US military. Doing this would have given the EU the advantage of having the US military signal broadcasting on nearly the same frequency as the civilian PRS signal. This strategy would protect the PRS signal from being jammed by the US military because in order to jam the PRS signal the GPS-M signal would itself be jammed thus protecting Galileo's guarantee of availability for at least one signal. Additionally, a near overlay would have made the manufacture of PRS signal receivers very simple since a single band receiver could receive either signal depending on the circumstances and satellite availability. But this proposal prompted a quick response from the US.

In a January 2001 letter from US Deputy Defense Secretary Paul Wolfowitz (Appendix 1), the US expressed grave concern over this design feature. In the letter to European defense ministers, Wolfowitz stated that "the addition of any Galileo services in the same spectrum as the GPS M-code will significantly complicate our ability to ensure availability of critical military GPS services in a time of crisis or conflict and at the same time assure that adversary forces are denied similar capabilities."[42] Clearly, the issue was the possibility of jamming the M-code frequency due to signal fratricide. This would occur if the US military found it necessary to jam all non-US navigation system signals. If the PRS signal were jammed on order of DoD then there would be a real possibility of the US jamming its own military signals as well.

Another issue was the economic prospects being offered up for European defense applications that were not lost on the Directorate of Transport and Energy. An EC paper released as early as December 2001 enunciated a position that GNSS should be part of all future defense systems and that a European refusal to adopt Galileo as a European controlled and independent system supporting EU national defense would forever relegate Europe to a position of being "under the thumb" of the US military. "If the

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[42] Paul Wolfowitz, Deputy Secretary of Defense, Letter to European Defense Ministers, (Washington D.C.: December 1, 2001). http://www.free-photos.biz/images/business/management/galileo_-_wolfowitz_-_letter.jpg

Galileo program is abandoned" says the paper, "we will, in the next 20 to 30 years, lose our autonomy in defense."[43]

A second paper from the same Directorate published in March 2002 reemphasized the same position by stating "if the EU finds it necessary to undertake a security mission that the US does not consider to be in its interest, (the EU) will be impotent unless it has the satellite navigation technology that is now indispensable. Although designed for civilian applications, Galileo will also give the EU a military capability."[44]

There were still other security or defense issues that needed EC attention as well. For instance, what is to stop individual states from unilaterally using the PRS for military actions outside of the EU? What if Great Britain or France or even Bulgaria, for example, launches an expedition to restore order somewhere unilaterally or as a coalition without EU or NATO participation? What if Galileo were used by EU members against each other like Greece and Turkey attempting to settle a border dispute in Cyprus? How would Galileo's signals be regulated and would that be important? If it were important then who would control Galileo signals and would some EU governing body jam Galileo's signals to participating EU member states? These are thorny issues and the answers have not been formally addressed but would in all probability be negotiated depending on the circumstances although resolution might prove elusive given that very difficult problems rarely lend themselves to consensus or unanimity.

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[43] European Commission Position Paper, "Galileo: An Imperative for Europe", December 31, 2001 ref in *GPS World*, May 1, 2002 in "Military Role Emerges for Galileo". http://www.gpsworld.com/gnss-system/military-role-emerges-galileo-748

[44] European Commission, *Galileo: The European Project on Radio Navigation by Satellite*, (Paris: March 26, 2002), 4. http://ec.europa.eu/dgs/energy_transport/galileo/doc/galileo_info_note_2002_03_26_en.pdf

Taking the time to look at defense applications for Galileo in order to put it into context helps define the system more broadly. The ESA projected 30-year cost of the Galileo system of 30 satellites was calculated to be in the neighborhood of €6.6 billion back in 2002. At the same time, Airbus projected the 30-year cost of a 36-plane wing of A400M military cargo planes at €10.8 billion, which helps frame Galileo in terms of other major projects being considered by the EU.[45] These calculations do not include the expected economic return from Galileo user fees whereas no direct return is expected from the A400M's. So the question to be seriously considered is whether, from a defense perspective alone, scarce resources should be applied to Galileo at the expense of other high-end military systems?

There is no doubt that inputs from both GPS and Galileo would provide a significant upgrade of positioning, navigation, and timing requirements for the US and European military establishments. It would enhance the precision targeting capabilities of all ordnance and reduce the exposure of military forces to hostile fire in non-permissive environments. It would improve the availability of signals in urban settings that are considered the most difficult places to fight because the availability of more satellites translates to improved satellite visibility in the urban canyon environment and that will enable more situational awareness for the military theoretically reducing their exposure in danger zones. Furthermore, it should seriously enable the fielding of a new generation of remote controlled aircraft and land vehicles because of greater signal availability, reliability, and accuracy. There are bound to be many more military

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[45] James Hasik and Michael Rip, "An Evaluation of the Military Benefits of the Galileo System", (Portland, OR, *In Proc. ION GPS 2002*, Sept. 25, 2002. Institute of Navigation): 320-329.

applications that Galileo could contribute to as an enabler if the EU chooses to expand the application envelope to specifically include defense issues.

The major issue still remains that the system was designed and is being built as an instrument of peace that will provide improvements to the everyday lives of its users, primarily to those people who live in Europe. It is not a military weapons system and there is resistance in the EU community to using Galileo as such. It is unknown how this conundrum will eventually work itself out but it does appear that Galileo will be tasked to support military operations as the need arises. It is foolish to consider otherwise.

System security, both internal and external, was a major focus during the development of Galileo. EC Regulation No 1321/2004 tasked the GSA to manage, among other things, "all aspects relating to the system's safety and security. " This agency was responsible for defining the security requirements and any cryptography necessary for signal security. It would also be the agency responsible for the fidelity and security of the PRS signal to end users, "and of possible measures that could be taken by the Council in the event of a threat to the security of the European Union or of a Member State arising from the operation or use of the system, or in the event of a threat to the operation of the system in particular as a result of an international crisis."[46] If the EU or its member states were threatened and the threat involved Galileo then the issue would go before the Council of the EU for adjudication and action.

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[46] Council of the European Union, COUNCIL REGULATION (EC) No 1321/2004 on the establishment of structures for the management of the European satellite radio-navigation programmes, (Brussels: Official Journal of the European Union, 2004), Art 2, sec j. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:246:0001:0009:EN:PDF

1. INTEROPERABLE WITH GPS

The next piece of the project that proved to be difficult and time consuming to solve was the decision on whether or not Galileo would be fully interoperable with GPS. In this case the term interoperable would include the capacity for GPS programmed receivers to be capable of receiving Galileo signals and vice versa. This was a very large decision because of its potential economic impact on future fees and licenses. The US did not assess licensing fees for GPS receivers making signal reception truly free. The Galileo project, on the other hand, had language that proposed the collection of licensing fees for each receiver as a method of paying down the cost of the project. The obvious question is why would someone pay a fee to design and build a receiver that works for GPS and Galileo if receivers are available, stamped 'Made in America", that would also work for GPS and Galileo that have no fees associated with them? This was another example of the naiveté of Galileo's governing bodies as they struggled to design and build this huge, trans-European, technological marvel.

In defense of the EC, the ESA, and the GJU, it is important to consider just how difficult it might be to finally achieve true interoperability between Galileo and GPS. The task is not particularly difficult from an engineering perspective to ensure receivers will operate properly with either system so long as the design architecture of both systems is available to receiver manufacturers. What proved more contentious was the legal lash up between the civilian controlled (with initial EU oversight in the form of the GJU and later in the GSA) Galileo and the US GPS that is controlled by DoD.

One of the key enablers of Galileo for users of the Commercial Service is a guarantee of performance that includes guaranteed availability of signal. A civilian system like Galileo can capably offer this kind of service in a peacetime environment. However, gaining acceptance to performance guarantees from DoD, especially on availability of service, could prove to be more difficult due to military necessity relative to satellite location and signal availability. One of DoD's response strategies when the US is seriously threatened is to initiate regional jamming of PNT signals from all sources in order to deny service to those threatening the national security of the US. If both systems were interoperable, including receivers, then it would be difficult for Galileo to advertise itself as a civilian only system when DoD was prepared to jam its signals whenever the situation was deemed critical enough. Although it has yet to occur, the threat of interruption remains a possibility. So much for service guarantees.

2. THE PRIVATE SECTOR AND PPP FAILURE

The private industries that were interested in participating in the Galileo project are the major space and defense industries of the EU. These firms are well known multi-national corporations whose headquarters are located in Europe.

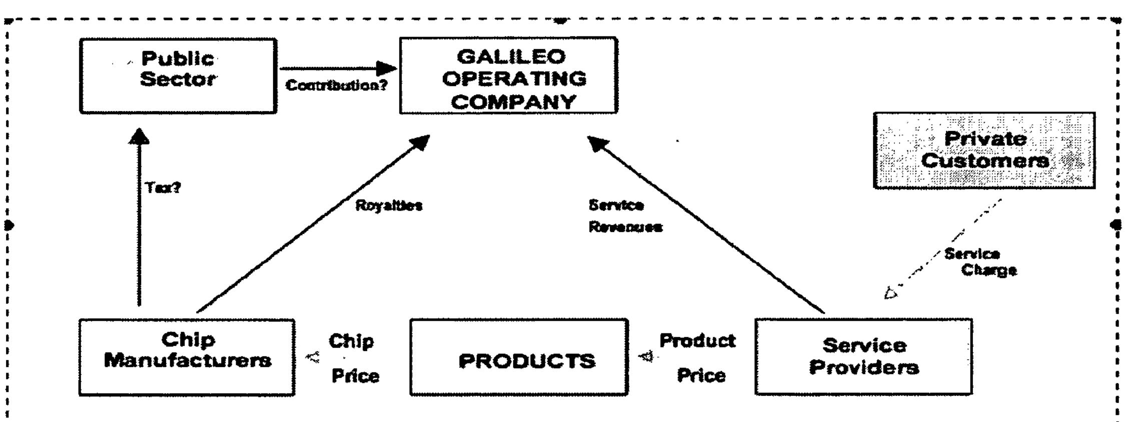

Figure 1 Initial Structure of the GOC

Eight major corporations formed the core group of the proposed Galileo Operating Company (GOC). As proposed, the GOC would be the organization that operated the concession. Each of the players brought specific expertise to the program and all had previous experience in space systems.

EADS is a major multinational firm headquartered in Leiden, the Netherlands, and generated some €42.8 billion in revenues for 2009 and employed nearly 120,000 workers. It is a leading aerospace and defense corporation that includes Airbus (civil and military aircraft), Eurocopter (helicopters), Astrium (builder of space launch systems such as Ariane and Galileo) and Cassidian (military and civilian security applications). EADS Astrium Satellites is located in Germany where most of Europe's satellites are built.

Thales is a large French electronics systems manufacturer with 68,000 employees in over 50 countries, headquartered in Paris, and with 2010 revenues in excess of €13 billion. They are the major European manufacturer of satellite system components. Thales advertises itself as the only source of beginning to end positioning, navigation, and timing systems to include total system service in Europe. It is also the world's third largest manufacturer of GPS receiver equipment.

Inmarsat is a privately owned British company specializing in satellite telecommunications systems and services such as the Broadband Global Area Network or BGAN. Inmarsat is a major provider of maritime distress and safety services across the globe that is commonly used as a public service.

The Italian conglomerate Finmeccanica is the largest high technology entity in Italy. It employs some 75,000 works and saw revenues of €18.7 billion for 2010. Its primary forte is military and civilian aircraft, electronics and satellites. It is headquartered in Rome.

AENA or Aeropuertos Españoles y Navegación Aérea is the largest airport administrator in the world with 47 airports under contract. It is wholly owned by the Government of Spain and is headquartered in Madrid. AENA is a Public Business Entity entrusted with the planning, development, building, installation, operation and managing of the 47 Spanish civil airports and the air navigation system for all airspace under Spanish responsibility, with five Area Control Centers covering four Flight Information Regions (FIR/UIR). AENA also manages 15 airports in Central and South America. The company also integrates all Spanish civil aeronautical infrastructure activities in one single organization staffed by qualified professionals, with an advertised business philosophy of keeping the best of public service spirit, technological innovation and safety management.

Hispasat is a Spanish owned company that owns and operates a group of communication satellites developed by the Instituto Nacional de Tecnica Aeroespacial (National Institute for Aeronautical Technology) and focuses on delivery of digital radio and television signals. It had revenues of €181 million in 2010.

Alcatel-Lucent is another French high technology multinational corporation headquartered in Paris that employs nearly 80,000 workers. It provides telecommunications solution sets across the globe to users needing voice, data or video services. Alcatel-Lucent saw revenues of nearly €16 billion in 2010 but also posted a corresponding €334 million loss. It owns Bell Labs that is considered to be one of the preeminent R&D labs in global communications.

TeleOp GmbH is located in Oberpfaffenhofen/Wessling, Germany near what is to be the Galileo Control Center. TeleOp was formed specifically by the major industrial concerns to operate as the execution arm of the concession consortium. TeleOp was slated to provide satellite operations, logistics support, application expertise, and market access for Galileo by leveraging the capabilities of all members of the consortium into a single point of contact.

That is the list of the major private sector players who, along with the GJU, were responsible for what was to become the single largest fiasco of the Galileo Project. Project plans and specifications had been drawn up during the Development phase and with that the GJU published requests for proposals in October 2003. These were based on the Mission High Level Definition and Mission Requirement documents that had been developed by the ESA without major industry inputs.

However, while there was significant interest from two major consortiums in the project, there was little initial desire for the two bidders to collaborate with the GJU on the scale necessary to actually offer substantive proposals, as there didn't appear to be any unanimity amongst the bidders on actual requirements and specifications. In other words, the specification package for Galileo was not complete enough for the bidders to formulate complete bids.

An audit of the failed bidding proceedings conducted after the fact by the European Commission found serious fault with the actual design of the PPP and with the initial bid packages released to the private sector. According to the report, "the PPP was inadequately prepared and conceived. As a result, the GJU was required to negotiate a

PPP which was unrealistic."[47] That Galileo was the largest project ever attempted of its kind in Europe apparently did not prompt the member states to work with any kind of unity of effort within a unified leadership organization.

EC rules stipulated that decisions be made by qualified majority many of the larger problems like assumption of risk and delineation of work throughout the states remained nearly intractable. The EC, through the GJU, as unable to reign in the issues that the private sector was raising due to a seeming lack of requirement specificity. The audit concluded that "the Commission proposed, and the Council adopted a PPP for the deployment and operational phases of Galileo in order to obtain a political consensus. The Commission's documentation defined the characteristics of a concession, but with arguments based on general statements rather than on reasoning specific to Galileo, and an ambitious timetable was proposed for procurement."[48] Industry, for its part, was complicit in the failed process in that they did not press the GJU for clarity and specificity from the bid packages.

This was the largest trans-European project ever and there were no firm proposals submitted to the GJU. There were two major reasons for the failure. First, there was no consensus on risk sharing between the public and the private stakeholders. This was the single largest issue preventing the completion of negotiations. The private consortiums expected the public sector to shoulder a large portion of the financial risk and legal liability associated with suits being brought against the operators in the event of lost or

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[47] European Court of Auditors, Special Report No 7, *The Management of the Galileo Programme's Development and Validation Phase*. (Luxembourg: 2009). 23. http://eca.europa.eu/portal/pls/portal/docs/1/8036724.PDF

[48] Ibid., 24.

interrupted service. The GJU had not made accommodations for a risk sharing protocol and therefore left it to the private sector to consider.

The other major issue revolved around fair returns on investment based on geography and the location of ground elements within the boundaries of particular member states. It was all about providing jobs to specific member states as they were reflected in the organization of the competing consortiums. Germany, once again, was proving to be somewhat recalcitrant on this issue as it demanded guarantees of project leadership and contract awards. German Transport Minister Manfred Stolpe laid it out for the German state at a Transport Minister meeting in 2005. He said that "we (Germany) will only free up additional resources when German interests are taken into consideration. We want the satellite control center and the inclusion of a German industrial entity (TeleOp GmbH) in the future Galileo consortium, as well as appropriate participation of German industry in building the system."[49]

The nearly year long period of apparent confusion continued into 2005 when both competing consortiums submitted bid proposals to the GJU for contracts to build, deploy and operate Galileo.

One of the consortiums was called EUrely and was composed of over 45 companies from across the globe. The major stakeholders were Alcatel, Finmeccanica, AENA and Hispasat. One of the major strengths of the EUrely consortium was the fact that Alcatel was the prime contractor for EGNOS and therefore was in a position to provide a head start into the development of Galileo and its systems.

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[49] Michael Taverna, "ESA Rolls Out Plan B for Galileo", *Aviation Week and Space Technology* 163, no.16 (October 24, 2005): 30.

The second bidder called itself iNavSat. This consortium had over 40 global corporations associated with it and was led by EADS, Thales, and Inmarsat. Negotiations between the consortiums and the GJU were difficult. Both bidders submitted proposals to the GJU with the intention of being awarded the concession to build and deploy Galileo. Unfortunately, GJU was unable to award the concession to either bidder due to the fact that both bids were too closely aligned and the degrees of separation between the proposals were too close for an award.

After negotiations with the GJU for a concession had stalled completely in early 2005, the GJU held deliberations with the two bidding consortiums and allowed the major players to further consolidate and form a single company called the European Satellite Navigation Industries (ESNI) with the expectation that the single entity would submit a proposal to the GJU. The same major private corporations that now made up ESNI agreed to share the bulk of the costs to finally build, deploy and operate Galileo. The participating companies were EADS, Thales, Inmarsat, Alcatel-Lucent, Finmeccanica, AENA, Hispasat, and the new German consortium TeleOp GmbH.

The major stakeholders proposed points and counterpoints as they attempted to design and craft an industrial organization that was capable of performing according to project requirements. Private sector negotiations amongst the major players were fractious. Unanimity was lacking and the various corporations could not even agree on who would be the CEO of the new consortium. At no time did ESNI speak with a single voice. The five major space member states and the industrial players had a round of meetings later in 2005 and hammered out a plan of action to finally get the project back on track and moving toward completion.

The meeting objectives had been to address the issues of risk, geographic returns and locations of assets. The plan allowed for the headquarters of the Galileo concessionaire or overall operations company to be located in Toulouse, FR, and have responsibility for the administrative and marketing aspects of Galileo.

Actual operations of the system would be entrusted to Inmarsat in the UK and it would have all management responsibilities as overseer of global network operations to include performance and operational security. There was agreement to locate one of the two control centers in Germany and the other in Italy as originally proposed. The plan also called for all backup systems and all aspects of Galileo safety related systems to be located in Spain.[50] Everyone needed to get a piece of the pie.

In spite of the realignment of industry in an effort to win the contract for the Galileo deployment, it still did not happen as envisioned. The GJU could not make an informed determination of a winning bid. As originally drawn and agreed upon, private industry would assume 2/3 of the cost of deploying and managing Galileo beginning in the Deployment phase. Although there was tacit agreement of that plan from the interested parties it proved to be nearly impossible to get all of the private stakeholders to sit down and agree on a common business plan to make it happen. The issuance of lucrative procurement contracts to specific members of the consortium proved to be especially vexing.

There was also concern within the Parliament that the project was moving away from the original goals set forth by the EC and that of the various committees. The Committee on Transport and Tourism for the Committee on Industry, Research and Energy, commented in January 2005 on a Parliament Resolution for a regulation on the

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[50] Glen Gibbons, "GNSS Trilogy: Our Story Thus Far", *Inside GNSS*, Premier Issue, (2006): 31.

implementation of the Deployment and Operating phases of the Galileo program of satellite radio-navigation. The Committee supported the need to increase allocation up to €1 billion in public funds to keep Galileo in business but raised other issues to insure proper stewardship of the public's treasure.

The Committee recommended that the issuance of addition public funding did not in any way exempt private contributors from their pecuniary responsibilities during the latter phases of the project. It also recommended that there be some procedure put in place that will provide a repayment to the Community against its investment by suggesting that the contract winners be limited to some specific levels of incoming revenues. Also very importantly, the Committee recommended that "the concession contract also provides for the concessionaire to receive the revenue from licenses and intellectual property rights for system components, ownership of which rests with the Supervisory Authority (GSA)."[51]

Then there was an Opinion released one month later in February of 2005 by the EESC that made specific references to the problems in working cooperatively in a PPP. This was released during concession negotiations when both sides were struggling to come to some agreement. It stated that the EESC was concerned about the Parliament and Council mandated procedures necessary for moving the project out of the public realm and into the Deployment phase where primary responsibility would pass to industry. The report suggested that new procedures needed to be drafted immediately to

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[51] A6-0212/2005 Opinion of the Committee on Transport and Tourism for the Committee on Industry Research, and Energy, on the proposal for a regulation of the European Parliament and of the Council on the implementation of the deployment and commercial operating phases of the European programme of satellite radio-navigation (COM(2004)0477 – C6-0087/2004 – 2004/0156(COD)), (Brussels: January 7, 2005), 32. http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+REPORT+A6-2005-0212+0+DOC+PDF+V0//EN

remove "complex, overlapping, and duplicated control measures, which are neither facilitating nor clear." [52] The Opinion also reminded the Parliament that the GSA, the agency created to oversee the Deployment phase and private industry involvement, was not going to be set up and running until 2005, meaning the agency could not be ready to provide the oversight required by Parliament which could necessitate another delay in contract decisions.

The Parliament also recognized that the timetable for the Deployment phase of the project had slipped by at least two years and now expected full operating capability by 2010. There was also recognition of the increasing costs associated with the project. The projected share of public funds, still limited to 1/3 of total requirements during the Deployment phase, had risen significantly beyond the original €500 million allocation. The Resolution provided that the needed financial support was not sufficient by stating that "it is therefore necessary to foresee a sum of €1 billion at 2004 prices from the Community budget to finance the deployment and the commercial operating phases of the programmes for the period 2007-2013, with its own budget line in the Community budget, thereby enabling the budgetary authority to link the funding to the meeting of deadlines for the various programme phases."[53]

Time finally ran out on ESNI and its apparent inability to perform to expectations. The BBC reported on a meeting of the EU transport ministers in March of 2007 where a deadline was set for ESNI to come up with a bona-fide business plan to include a single

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[52] Official Journal of the European Union, European Economic and Social Committee, *on the Proposal for a Regulation of the European Parliament and the Council on the implementation of the deployment and commercial operating phases of the European programme of satellite radio-navigation*, (Brussels: February 10, 2005), Sec 2.11, 2.12. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2005:221:0028:0032:EN:PDF.

[53] Ibid., Amendment 8. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2005:221:0028:0032:EN:PDF.

company structure and the appointment of a CEO who was authorized to speak for every member without contradiction. The ministers also threatened to reopen the bidding process if the industry bickering did not cease.[54] It had been nearly two years since the ESNI had submitted a proposal and still both sides could not come to a common agreement.

After missing two deadlines set by the EU to finalize the corporate organization, the EC finally proposed to the Parliament that it, the Parliament, assume full responsibility for the Galileo project to include funding. More specifically, this meant that the EC was proposing to abandon the PPP concept in favor of public ownership and operation of the project. It also meant that the EC was in favor of having the EU assume 100% of the costs associated with Galileo thus eliminating the possibility of private sector contributions and shared risk.

In the spring of 2007, the EU formally moved to take control of Galileo and removed the group of eight companies called the ESNI from the project. The consortium had abandoned the project earlier in 2007 unilaterally forcing the EU to act to continue the project or cancel it. Some reports indicate that business interests could not mitigate the risk involved with such huge expenditures without having more confidence in potential returns on investment. Apparently there were some in the business community who were convinced the given the choice of using the free services offered by GPS or paying for a slightly improved Galileo that the user would naturally gravitate to GPS. For whatever the reasons, and there were a number of them, Europe's largest trans-European project had undergone a complete makeover nearly nine years into its life.

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[54] BBC, "Galileo companies given deadline", *BBC*, March 22, 2007. http://news.bbc.co.uk/2/hi/science/nature/6479879.stm

One of the major impacts of the makeover was the assignment of huge additional costs on an already stretched EU budget. This was especially true of the near term in that the EU budget did not contain additional funding for Galileo and this funding would have to come from existing allocations almost immediately. The EU's assumption of full responsibility for Galileo did not sit well with all parties across Europe.

Germany was the EU's largest donor nation and continued to demand assurances its native industry would be receiving its fair share of contracts. Spain entered the fray with demands for a larger ground station and control presence than had previously been agreed upon while Sweden and the Netherlands were concerned generally about the ballooning costs of the project. But it appears that the member state with the least amount of confidence in the need or viability of Galileo was Great Britain.

The British House of Commons offered the most viral and strident opposition to the continuation of Galileo without private financing. A 2007 report by the House of Commons Transport Committee opined that "the process for reaching a decision on the future of Galileo and its funding is impenetrably complex. We fear that this complexity, along with the fact that the Galileo decision is now caught up in the negotiations on the 2008 EU budget, is creating an unstoppable momentum for a very expensive decision that is not supported by any robust evidence. We are deeply concerned that, with no one individual or body taking ultimate responsibility for a decision of this magnitude, a path of least resistance will simply be taken. This path is rapidly becoming a decision to proceed with and fund Galileo in the manner proposed by the European Commission in September. The Galileo train appears to have left the station without a qualified driver or anyone to apply the brakes. It would be a shameful indictment of EU decision-making if our worst fears were vindicated."[55]

In another broadside launched by the Transport Committee 2007 put the situation in clear context when it said of the struggling Galileo project that, "what taxpayers in the United Kingdom and other European countries really need and want is better railways and roads, not giant signature projects in the sky... The Commission is poised to spend billions of taxpayers' money on a satellite system without any realistic assessment of its costs and benefits... The government must stop this folly and endeavour to bring the European Commission to its senses."[56] The report went on the say that there is significant doubt inside the space industry that projected future revenues from Galileo would materialize as expected. There are also concerns that Galileo may arrive on stage already obsolete due to cost overruns and production delays. The report cites US and Russian efforts to upgrade their respective systems and the coming on-line of China's COMPASS global navigation system as being the biggest threats to Galileo's success.

In the end all of the member states finally supported the continuation of the project and voted to fully resource Galileo at the levels necessary for mission success. Once consensus was reached in late 2007 the tempo and the progress experienced a remarkable resurgence. The ESA was the new procurement manager and the GSA was tasked to manage the progress to include market development. Even though the project was three years behind schedule the time had come to transition into the Deployment phase.

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[55] House of Commons Transport Committee, *Galileo: Recent Developments HC53,* (London: November 7, 2007), 28. http://www.publications.parliament.uk/pa/cm200708/cmselect/cmtran/53/53.pdf

[56] Lewis Page, "Galileo slammed by UK politicians", *The Register*, November 12, 2007. http://www.theregister.co.uk/2007/11/12/galileo_shoeing_uk_pols/

F. POST PPP

The Development phase had proved to be much more difficult to accomplish than had ever been envisioned by the European Parliament or the Commission.

The EP came to the project's rescue in mid 2007and supported a movement by the member states finance ministers to allocate the additional €2.4 billion required by stripping funds from other projects.[57] Galileo had obviously become a project too large to fail. Funding would come from unspent agricultural subsidies and were readily available. However, this decision created serious internal strife amongst the member states just when the Galileo project was in a real state of flux. This did not sit well with the Northern European states of Germany, Netherlands, and the UK who contribute the bulk of the agriculture funds to EU coffers. There was an expectation that those major contributors would have those monies returned to their respective treasuries if not spent on agricultural subsides. The concern here was all about 'fair return' and whether or not each country would get a proportional return on its Galileo investments.

In response to a Parliamentary question on funding, Lord Malloch-Brown answered for the UK Government that, "The European Commission's working document of May 2007 accompanying the Commission Communication 'Galileo at a crossroad: The implementation of the European GNSS Programmes', suggested that reasons for the failure included continuous unresolved disputes over the share of industrial work, unresolved negotiations on the transfer of design risk, the technical complexity of the programme, and insufficiently strong and clear public governance.

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[57] Rob Coppinger, "Galileo navigation satellite provider to be dismantled", *Flightglobal,* November 30, 2007, http://www.flightglobal.com/articles/2007/11/30/219984/galileo-navigation-satellite-provider-to-be-dismantled.html

Ministers at the Transport, Telecommunications and Energy Council in June endorsed the Commission's analysis, and concluded that the deployment phase of the programme would best be carried out with an alternative procurement model."[58]

The issue was cost versus revenues and it appeared there was no consensus on realistic costs or future revenue streams leaving the door open for conjecture and grandstanding by politicians across Europe. It looked as if European taxpayers were the big losers over the collapse of the PPP supporting Galileo. In seven years the major corporations could not come to full agreement on how to proceed with the deployment of the satellite array, mitigate the risk of signal failure, and still contribute the €2.4 billion needed to finance the next phase of the project.

This was not the only issue; there was also a serious lack of understanding and cooperation between Galileo's regulatory authority, the GSA, the GJU, and the Galileo Operating Company (GOC). Unfortunately, the GOC never reached an operational level because there were too many parochial agendas exhibited by the corporations and by the degrees of willingness that the member states and intergovernmental organizations were working toward a common goal.

The capstone event of the Development phase was to be the launch of four purpose built test satellites of the array along with several operational ground stations and an operational control center in Germany as a validation of the system and the end of the Development phase.

The first two validation satellites were launched in an effort to prove the concept and claim ownership rights of Galileo's signal frequencies. These first test satellites

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[58] Gawain Towler, *Black is White: Government Deception and the Galileo Project*, (London: The Bruges Group, February 26, 2008), 9.

were referred to as the Galileo In-Orbit Validation Elements or GIOVE A & B. The first, GIOVE-A, built under the auspices of the ESA by Surrey Satellite Technology, Ltd., of Great Britain, was launched into space by a Russian Soyuz rocket from Kazakhstan on December 28, 2005. GIOVE-A was launched more than 12 years after the first EU study, sponsored by the European Committees for Transport and Science, and Research and Development, was funded and approved to investigate the possibility of building a European GNSS that would compete on the global stage with America's GPS. The launch was past due and over budget but it was finally a reality, and it worked exactly as advertised.

The second test satellite, GIOVE-B, was also launched from Kazakhstan on-board another Soyuz rocket on April 27, 2008. The European Satellite Navigation Industries (ESNI) had the initial contract to build GIOVE-B. The original requirement under the terms of the contract called for GIOVE-B to be fully launch capable by the end of 2005 and it failed to meet that timeline. However, when the PPP was dissolved in 2007 due to the inability of the EC and ESNI to agree on a workable partnership, the ESNI contract for GIOVE-B was revoked and a second contract was awarded to Astrium GmbH of Germany for completion of the project resulting in a three year delay in launching GIOVE-B.

The major issue for GIOVE-B all along had been the make-up of ENSI. These were the powerhouse industrial corporations of Europe and it seemed they were operating without adult supervision. There was already a high level of built-in stress because of the inherent competition that existed among the partners and one entity was reluctant to take direction from another making decision making nearly impossible. At the same time, the major member states of the UK, Italy, Germany, Spain, and France were demanding absolute adherence to the fair return policy of the ESA. The process was seriously flawed at the public and the private level.

Those problems aside, there were two main objectives that had to be met with the launch and validation of the GIOVE satellites. First, it is important to understand that the International Telecommunication Union (ITU) in Switzerland controls radio frequency distribution across the globe and, because signal generation is the primary task of any GNSS, that makes the ITU a critical enabler for any new GNSS being deployed. At issue is the fact that there are a finite number of frequencies available for use and obtaining the usage rights to new frequencies was an absolute requirement before Galileo operations could begin.

The ITU responds to requests from the public and private sector for the opportunity to reserve and have allocated certain bandwidths of frequencies to support their specific requirements. The ITU reviews and evaluates the requests and then has the responsibility to reserve available frequencies to the requesting organizations or not. Frequencies are carefully monitored and allocated because of the possibility of frequency interference by other users based on signal overlap, strength, or duration is a real concern for users. When the ITC reserves frequencies for an organization then the agreement stipulates that the requesting organization has an agreed upon time to actually begin using the frequency or risk having the reservation rescinded. States cooperate voluntarily with the ITU and not all states work within the confines outlines above as will be seen in Chapter IV.

The ESA's reservation for the Galileo frequencies was set to expire in June 2006 and the validation of signal generation from GIOVE-A to a tracking station on earth occurred for the first time on January 12, 2006. Claiming ownership of its reserved frequencies was the primary objective for getting GIOVE-A launched in time to avoid losing the frequency allocations. As a result of the extensive delays in getting GIOVE-A and B launched, the ESA issued a third contract for GIOVE-A2, another validation satellite, to Surrey Satellite Technology, Ltd., with an expectation of a relatively quick build and launch in order to protect Galileo's frequency reservations. Because of the extensive delays with the test satellites and the project generally, GIOVE-A only claimed two of the proposed five frequencies that were proposed originally. GIOVE-A was not equipped to test and validate the PRS band and that would prove to be a contentious omission in the near term for the EU.

The other major requirement requiring validation was the confirmation of the performance parameters of the super sensitive and super accurate atomic clocks that were installed on the GIOVE satellites. The design performance parameters for the atomic clocks were one of the major risk factors that were never resolved between the ESA and the corporations. If the clocks did not perform according to design then the performance guarantees for Galileo service would be at risk.

There were two different clocks installed on the GIOVE satellites. One type was the rubidium atomic clock, accurate to within 10 nanoseconds per 24 hours, and the other is a hydrogen-maser clock, accurate to within one nanosecond per 24 hours and was to be the singular most accurate clock ever launched into space. Both types provide significant improvements in positioning, navigation, and timing signaling service compared to the current GPS satellite array. The accuracy of the clock correlates directly to the fidelity of the signal since the location is measured by the time it takes for a signal to emit from the satellite hit the earth and return to the satellite. When four or more satellites are used simultaneously for location determination then a specific location can be ascertained down to a known and predictable position.[59] The accuracy of the onboard clocks is the most critical aspect of the accuracy of the PNT signal.

Signal generators and signal receivers were also scheduled for testing during this validation period, as was the performance of all subsystems built into the ground station.

The consensus opinion in the EC stressed the importance of getting at least four satellites deployed as soon as possible in order to begin operations. So the focus was on getting the first four satellites built and deployed.

These first satellites built after GIOVE are called the ProtoFlight Model (PFM) with subsequent satellites consisting of three Flight Models (FM2, FM3, and FM4). They have been under construction by an EADS-Atrium led consortium and are expected to be operational in space by late 2012. The first two scheduled for launch, PFM and FM2, were shipped to the European space launch facility in French Guiana and launched on October 21, 2011 marking the beginning of the actual Deployment phase of this long running project. Both were mated to a Russian Soyuz-Fregat ST-B launch vehicle and sent into a 23,200 km MEO to be the first two of 30 satellites making up the Galileo constellation. FM3 and FM4 are scheduled to be launched sometime later in 2012 from French Guiana and will finally enable Galileo to provide positioning, navigation, and timing signals to waiting receivers. The current schedule calls for two satellites to be

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[59] ESA BR-251, *The First Galileo Satellites*, (Noordwijk, the Netherlands: ESA Publications Division, 2006), 3-4. http://www.esa.int/esapub/br/br251/br251.pdf

launched every quarter through 2014 until 24 satellites have populated the array and Galileo can advertise itself as being at full operational capability.

G. CONCLUSION

If the current launch schedule is met over the next several years it seems likely that Europeans will begin to see benefits from Galileo in 2015 when a sufficient number of satellites have been put in orbit to form a functional array. Until then, it will be business as usual with GPS.

One thing is certain. The Galileo project has made steady progress since the PPP failure back in 2007. However, the budget cost overruns continue to plague the project. Over €4.5 billion has been allocated to fund Galileo through 2013 and it seems that at least €7 billion more will be required to fund it out to 2020. These costs will be ameliorated if Galileo provides the huge, some say up to €90 billion, economic and social benefits over the next 20 years or so that are anticipated to be generated.

There are a number of important variables that will be coming into play within the next four to seven years that will certainly clarify the GNSS picture. If GPS III comes on line before Galileo then the EU will see GPS once again being the 'gold standard' of GNSSs and will be forced to play catch up. If GPS wins then Galileo and the EU will be at a distinct disadvantage trying to collect fees for PNT service of any kind because GPS will be offering equal or better services at no cost to the same markets.

There appears to be consensus among member states that Galileo is a dual-use system and will be used to support member state military forces. But there are more unknowns than knowns in the actual application of Galileo capabilities in military operations. One critical unknown that needs resolution is China's intent to overlay its encrypted signal frequency on the proposed Galileo PRS frequency. The EU had the foresight to reserve five frequencies for Galileo operations but did not have the where-with-all to validate all five with the GIOVE-A deployment thus leaving an opportunity for China to act.

Another critical issue related to the dual-use nature of the system is the fact that NATO will continue to use GPS as its primary PNT service. The major implication for the EU is that all military user equipment will be primarily GPS centric with the secondary capability to prosecute Galileo PRS if and when it comes online. If the EU does not resolve its signal overlay conflict with China and Galileo's PRS ends up on the same, or nearly the same, frequency as COMPASS then it would be a valid assumption that NATO military equipment would not use PRS at all because of security concerns. In any event, it appears that PRS will have to be offered to the military at no cost because GPS is offered at no cost and this will deny EU coffers another stream of revenue from services.

Another looming issue has to do with the Asian market for user equipment. If China's COMPASS comes on line before Galileo then the Asian market for EU manufactured user equipment will be seriously jeopardized and that would be a major setback for Europe's space industry. The EC made the decision early on to solicit international partners in the design and development of Galileo. China responded in the affirmative and contributed €200 million to the cause with a valid expectation of participation. That expectation was eventually dashed by member state second thoughts about sharing technology with China.

It will never be known how much this aborted attempt at international cooperation with China is going to cost the EU. What is known, however, is that China's COMPASS is on track to be a serious competitor for Galileo and China has a very clear understanding of the potential economic and technological gains waiting to be realized from capturing the bulk of the Asian PNT user equipment market.

To a certain degree, the same can be said for the EU failure to capitalize on India's interest in becoming a Galileo partner. The EC's reluctance to extend an open welcome to Indian participation may have cost the EU the entrée it needed to be the major provider of user equipment to the Indian sub-continent. There is no doubt the original intent of the EU to promote Galileo to a global audience and welcome international cooperation and partnership was a noble example of liberalism. However, walking that walk proved much more difficult than envisioned and, in the end, it probably proved to be a failed experiment.

It may very well be that Galileo ends up being a captive system built in Europe for Europeans and is destined to be a source of pride and accomplishment but not profit. That chapter on Galileo waits to be written.

CHAPTER IV

GNSS COMPETITION

A. INTRODUCTION

Although a strong argument can be made that the EU chose to build its Galileo system in order to gain independence from GPS and provide industrial security for its member states, the same cannot be said for other global states. The purpose of this chapter is to provide a roundup of efforts by other global states to provide themselves with space-based positioning, navigation, and timing capabilities. Each state is motivated by a different set of circumstances and each has expectations of different outcomes from their efforts but there are commonalities across all of the strategies.

This chapter will look at the two other major competitors of GPS as well as two states that have invested heavily into space navigation and can be considered as regional players.

GLONASS is what Russia considers the equivalent of GPS. As will be seen, there are a number of significant similarities of this system with GPS and a number of significant dissimilarities as well. GLONASS was designed as a global system and was created by the Soviet Union during the height of the Cold War. Its track record for successful operations has not been good over the years and this chapter will delve into the problems associated with the system. It has been a long and tenuous journey but it appears Russia has finally done a GLONASS make-over to the degree that it is now considered at least a worthy competitor of GPS in terms of accuracy and reliability.

The People's Republic of China decided nearly three decades ago that its future could be better secured with a captive GNSS. COMPASS or BeiDou-2 is the name of its global system. China has been working on acquiring its own space-based PNT system since the 1980's and is well on its way to success.

India is another global player that developed an internal need to possess PNT capabilities. In this case, India was not particularly interested in obtaining global navigation capabilities but did need to have a captive, secure, and dependable regional capability.

Japan is the fourth global player that will be studied. Being the primary Asian ally of the US, it is not surprising that Japan relies on GPS for most of its services. However, this is a state that recognized a need for PNT capabilities that exceeded the limits of what GPS was offering. Like India, Japan did not have a requirement for a global perspective rather it was searching for a capable regional capability with much greater accuracy and availability.

There are other states that have interests in obtaining PNT capabilities besides those already mentioned. Presently however, there are no other players on the immediate horizon with the capabilities or the national commitment to support even a regional system. The four major players, the US, the EU, Russia, and China, have courted various states off and on again with agreements on the use and availability of their captive GNSS capabilities. Generally speaking, these enticements of service are all coupled with some degree of reciprocity in economic or political favor. These efforts will not be investigated in this chapter.

This chapter will attempt to explain the rationale behind the efforts of each state while paying particular attention to the national security and economic aspects of their behaviors. It is also important to realize that Russia and China are not the most transparent nations on earth and that access to official government documents detailing government proceedings and decisions are difficult or impossible to get. Instead, much of the information available on GLONASS and COMPASS comes from industry publications, newspapers, international organization meetings notes, and blogs.

B. GLONASS

GPS is not the only GNSS that was spawned by the Cold War. When the Soviets realized the quantum leap in munitions targeting accuracy that GPS was providing the US during the Cold War it had little choice but to devote the necessary resources to creating a similar system or risk losing its global competitiveness in a number of key areas. What was at stake was the accuracy and effectiveness of the Soviet fleet of intercontinental ballistic missiles, nuclear submarines, and nuclear capable intercontinental bombers. What the Soviets needed were global capabilities. The Soviets would call their system GLONASS or GLobal Orbiting NAvigation Satellite System (GLObal'naya NAvigatsionnay Sputnikovaya Sistema).

GLONASS was and still remains similar to other global systems in several respects. It was designed with a 27 satellite constellation operating in MEO. It was controlled with a system of ground support stations and its user segment required receivers built to process its signals. Beyond these three very general design considerations the Soviet system was very different from GPS.

Originally conceived during the Cold War in the 1970's and now under the auspices of the Russian Federation Government's Russian Space Forces of the Ministry of Defense, the full system consists of 24 satellites (and three spares) and a ground control segment located entirely within the boundaries of the former Soviet Union. The satellites have been upgraded several times since inception and are referred to as GLONASS (1982)[1], and then upgraded to GLONASS-M (2003), upgraded again to GLONASS-K (2011), and then the future upgrade of GLONASS-KM (2015+).

GLONASS was designed and built as a dedicated military-only system. However, the decision was made in 1988 to open GLONASS unencrypted signals for civilian use. The dual-use nature of GLONASS was reinforced in 1995 just prior to reaching full operating capacity when the Russian Federation released Presidential Decree No. 237. It stated that the Ministry of Defense, the Russian Federal Space Agency, and the Ministry of Transport "are to provide deploying of the GLONASS global navigation satellite system and the beginning of its operation with its full complement in 1995 in order to service national civil and military users and foreign civil users according to the existing commitments."[2]

This is a significant event in the GLONASS saga because it demonstrated a clear awareness by Russia of the economic potential to be gained from making GLONASS available to the global markets. As will be seen, it would take more than a decade to realize any benefit from this decree but it is obvious that a clear path forward had been mapped and would be followed. GLONASS is similar to GPS in the sense that both

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[1] Some documents refer to the satellites as GLONASS and others refer to them as Uragan while using the GLONASS moniker to describe the entire system. The actual name of the satellite family is Uragan. For the sake of simplicity, this work will only use the term GLONASS.

[2] Hofmann-Wellenhof, 342.

systems broadcast two different signals. GLONASS offers a standard accuracy signal for civilian applications similar to the GPS C/A signal and the high accuracy encrypted code for military applications that is similar to the GPS P-code.

In the 90's the newly organized Russian Federation was confined to an economic straitjacket and the effects on Russia's once proud space program were nothing short of devastating. Russia's space assets had declined by over 150 percent during the 1990's. By 2004 Russia's orbiting fleet was reduced to 96 space vehicles with 65 percent of them operating beyond their life expectancies. Fourteen of those space vehicles were GLONASS satellites and that wasn't sufficient to even provide full service over Russia much less the world. At the same time, US space assets included an astonishing 415 satellites in orbit giving the reader some sense of the degree of disparity between the space capabilities of the current superpower and the former superpower. Even more telling was the 2004 US space budget of $16.4 billion compared to the miniscule $0.8 billion space budget of Russia.[3]

After his 2000 election, President Putin recognized the value of a strong space program for the collective health and prestige of Russia, both domestically and internationally, and took a strong personal interest in reviving Russia's lagging space efforts. He singled out GLONASS as one of the primary pillars of that resurrection.

1. EARLY DAYS OF GLONASS

The Soviet development of a satellite based navigation system in many ways parallels efforts by the United States in the same field. Initially, government scientists

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[3] Charles Lutes and Peter Hays, ed., *Toward a Theory of Spacepower: Selected Essays,* (Washington D.C.: National Defense University Press, 2008), Chapter 23, 1.

responded to the need for a system that would provide navigational aids to Navy ships and ballistic missile submarines at sea. They developed a four satellite system called Cicada that was put into service in 1979. Cicada was a VHF system similar in nature to the US Transit system of the same time period. Cicada satellites operated from polar orbits and generally required more than 15 minutes to compute a position. Eventually, these early navigation satellites were also equipped with distress beacon receivers and marked the beginning of the global Cospas search and recovery system that is still the primary global search and rescue system used by all nations.[4]

There were three serious drawbacks of the system with the first being a requirement for the user to know their velocity or movement speed in order to plot a position, secondly, the user needed to know their elevation (this was not a problem for ships at sea), and finally the system was not available 24 hours per day. The system was better than nothing but needed significant upgrades in order to be usable by land forces in a tactical environment.

2. RESPONSE TO GPS

These early systems were appropriate for the time but could not support the greater needs of the military forces that were prosecuting the Cold War. The Soviet Union needed PNT capabilities to improve the targeting accuracy of its ICBM's and that need led to the development of GLONASS. The US launched the first GPS satellite into orbit in 1978 forcing the USSR to accelerate its effort in order to keep abreast of US targeting capabilities. The first GLONASS satellite was launched four years later on

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[4] Federal Space Agency, Information-Analytical Centre, *Navigation space systems of the I generation,* (Korolev, Russia, 2012). http://www.glonass-center.ru/en/guide/index.php

October 12, 1982 into a circular MEO at an altitude of 19,140 km. Both systems were expected to be fully operational by 1994 or 1995. In order to make up for lost time, the Soviet launch schedule was significantly more aggressive than the GPS schedule. In order to achieve the goals set by the Soviet Ministry of Defense there were certain trade-offs in satellite design or performance that had to be made due to deficiencies in Soviet technology.

While the expected performance parameters from all GNSSs are roughly the same it cannot be said that they are all designed and built alike. GLONASS is a very different system than GPS in a variety of ways. The geography of the Soviet Union played heavily into the original design of the system. Most of the USSR is situated in the northern latitudes and this required the GLONASS satellite constellation to utilize a circular MEO but with the satellites looking more northerly than GPS satellites[5]. Theoretically, GLONASS would have an accuracy advantage over GPS in the polar region due to the satellite inclination. This is of particular importance since the flight paths of ICBM's traveling between the US and the USSR generally use a polar trajectory[6].

GLONASS was designed to operate at full capacity with an array of 27 satellites including 24 operational and three spares in three orbital planes of eight in space. GPS also operates with 24 satellites but the array is distributed along six orbital planes. The Soviets built their system with three orbital planes in order to support their projected launch schedule. Unlike the US that was generally launching one satellite at a time; the

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[5] A satellites view of earth is generally measured against the equator and being directly over the equator would represent 0 degrees. GLONASS satellites are inclined 64.8 degrees from the equator versus 55 degrees for GPS satellites. This means that GLONASS has better theoretical coverage in the northern latitudes and lesser coverage in the temperate latitudes where GPS is better.

[6] P. Daly, "Navstar GPS and GLONASS: global satellite navigations systems", *Electronics & Communication Engineering Journal*, December 1993, 349-350.

Soviet plan envisioned launching three GLONASS satellites at a time atop the massive Proton launch vehicle. Populating three orbital planes was considered the best and most efficient design based on the aggressive launch schedule.

The first generation of GLONASS satellites left a lot to be desired when compared to first generation GPS units. The single most significant difference between the early GLONASS and GPS satellites is the life expectancy of the individual space vehicles. First, GLONASS satellites were built with an expected life span of just three years. GPS satellites were built with an expected life span of five to seven years. Most GPS satellites exceeded their life expectancy by 50% at least while most GLONASS satellites failed within their design parameters.

The first six GLONASS satellites, Block IIa, averaged 16-month life spans. There were then 12 Block IIb satellites launched during the 1987-88 timeframe but six of them were lost in launch pad failures. The remaining six had an average lifespan of 22 months. Block IIv GLONASS was the most numerous of the first generation of GLONASS satellites with 25 being deployed into orbit. This model also had the best operational life with many of them working beyond their 3-year design point while the best performing Block IIv satellite remained operational for 68 months. As was the case with many of the weapons systems built by the Soviet Union, there was reliance on quantity and not necessarily on quality. Once a minimum design expectation was met the prevailing sentiment was to go to full production in order to maximize economies of scale. This aspect of Soviet military doctrine can be seen in all aspects of the Soviet military system. This played out in two important areas in GLONASS satellite production.

The first is the disparity in life span in the base design of the satellite components. GPS satellites were designed and built to operate in the vacuum and super cold temperatures of space while GLONASS were not. The Soviet Union generally lacked the expertise, the time, and the resources to do the research and testing required for operations in a space environment so they built a satellite with a pressurized bay that would provide earth-like atmosphere and temperature control for the individual components. Not only did this design aspect add significant weight to each satellite but it also added many more failure points to the design and was one of the primary reasons for a reduced life cycle to a mere three years. A pressurized bay design also facilitated an assembly line approach to satellite production using proven technology thereby allowing the Soviets to make up for lost time and remain competitive against GPS with a much more aggressive launch schedule.

A second major design difference between the two systems was the method of satellite signal generation and reception. GPS utilizes something called a Code Division Multiple Access (CDMA) generation system while GLONASS depends on something called Frequency Division Multiple Access (FDMA) generation.[7] Simply stated, that means that all GPS satellites in the array broadcast their signals on the same frequency and satellite differentiation is attained because each satellite signal contains the specific parameters (ephemerals) pertaining to each individual satellite.

Each GLONASS satellite, on the other hand, broadcasts its signal on a separate frequency. This method does two things. First it is more difficult to jam because there are many more frequencies to jam against the single one that GPS uses. Secondly,

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[7] Norman Bonnor, "A Brief History of Global Navigation Satellite Systems", *Journal of Navigation* 65, no. 1 (January 2012): 7.

receivers need only discriminate against between frequencies making receiver design easier than GPS units that needed to discriminate signal codes from 27 satellites on one frequency. Conversely, tracking multiple frequencies actually reduced the accuracy of GLONASS readings because of the actual difficulties encountered trying to tune multiple frequencies and signals and the varying effects of the atmosphere on radio waves.

In a 2005 report, the Swiss Institute of Science Research and Engineering reported that GPS accuracy was in the one meter range while GLONASS-M consistently performed in the seven or eight meter range. The report attributed this discrepancy to the use of FDMA for signal generation and, to a lesser extent, problems in the satellite software and quality issues with the atomic clocks.[8] This is another example of Soviet willingness to design military systems that are 'good enough for government work' and are not necessarily state of the art systems but are easier and cheaper to manufacture and deploy.

Because GLONASS was considered a secret military system the Soviet Union did not apply for frequency allocations from the ICU leading to numerous complaints from global users over GLONASS signals interfering with other frequency users. In 2003 Russia pledged to change its signal generation systems to CDMA in all future GLONASS-M satellites thus phasing out use of FDMA signal generation. This modification also simplifies system interoperability with other GNSSs and supports Russia's stated desire to become interoperable and compatible with other GNSSs.

Soviet receivers were robustly designed and were typically much larger, heavier, and generated more heat than their US counterparts. This limited the availability of

[8] Glen Gibbons, "GNSS Trilogy: Our Story Thus Far", *Inside GNSS*, January-February 2006. 29. http://www.insidegnss.com/pdf/trilogy_sec.pdf

receivers to those platforms with the capability of managing the weight and heat. GPS receivers were readily available in hand-held configurations and were more field-friendly than their Soviet counterparts.[9] Combined GLONASS/GPS receivers started becoming more available in the mid-2000's but were still somewhat larger than their GPS counterparts.

This is an important aspect of the competing designs that really didn't manifest itself for at least a decade or longer. When President Putin decreed that the Russian Federation would reach out to other states in the spirit of international cooperation he put space projects near the top of the list. GLONASS became a major state priority and was prominently advertised as a free service to anyone who wanted to use it. The problem was finding a receiver as there were very few on the market and nearly all were manufactured by Russian state corporations and were very expensive compared to the inexpensive and ubiquitous GPS receivers. Putin's continuing interest in the project was a good omen for the future of GLONASS.

3. POLITICAL DIMENSION OF RESURRECTING THE SYSTEM AND PUTIN

Although Russia is proud of the fact that it was able to design, build, and then deploy a sophisticated space system like GLONASS, it has also been forced to admit that funding shortages that began even before the system attained full operational capacity in 1996 ate away at it like a cancer. Three-year life expectancies from the GLONASS satellites really doomed GLONASS because there was not sufficient political will or national treasure available to maintain such an aggressive satellite replacement schedule.

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[9] Andrew Kramer, "Russia Challenges the U.S. Monopoly on Satellite Navigation", *New York Times*, April 4, 2007.
http://www.nytimes.com/2007/04/04/business/worldbusiness/04gps.html?pagewanted=all

Consequently, GLONASS quickly fell into a non-mission capable status reaching its nadir in early 2001 with just seven operational satellites and no replacements on the horizon for nearly a year.[10] It had become as tired and non-functioning as the Russian military machine in general.

When the Cold War ended and the Soviet Union ceased to exist the need for GLONASS waned and the funding stream dried up leaving the system fully degraded and inoperable. This was a time of transition for the old Soviet space industry. Long renowned for their robust satellite designs and very reliable and cost effective launchers, the Russian space industry turned to commercial 'buy-sell' strategies in order to preserve their space system industrial capacity. This strategy proved to be very successful and saved the industry for future rejuvenation. Amazingly, Russia controlled over 40 percent of the commercial launch market across the globe in 2005 compared to about 30 percent for the US, 16 percent for China, 6 percent for the EU and 2 percent for India.[11]

Among the challenges facing Russia's space industry beyond the loss of funding was the growing shortage of qualified scientists and technology personnel available to the industry. The first generation of space workers had retired by the 1990's and reduced funding had taken the luster off of space work as a career such that Russia was forced to seek international partners in order to prop up its scientific programs.

Just as President John F. Kennedy had energized the US space program during the 1960's, President Vladimir Putin also took an active interest in space systems as an avenue to increased economic prosperity for the industrial sector and as a way to increase Russia's standing amongst nations during the decade of the 2000's. One of the first

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[10] Georgy Polischuk and Sergey Revnivykh, "Status and development of GLONASS", *Acta Astronautica* 54, (2004): 951.

[11] Lutes and Hays, Chapter 23. 3.

things he did was have the Russian Federation issue a Presidential Decree in 1999 declaring that GLONASS was a dual-use system and would be available to anyone, anywhere, free of charge. Through his advocacy GLONASS was given its own budget line and its funding stream was increased sufficiently to bring the system back to life within a ten year period.

At the same time there was recognition that GLONASS was still considered an integral part of Russia's national security strategy and infrastructure.[12] But it was not considered the critical element that it once was. The Russian Navy rarely leaves home waters anymore, Russia no longer deploys a fleet of ballistic missile submarines along the US coastlines, and its nuclear bombers rarely take to the air except in infrequent exercises. That means that those strategic forces no longer require the services of GLONASS on a recurring basis. Emphasis on offensive operations has ebbed and the focus has shifted to unarmed space vehicles designed to support the economic security and prosperity of Russia.

The Federal GLONASS Mission Oriented Program 2002-2011, adopted in 2001, confirmed Russia's future commitment to redeploying its satellite navigation system as a global equal to GPS. One measure of the changing nature of space systems within Russia's ruling hierarchy is the fact that the GLONASS program became, for the first time, part of a transparent public framework of a federal program and removed it from the deep recesses of a top secret Ministry of Defense program.[13]

The Program called for the maintenance, deployment, modernization, and operation of the system. It called for the development and mass production capability of

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[12] Polischuk and Revnivykh, 949.
[13] Ibid. 950.

user equipment including those required for civilian use and allowed for the upgrading and expansion of the ground support segment. The Program also recognized the value of GLONASS toward the improvement of civil society by calling for the integration of GLONASS capabilities in all facets of transportation, mapping and surveying, and the development of a new generation of military equipment.[14]

The GLONASS Interagency Control Board was also established in 2002 to coordinate activities among the four primary stakeholders of GLONASS. The two major players are the Russian Space Agency (Roscosmos) responsible for system design and development and the Ministry of Defense that is responsible for operations and maintenance of the system. The other two stakeholders are the Ministry of Industry and Energy that is responsible for the development of user equipment and the Ministry of Transport that is responsible for the integration of GLONASS into the transportation infrastructure of the Federation.

The new organizational structure established for the rebirth of GLONASS was followed in 2004 with a truly landmark event as Russia and the US formed the GPS/GLONASS Interoperability and Compatibility Working Group. This was particularly significant in the sense that these two Cold War legacy systems had been an integral part of the global MADD scenario and now both sides were sitting down and exchanging design secrets in an effort to truly work together in an effort to ensure the interoperability and compatibility of both previously top-secret systems.

An update to the GLONASS Mission Oriented Program in 2006 further defined the goals of the project. The first goal was achieving a minimum regional operational capability by 2007; the second was gaining full global operational capability of 24

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[14] Hofmann-Wellenhof, 344.

satellites by 2009; and lastly, ensuring that GLONASS performance was comparable to GPS by 2010.[15] As it turns out, GLONASS did reach minimum regional operational capability of 18 satellites by 2007 but failed to reach full operational capability by 2009. That waypoint was reached for the first time since 1996 on October 3, 2011 with the launch of a single GLONASS-M satellite that became the 24th operational segment of the constellation.[16] It is debatable whether or not GLONASS' performance has improved sufficiently to be fully comparable to that of GPS; but in any event, it has largely closed the gap.

4. ECONOMIC IMPACT

GLONASS redeployment has been financed under the Federal Target Programme GLONASS 2002-2011 and was allocated 70 billion rubles or about $2.4 billion over the ten year budget bill and possibly up to $12 billion in maintenance and upgrades during the 2012 to 2020 timeframe.[17] This is considerably less than the estimated €12.9 billion ($17 billion) cost of Galileo out to 2020 or the estimated $22 billion cost of the 40 satellite GPS III program out to 2020[18]. Russian budgetary expenditures on all space activities in 2007 were quite low by Western standards. The 2007 Federal Space Agency budget was 13 times less than the NASA budget and a full three times less than the ESA

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[15] Hofmann-Wellenhof, 344.

[16] Stephen Clark, "Soyuz Rocket Launch Restores Russian Satellite Navigation System", *Space.com,* October 3, 2011. http://www.space.com/13161-soyuz-rocket-launch-russian-satellite-navigation.html

[17] "Russia to Launch 2 GLONASS satellites in 2012", *RIA Novosti* (Moscow: February 22, 2012). http://en.rian.ru/russia/20120222/171464010.html

[18] United States Congress, *The Global Positioning System for Military Users: Current Modernization Plans and Alternatives,* (Washington D.C: Congressional Budget Office, October 2011). http://www.cbo.gov/sites/default/files/cbofiles/attachments/10-28-GPS.pdf

budget.[19] Those are amazing numbers considering the scope and size of the space program during the Soviet era.

Russia has long been one of the world's major purveyors of arms and the economic decline of the Russian state and its military put exports from its huge military industrial complex in jeopardy. Interestingly, Russia was rolling out new weapons systems by 2003 that were enabled by the combined GLONASS/GPS PNT capabilities. Because GLONASS was not fully operational at the time and precision weapons required space-based navigation support the Russian arms industry designed their new systems to prosecute GPS civilian signals. The receivers were also capable of prosecuting GLONASS signals at some point in the future as they became available.

Capitalism was on display when Nikolai Testoedov, the director general of the Scientific Industrial Association of Applied Mechanics (NPO PM), made the following remarks to reporters in 2007. NPO PM is the primary satellite design bureau in Russia and was responsible for GLONASS satellite designs. He was referring to the newly designed GLONASS-M when he said the efforts to restore GLONASS must "not repeat the mistakes of the past" and that it required extended functionality of each satellite and the absolute ability of the whole system to operate profitably.[20] Who would have predicted that Russian state corporations would at some point be required to show a profit? It was an amazing turnaround from the old Soviet days.

One of Russia's primary arms trading partners over the past four or five decades has been India. It is the second largest nation on the globe by population and represents a huge potential market in terms of goods and services. India, for its part, has considered

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[19] Mathieu, 61.

[20] Henry Ivanov, "Ramping up Glonass", *Janes Defence Weekly* 44, no.1 (January 3, 2007): 21.

China a security threat at least since the Sino-Indian war in 1962. Russia recognized an opportunity to use space development as a foreign policy tool while at the same time improve its domestic economic situation when it entered into its first space cooperation agreement with India in 2007. Part of the agreement involved cooperation in the redeployment of GLONASS with India providing some launch services for GLONASS satellites and India's domestic industry having the opportunity to assist in the design and manufacture of GLONASS receiver units. This arrangement would offer Russia direct access to the Indian market for GLONASS services and support equipment. A subsequent agreement in 2011 provided India with GLONASS military signals that would improve the precision delivery of Indian missiles including those from its nuclear submarine.[21] India is the only state that Russia has given access to GLONASS precision code.

With an expectation of a fully functioning GNSS at some time in the near future, Russia also enacted several new laws mandating the use of GLONASS or GLONASS/GPS user equipment for all state applications including transportation, maritime, and surveying. This policy supported the agreement signed with India to cooperate on the design and manufacture of user equipment and the development of the ground station support network. The policy did not address interoperability with Galileo or BeiDou and seemed to limit market access to those systems' user equipment, at least at the state level, and favored GPS. The reason for this exceptionalism could be that GPS is the only operational GNSS at the current time and therefore Russia really had no choice. However, the Galileo ICD had been released and Russia still determined not to include

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[21] Sandeep Dikshit, "India strikes deal with Russia on GLONASS", *The Hindu*, December 19, 2011. http://www.thehindu.com/news/national/article2726888.ece

Galileo in the official decree and that may signify a payback of sorts for being snubbed in the early development of Galileo by the EU.

Additionally, tax policy was modified to support the use of GLONASS receivers by increasing the tax on GPS-only receivers to 25% from 5% while maintaining the 5% tax on dual-system GPS/GLONASS receivers. Domestic receiver production was expected to grow to 500,000 units for 2011, up from less than 100,000 in 2010.[22]

One of the very serious shortcomings of GLONASS was the need for a complete upgrade of the software installed throughout the system in order to develop a new generation of ground support and user equipment. Testoedov addressed the software issue directly by saying that the "center of attention is now firmly on applied software. This is the key to commercialization and India, with its fast-developing IT sector, is expected to bring a valuable contribution to GLONASS commercialization."[23]

International relations between Russia and the EU have become strangely compartmentalized over the past ten years. Russia continues to provide significant launch capability in support of the Galileo project but there is little cooperation between these two states on other GNSS specific issues. Russian Soyuz rockets have lifted the first four Galileo satellites into orbit but the new generation of receivers being built in Russia won't prosecute Galileo signals. There can be no doubt that economic gain is a major component of the political policies being promulgated by the competing entities in this market.

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[22] Maxim Pyadushkin, "Back to Square One", *Aviation Week and Space Technology* 173, no. 1 (January 3, 2011): 2.

[23] Ivanov, 21.

5. GLONASS AND UPGRADES TO M AND K

As is with nearly all new technology, scientists and researchers begin working on upgrades to the systems even as they continue to produce current models. In the case of the original GLONASS satellites, it was imperative to upgrade the system in order to bring the system back into operation after it had been left to degrade and decay for lack of funding in the late 1990's. In 2001 the Russian Space Agency unveiled the plans for a second generation of GLONASS satellites called the GLONASS-M. There were a whole slew of technical upgrades incorporated into the new design and most of them will not be discussed in this work because they are not necessarily relevant to the purpose of the research. However, there are some upgrades that are important to the story and will be covered.

The most obvious difference between the two generations is the service life. GLONASS-M was designed with a service life of seven years that more than doubled the service life of the original models. GLONASS-M satellites had an advertised civil signal horizontal positioning accuracy of 57-70 meters and a vertical positioning accuracy of 70 meters which was better than before but still less accurate than GPS.

In 2003, Russia committed to manufacture and deploy 34 GLONASS-M satellites with the last launches occurring in 2012. All 34 GLONASS-M satellites met the timeline and have been launched, as of January 2012, in pods of three (two were launched as single units on special rockets) with one launch failure in December of 2010 resulting in the destruction of three satellites.[24] GLONASS reached Initial Operating Capability (IOC) in 2008.

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[24] Bonnor, 8.

The third generation of GLONASS satellite is called the GLONASS-K. Several major upgrades were made to the K model including an increase in the service life to 10 years, a reduction in weight by half due to a non-pressurized design, and a transition to CDMA signal generation. All in all, the GLONASS-K satellite is very competitive with the GPS IIR series in accuracy. However, it is too early to tell if these variants will meet or exceed their design life making them as reliable as the IIR's.

6. RELATIONS WITH EU AND DECISION TO USE SOYUZ BY EU

Russia and the EU linked GLONASS and Galileo together as early as 2001 as part of their 'Space Partnership'. At the time neither player had an operating system that would compete with GPS. The EU was interested in reaching out to Russia cooperatively in order to improve their collective mutual capabilities in areas that included the future interoperability between GLONASS and Galileo and the development of a new generation of launch rockets. Over the past couple of decades Russia has concluded agreements with the United States, the EU, India, China, and Brazil involving space systems cooperation. A 2001 memorandum on "New Opportunities for a Euro-Russian Space Partnership"[25] between the EU, the ESA, and the Federal Space Agency (FSA) is an early example of Russia's willingness to maintain its place as a major space systems provider in a multi-polar world moving away from the militarization of their space industry and moving into the global commercial market for their products. Two of the goals of the agreement were to provide a political framework for future work to include Galileo-GLONASS cooperation, and prospects for new launcher systems. There was a real effort undertaken to work together toward common goals by Russia and the EU. This

[25] Mathieu, 29.

basic agreement was followed by additional cooperative agreements or workshops in 2002, 2003, 2005, 2006 and 2010. These follow-on agreements included long-term cooperation for the development, construction and use of space launch vehicles, laid down the terms for the upgrade of the EU operated Kourou launch pad in French Guyana to permit the operation of Soyuz-ST rockets from that location, finalization and implementation of the 2001 Galileo-GLONASS agreement and cooperation on the development of GNSS user applications.[26] Negotiations on GLONASS/Galileo issues were increasingly hampered by dual-use technology transfer issues and in the end produced very few tangible outcomes.

On the other hand, the level of cooperation that exists between the EU and Russia in developing new launch systems is quite significant with both sides investing in new technologies that will provide mutual relative gains. "Both the EU and Russia stand to gain a lot from co-operation in space: it is a strategic choice for industrial competitiveness in both our countries", said European Research Commissioner Philippe Busquin. He went on to say that he looked "forward to stepping up our joint efforts within the EU-Russia Space Partnership, a long-term technological and industrial engagement and a shared dream to reach for the stars together, an inspiring example for our youngest generation."[27]

By the time of the Munich Satellite Navigation Summit in 2005, Russia's space community was providing the Galileo project with a number of critical components

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[26] Delegation of the European Union to Russia, *SPACE,* (Moscow: 2007). http://eeas.europa.eu/delegations/russia/eu_russia/fields_cooperation/space/index_en.htm

[27] European Union, *EU and Russia advance space co-operation agenda,* Press Release, IP/03/413, (Brussels: March 19, 2003). http://europa.eu/rapid/pressReleasesAction.do?reference=IP/03/413&format=HTML&aged=1&language=EN&guiLanguage=en

including the use of Soyuz launch vehicles for Galileo satellites. Russian scientists were also heavily involved in the development of the hydrogen maser clocks scheduled to be used by Galileo and, surprisingly, the delivery of laser retro-reflectors which are required to measure the altitude of the satellite in space to within several centimeters.[28]

7. AGREEMENT IMPLICATIONS BETWEEN US AND RUSSIA

GLONASS was, at one point in early 2000, being used by Russia as a bargaining chip in the contentious negotiations surrounding the possible withdrawal of the US from the 1972 ABM treaty. Hoping to pressure the US into continued adherence to the treaty conditions of not developing a National Missile Defense (NMD) or an East Asia Theater Missile Defense (TMD), Russia proposed that China become a partner in GLONASS in order to improve the military performance of its weapons systems. In the words of Yuri Golotyuk reporting for RIA Novosti News Agency, "it is already clear that the talk is not about the offer to China of the commercial 'conditions of the use' of cosmic navigational system, but actually of the possibility of joint use of GLONASS in the interests of military establishments of the two countries."[29]

A partnership with China that included unfettered access to GLONASS would provoke significant anxiety not only in the US but also among other Pacific Rim states. It would represent a quantum leap in China's military capabilities in precision targeting of missiles, rockets, and artillery fire. It would also improve the ability of China's People's Liberation Army's Navy to operate in the close coastal waters of China's

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[28] Sergey Revnivykh, *GLONASS: Status and Perspectives,* Satellite Navigation Department, Mission Control Center, Central Research Institute of Machine Building, (Moscow: March 9, 2005). 23. http://www.munich-satellite-navigation-summit.org/Summit2005/Beitraege/3Ses1-Revnivykh.pdf

[29] Jyotsna Bakshi, "Russia-China Military-Technical Cooperation: Implications For India", *Strategic Analysis* XXIV, no. 4 (July 2000): 14. https://www.ciaonet.org/olj/sa/sa_jul00baj01.html

immediate neighbors and throughout the South China Sea. It could also be used to control the operations of forces on land and support the projection of land power by the PLA. The issue of a joint Russian-Chinese partnership in GLONASS receded after time and is an example of one chip that was not played in the game of great power politics between the US, China, and Russia.

The use of GLONASS as a bargaining chip in one set of great power negotiations does not mean that it cannot be used positively in another political area just as well. Over time the US and Russia began working together in order to minimize global confusion resulting from competition between GPS and GLONASS. Therefore, both sides determined it was in their best interests to cooperate on bringing both systems into a position of interoperability and compatibility. A joint statement signed by both sides in 2004 called for free civil signal service for all users by both systems. The statement also pledged both sides to cooperate and promote international GNSS organizations. They also agreed to ensure compatibility and interoperability and finally, both sides agreed to cooperate closely on search and rescue systems.[30] It was abundantly clear that GPS and GLONASS had come a long way since the secret days of the Cold War.

In another series of high level meetings beginning in 2004, both countries entered into serious discussions on how both countries might cooperate to prevent the unauthorized use of either GNSS by terrorists. While both sides have declared their individual systems to be fully dual-use they both recognize the economic and domestic importance of those systems and are fully committed to ensuring they remain transparent,

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[30]Revnivykh, 25.

available to all who want to use them for peaceful purposes, and considered a part of the global commons.

8. AGREEMENT IMPLICATIONS BETWEEN EU AND RUSSIA

The EU and Russia have become relatively interdependent since the end of the Cold War. Some of it has to do with Russia's energy exports to Europe and with Europe's exports of goods and services to Russia. One of the critical aspects of the relationship has been Europe's willingness to share technology with Russia. Comparatively speaking, the EU has consistently embraced the concept of peaceful international relations through interdependence. This work is not a review of the larger relationship between these two entities but an effort to perhaps better understand the evolution of the EU's quest for PNT independence and Russia's quest to remain internationally relevant through its legacy space programs.

The EU has not had a common foreign policy nor has it had a common defense policy outside of the NATO alliance. It has relied on a US security umbrella to shield it from external threats since 1945. Since that time, the EU and its member states have been able to grow and prosper without consideration of security threats to its borders and its institutions have developed without national security constraints. Russia, for its part, relies on the EU as its major trading partner and generally presents itself as a non-threatening and peaceful neighbor.

It appears that the EU and Russia have increased their level of interdependency using the peaceful applications of technology on space systems and exploration. It was only when US ITAR policies became serious roadblocks to dual-use technology transfers that the increasing close relationship between Russia and the EU on the development of their respective GNSSs began to cool. In other areas such as deep space exploration, launcher systems, and manned flight technology, that relationship has continued to grow.

The basis for this EU-Russia cooperation and partnership is the Partnership and Cooperation Agreement (PCA) that was signed in 1997. Article 62, Science and Technology, sets the stage for EU/Russia cooperation in PNT technologies. It states that "the Parties shall promote bilateral cooperation in civil scientific research and technological development (RTD) on the basis of mutual benefit and, taking into account the availability of resources, adequate access to their respective programmes and subject to appropriate levels of effective protection of intellectual, industrial and commercial property rights (IPR)."[31] This article seemed to indicate that scientific endeavors should be shared for the sake of science and not necessarily be hoarded for the sake of state. The agreement highlighted the thawing of relations between the EU and Russia, the establishment of most favored state status between them, and the creation of a large all-encompassing free trade area to encourage a deepening of relations and interdependence between the EU and Russia. This agreement was the first of its kind but certainly not the last between these two entities.

Then the EU and Russia issued another memorandum in 2001 called "New Opportunities for a Euro-Russian Space Partnership". Some of the focus of this memorandum was on the possibility of a long term partnership in launchers and GNSS

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[31] *AGREEMENT ON PARTNERSHIP AND COOPERATION establishing a partnership between the European Communities and their Member States, of one part, and the Russian Federation, of the other part, Official Journal L 327 , 28/11/1997.* 21997A1128(01). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:21997A1128(01):EN:HTML

between the two entities. Additional statements were released every year after touting the increasingly close bonds between the EU and Russia on space cooperation.

The initial draft of the PCA was expanded several times and by 2005, both sides had agreed upon a Road Map for the Common Economic Space. The objective of Chapter 5, Space, was to build an effective system of cooperation and partnership between the EU and the Russian Federation in a number of fields of space activities. Among those activities was "Space Applications: Global Navigation Satellite Systems (GNSS)."[32]

And then regionalism raised its ugly head and the EU-Russia honeymoon with shared technology and cooperation in space systems got competitive and complicated. Enter the United States and its International Traffic in Arms Regulations or ITAR.

It is important to understand that Russia, and every other space state, uses space in pursuance of its foreign policy objectives. It has also been working to increase the level of international cooperation, and the revenues it collects by cooperating, to provide additional capital to support its space programs including GLONASS. Securing a sufficient funding stream to support Russia's very ambitious space programs is a key component of its domestic political landscape. Closely associated with gaining outside funding is the need for Russia to acquire leading edge technology or place its programs at risk. Russia no longer possesses the capability to internally design and build the next generation of space vehicles and needs to jointly develop or buy some portions of the necessary technology.

Much of the technology that Russia needs to build its space systems is listed in ITAR. This makes a difference because most European defense or space firms also

[32] Mathieu, Annex E, Chapter 5.

compete for US contracts and failure to comply with ITAR puts those firms in jeopardy of losing their ability to complete in the US market. This is a huge consideration. The problem is not necessarily with European firms transferring technology to Russia since Russia and the US have been space partners since the Skylab days of the 1970's. The problem is with the other space partnerships that Russia has initiated regionally. The real issues facing EU-Russia space cooperation is Russia's space partnerships with India and China, both of whom are on the restricted list for ITAR technology transfers.

Obviously, Russia has tremendous economic opportunities with the Indian and Chinese markets if it can leverage its advantages in space systems against the needs of those two states. For example, Russia sees a huge market for GLONASS receivers in India because India adopted GLONASS as its primary GNSS. India also offers Russia a large pool of trained scientists and engineers who would be available to cooperate with their Russian counterparts on new systems. This commercial market is not available in Europe due to Galileo and Russian-Indian technology transfers are not subject to ITAR.

So the dichotomy facing Russia is whether to partner with the EU with its highly developed space technology sector or risk losing business in Europe in favor of improving its political position regionally and possibly gaining a significant economic advantage from partnering with India and, to a lesser extent, China. It now appears, at least for the most part, that Russia is favoring the Indian gambit to gain the South Asian economic advantage and is relying on the fact that its heavy lift launcher services will remain the launcher of choice out of necessity for Galileo satellites.

9. OTHER INTERNATIONAL COOPERATION IMPLICATIONS

Although the former Soviet Union, and now Russia, have maintained significant inter-governmental ties related to space system development for many years with China there was little cooperation concerning navigation systems until 2000 when Russia and China initiated the first meeting of a sub-committee dedicated to space cooperation. It was nothing more than establishing the protocols for future initiatives in a variety of space related areas that also included navigation systems. The bulk of cooperation in navigation systems involved the transfer of technology to China and was not the primary focus of Russia-China cooperative efforts. Manned space systems were the focus of most efforts.

Russia's space cooperation efforts are markedly different with India than with China. The two states share a common potential security threat in China and not only do both states share borders with China but both have also fought hot little wars with China over border disputes. Tensions over these simmering border disputes persist today. It's not surprising then that India would be one of Russia's most reliable buyers of Russian military arms and weapons systems.

India, for its part, has been rapidly modernizing its military forces including its naval forces that operate in the Indian Ocean. In order to be militarily competitive it required access to and integration of reliable and accurate PNT capabilities. What it needed was unfettered access to GLONASS high precision military signaling capabilities.

After a series of high level meetings Russia and India signed an international joint-framework agreement in December 2004 for India to participate in the GLONASS modernization program. At issue was Russia's ability to resource the aggressive satellite launch schedule that President Putin had approved in 2001. Russia had a shortage of launch vehicles that were available for domestic use because so much of Russia's launch capabilities were under contract for outside commercial duty. India had excess capacity with its proven GSNV launch vehicle and was willing to launch GLONASS satellites into orbit in return for eventual access to the high precision military channels and an opportunity to assist in the design, manufacture, and sale of GLONASS user equipment.[33] It would take another six years, until December 2011; with GLONASS reaching full operational capability until the two states would sign a memorandum with Russia providing India full access to its high precision channels.[34]

Signing the cooperative agreement with Russia also ended India's bid to be an international partner with the EU in Galileo. Not moving faster to bring India into the Galileo fold may have cost the EU access to the Indian sub-continent and its user equipment distribution potential. However, this is good news for Russia as it expands the GLONASS network, injects needed support into the program, and increases India's dependency on Russia for critical and enduring services.

Another example of Russia's willingness to reach out to other states with offers of space system cooperation occurred in 2007 when President Putin was on a state visit to Saudi Arabia. Putin was making the rounds of Middle Eastern states promoting the sale of Russia's military wares and arrived in Riyadh knowing that Saudi Arabia was the only regional state that had never purchased Soviet or Russian military equipment. In an apparent attempt to 'sweeten the pot' so-to-speak, Putin not only offered Russia's military equipment for sale to the Kingdom, but also Russian nuclear reactor technology,

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[33] Ivanov
[34] Dikshit

launch services for Saudi satellites, and an opportunity to buy into GLONASS as a working partner.[35]

As it turns out, the Saudis chose not to take advantage of any of President Putin's offers and it is difficult to discern why Putin would offer GLONASS to the Saudis considering that they may be the most politically aligned state in the region with the US and certainly have access to GPS. Perhaps it was a gambit designed to counter US efforts at closer cooperation with states of the former Soviet Union or counter recent US efforts to establish a missile defense shield along Russia's western flank. None the less, it was an interesting move considering that the US has not offered Saudi Arabia nuclear reactor technology or launch services for its satellites.

10. FUTURE OF GLONASS

As of March 19, 2012, GLONASS consisted of 31 total satellites in orbit including 24 in-service vehicles, three spares, one waiting to be commissioned, two undergoing maintenance and one conducting in-flight testing. GLONASS is fully operational.[36]

The Russian Federation appears to be committed to the long term operation, modernization, and maintenance of GLONASS. The overall policy shifts requiring system and industry financial self-sufficiency marks a great departure and cultural shift for Russia's state industry. The last chapter has not been written yet on whether Russia

[35] Subhash Kapila, *RUSSIA: PRESIDENT PUTIN'S SECOND STRATEGIC FORAY IN THE MIDDLE EAST,* South Asia Analysis Group, Paper 2154, February 28, 2007. http://www.southasiaanalysis.org/%5Cpapers22%5Cpaper2154.html#top

[36] Federal Space Agency – Information-Analytical Center, (Korolev, Russia: March 19, 2012). http://www.glonass-center.ru/en/GLONASS/

has developed to the point of being a reliable and consistent world provider of leading edge, world class, and commercial systems competitive with GPS. The good news for Russia is that US transparency has enabled GLONASS to partner with GPS in the sense of being interoperable and to have user equipment designed and built that support both systems making it possible for GLONASS/GPS mutual support in most applications.

C. COMPASS/BEIDOU

China has had a national space program since the 1950's and has progressed to the point of being the third nation, after the US and Russia, to put a manned spacecraft into orbit. It also launched an unmanned mission to the moon in 2007. At this point in time China can be considered a major space system player. They have a demonstrated nuclear capability that includes the deployment of nuclear armed ballistic submarines and the testing of intermediate range ballistic missiles. It provided a graphic demonstration of its space prowess in 2007 when it destroyed a satellite in space with an anti-satellite missile launched from the Chinese mainland. It has become a force to reckon with in global space politics.

China has demonstrated an interest in becoming the dominant regional player in Asia and those areas contiguous to the South China Sea. There are a number of flash points in the region that are contested by one side or another. The one issue that could be regarded as having the most potential for conflict is Taiwan. Although China has stated repeatedly that it will not have to go to war in order to gain control of Taiwan, it remains focused on having the military capability to do so if required in order to prevent that nation from declaring independence or if some foreign nation, such as the US, attempts to overtly support Taiwan's independence against the best interests of China.

China has been modernizing its military forces in earnest since Gulf War I in 1990. The application of precision guided weapons by the US against Iraqi forces was a wakeup call for China's People's Liberation Army (PLA). After analyzing the performance of US forces it developed a new roadmap for the future of its military forces. PLA leadership recognized the need to urgently move away from the brute force tactics of the 20^{th} Century and into the realm of high technology warfare being practiced by the US and the EU. Besides becoming world class players in computer network attack, cyber warfare, and anti-satellite capabilities, China has made significant improvements to the performance parameters of its rocket and missile forces.

Performance and accuracy improvements required reliable and accurate GNSS capability for its Rocket Forces and China made the strategic decision to build that capability internally. The new system would be called the COMPASS Navigation Satellite System or CNSS.

There may be other reasons having to do with Chinese history and culture that play into the development of a new navigation system as well. In the preface to a report on the development of COMPASS, the China Satellite Navigation Office describes the thinking behind the system by saying that "with a long history and a splendid culture, China is one of the important cradles of early human civilization. In ancient times, Chinese people used the Big Dipper (BeiDou) for identifying directions, and invented the world's first navigation device, the ancient compass (Sinan), which was a great contribution to the development of world civilization. In modern society, the Chinese-built BeiDou (COMPASS) system will become another contribution to mankind."[37]

China originally outlined its future goals to satisfy its need for a navigation system in the White Paper on Space Activities 2000. The paper identified one of China's developmental targets for the next decade "to establish an independent satellite navigation and positioning system. This will be achieved by setting up a navigation and positioning satellite group step by step and developing a relevant application system, which will eventually bring into being China's satellite navigation and positioning industry."[38]

This is the first mention of a navigation system in China's publically acknowledged future plans. The outline for the system is vague but expansive. It can be said with certainty that in 2000 China was looking to become a major player in space activities and was beginning to play harder in the game of global great politics.

The China Satellite Navigation Office put the purpose of COMPASS this way in 2011. It said that "the BeiDou system will meet the demands of China's national security, economic development, technological advances and social progress, safeguard national interests and enhance the comprehensive national strength."[39] The purpose statement is comprehensive in scope and nearly opaque in specific meaning. What is clear though is that it describes a system that will impact nearly every facet of China's

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[37] *Report on the Development of BeiDou (COMPASS) Navigation Satellite System*, China Satellite Navigation Office, V1.0, (Beijing: December 2011). Preface. http://www.china.com.cn/zhibo/zhuanti/ch-xinwen/2011-10/21/content_24259168.htm

[38] Information Office of the State Council, *China's Space Activities, a White Paper*, (Beijing: November 22, 2000). http://www.china.org.cn/e-white/8/index.htm

[39] *Report on the Development of BeiDou (COMPASS) Navigation Satellite System*, Preface

existence. China's leadership has clearly recognized the potential impact on China, the Party, and the people that COMPASS will have as it is built and deployed.

1. EARLY DAYS OF COMPASS/BEIDOU

It remains unknown what the actual impetus was for the development of an internally generated navigation system but it could reasonably be assumed that one big reason was that China needed new capabilities to assist in improving the targeting performance of its ICBM's. There is also no doubt that China recognized their vulnerability if it relied on GPS for its PNT needs after seeing the US block access on a regional basis during the Bosnian Campaign in 1999, Iraq in 2003, and Georgia in 2008. China had also seen Russia's reluctance to cooperate on access agreements to GLONASS military channels. China really was left to its own devices where GNSSs was concerned and it appeared it had the motivation and resources to build a local system. BeiDou was approved for development in 1994 and was subordinated to the PLA Rocket Force.[40]

The plan envisioned three phases extending out to 2020. Phase I was the deployment and initiation of positioning operations of a two-satellite demonstration array in geostationary earth orbit (GEO).[41] The concept was proven and the system known as BeiDou-1 became operational with the PLA in 2003. Phase two included the deployment and operation of a 12 satellite array that provided full regional coverage in East Asia that was deemed fully operational in 2011. The final phase is the upgrade of the regional

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[40] Scott Pace, "Expert Advice: The Strategic Significance of Compass", *GPS World*, December 1, 2010. http://www.gwu.edu/~spi/assets/docs/The_Strategic_Significance_of_Compass.pdf

[41] A geostationary orbit is one where the satellite is travelling at the same speed as the earth's rotation and is positioned at the 0 latitude which is the equator. A satellite in geostationary orbit appears to be stationary in the sky and is visible from the same position on the ground at all times. The primary advantage of a geostationary orbit is that the satellite is always in direct line-of-sight to the ground based antenna.

system to a constellation composed of 35 satellites and considered a GNSS with capabilities comparable to GPS and GLONASS and called COMPASS/BeiDou-2. It is expected to reach full operational capability by 2020.

BeiDou-1 was different from every other GNSS in a couple of areas. First, because of the orbital configuration and the fact that there were only two satellites in the system, BeiDou-1 was capable of providing 10m accuracy along longitudinally or east-west positioning but had difficulty providing accurate readings along the latitudinal or north-south positioning. In order to gain an accurate location using the system, the user was required to have a super accurate atomic clock on-board to confirm distance in addition to the standard receiving equipment in order to compensate for the lack of latitudinal accuracy.[42] This process was very cumbersome and required skilled operators and the situation was made much more difficult if the user was moving when attempting to gain positional information making the system difficult to use in a tactical military situation but not so difficult for a submerged nuclear submarine or stationary ICBM launch site.

A second operational departure from other GNSSs was the need to gain two readings in order to determine position. BeiDou-1 was designed as something called a radio-determination satellite system or RDSS. This means that the satellite was capable of two-way signal traffic. This is an important element of the system and has advantages and disadvantages relative to its application. Generally speaking, the user received a signal and then automatically generated a comparable return signal back to the satellite.

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[42] Geoffrey Forden, "The Military Capabilities and Implications of China's Indigenous Satellite-Based Navigation System", *Science and Global Security* 12, (2004): 229.

The satellite processed the return signal and then generated a new signal to the ground support station which did the actual position determination using both orbiting satellites. The ground support station then generated a position signal to the satellite which relayed the information to the user and, bingo, the user had a position fix. The timeline for receiving a position solution was in the 1 second range even with the multiple layers of processors.

This system did have one significant advantage over all other systems. Being RDSS it was capable of two-way communication. One of the targeted audiences for BeiDou-1 was China's huge fleet of commercial fishermen. This cohort became the largest user group of the system and lacking effective radio communications while fishing offshore, were able to communicate with each other and the China mainland using the messaging capabilities of BeiDou-1. It was sort of like the present day Twitter where each message was limited to some small number of characters.

The PLA also found the system supported the Chinese centralized command structure very well. BeiDou-1 provided the locations of forces to the command structure and allowed the command structure to effectively move forces in the battle space using the messaging capabilities of the system, again in spite of the lack of effective radio communications capabilities. These were important capabilities that BeiDou-1 provided to China that could be used against regional threats if necessary. It would be of immense assistance in the movement of Chinese naval or air forces in the event of any flare-ups in the South China Sea involving the US, Taiwan, the Philippines, or Japan for example.

One serious disadvantage of the RDSS was that the user was required to generate a message to the satellite in order to determine position. That means that the user was exposing their location to any potential threat that was equipped with radio directional equipment. Any relatively modern military or law enforcement organization has that capability and is capable of monitoring the location and movement of China's forces while using BeiDou-1. This issue was of minimal concern to the PLA if the threat forces represented developing states like Vietnam or Laos. BeiDou-1's use in the face of US, Japanese, or South Korean forces could be expected to be effectively used against China and proved a serious limitation.

China recognized the shortcomings of the original system and moved quickly to the Phase II upgrade of BeiDou-1 to compensate for the obvious PNT limitations by adding three satellites into Inclined Geosynchronous Satellite Orbit (IGSO)[43], four into MEO, and five into GEO. This effort began in 2006 and was completed by December 2011 giving BeiDou-1 regional PNT capabilities comparable to GPS.

2. DESIGN PARAMETERS INCLUDING ACCURACY AND DIFFERENT ORBITS

China's GNSS satellite array is different from its competitors due to the progression from BeiDou-1 regional system directly into the COMPASS/BeiDou-2 CNSS system. A regional system requires satellite orbits that provide satellite visibility more often than global systems because there are fewer satellites. The final BeiDou-1 regional array was composed of 12 satellites. Accurate positioning data requires at least four satellite signals. Of the twelve satellites, five were in geostationary earth orbit or GEO. This kind of orbit enables a regional GNSS because the satellites, traveling at the

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[43] An IGSO occurs when a satellite has its orbital plane canted by some predetermined number of degrees from the equator making it inclined. It is geosynchronous when it completes one orbit around the earth every 24 hours. From a point on earth a satellite in IGSO will weave what appears to be a small ellipse as it travels due to gravitational forces from the sun and moon.

same speed as the earth's rotation, seem to be motionless in the sky allowing a limited number of ground stations to constantly monitor their signals.

In China's case, its BeiDou ground stations were all located in China and each satellite must have a line of sight view to the ground station in order to operate properly. An additional three satellites were in inclined geosynchronous orbits (IGSO) which are orbiting at some angle from the equator north or south and are not moving at the same speed as the earth. Finally, there were four satellites in MEO operating similarly to other global systems. Simply stated, the GEO vehicles were always visible to the ground stations while the IGSO and MEO vehicles moved in and out of range depending on their trajectory.

3. POLITICAL DIMENSION OF BUILDING THE SYSTEM

China is clearly interested in being capable of countering US dominance in East Asia and that requires a strong diplomatic effort with other East Asian states that is based on both shared economic opportunities and the realization of China's military capability to project power at least regionally. Taiwan has remained a flashpoint during negotiations between the US and China. If Taiwan goes hot and military intervention is required, China would be expected to use missiles targeted at strategic Taiwanese locations that are situated in urban areas. GNSS capabilities are an absolute requirement for those operations in order to minimize civilian collateral damage. China cannot risk alienating the Taiwanese population with the indiscriminant use of weapons systems.

China has been relatively transparent in letting the world know what its plans and intentions were regarding the use of space. In a White Paper on China's space activities published in 2000, China says specifically that the aims and principles of its space activities is "to meet the growing demands of economic construction, national security, science and technology development and social progress, protect China's national interests and build up the comprehensive national strength."[44]

Having a space policy and being willing to cooperate on space projects is not new for China but publishing the policy for the world to consider is and it gives other states an opportunity to speculate on Chinese intentions. Specific cooperative programs since the 1950's between China and Russia remain clouded in mystery. But it is generally known that both states are currently open to cooperating on exploration missions to the moon and to Mars but even those specifics are not publicized. Russia also considers China a possible threat and has a strong self-interest to maintain a leadership position in space research and technology. Russia has apparently not chosen to cooperate with China on CNSS and has shared little technology on GLONASS with China.

When China moved to upgrade BeiDou-1 into a truly global system it also joined the International Committee on GNSS, or ICG, which is part of the UN's Office of Outer Space Affairs in 2005. The ICG was "established on a voluntary basis as an informal body for the purpose of promoting cooperation, as appropriate, on matters of mutual interest related to civil satellite-based positioning, navigation, timing, and value-added services, as well as compatibility and interoperability among the GNSS systems, while increasing their use to support sustainable development, particularly in the developing countries."[45]

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[44]Information Office of the State Council, *China's Space Activities, a White Paper,* (Beijing: November 22, 2000). http://www.china.org.cn/e-white/8/index.htm

[45] International Committee on Global Navigation Satellite Systems, (Vienna: December 2, 2005). http://www.oosa.unvienna.org/oosa/SAP/gnss/icg.html

Becoming a member of the ICG is another example of China's efforts to encourage international cooperation across a multitude of disciplines and to support its global economic priorities. It is also a member of a regional GNSS organization involving Japan and India on efforts to improve and enhance inter-model transportation across the region. China's willingness to engage in international cooperation, at least on GNSS issues, has increased the interdependency between the various players and has allowed China to be considered a major player economically and politically with the US, the EU and Russia in spite of the fact that CNSS was built as a strategic resource specifically to support the military and the economy of China.

Although BeiDou-1 was clearly designed and built primarily to support China's military forces, the structural organization for control of BeiDou-2 was put under a new organization residing outside of direct military channels. The China Satellite Navigation Center or CSNPC was established in 2006 to be responsible for the R&D, manufacture, and management of BeiDou-2. It makes sense that a non-military organization would represent the system on the world stage, especially as China espouses to support the peaceful uses of space.

China's international behavior mimics its 2006 White Paper on Space Activities. It is clear that China has gained competence and confidence since its first White Paper on space was published in 2000. Gone is the call for 'attention shall be given to international cooperation and exchanges' to be replaced by "the capability for independent innovation is a strategic basis for developing the space industry....while choosing some limited targets, concentrate its strength on making key breakthroughs and realize leapfrogging development."[46]

This is a key aspect of China's way forward. It is not interested in catching up, technologically, with the West, rather it has charted a course that calls for China's R&D community to move past legacy systems and come up with the next generation of technology in order to advance beyond Western capabilities but also to not waste time and resources building something that already exists. It is particularly difficult to predict outcomes based on this kind of national strategy.

4. ECONOMIC IMPACT

The US has recognized China's growing influence in East Asia and has countered that growth in a number of ways. One of the avenues that the US has used is its International Traffic in Arms Regulations or ITAR. There is a specific prohibition for any nation that builds space systems with US components to use Chinese launch vehicles for the deployment of civilian satellites. This sanction has forced China to rely mostly on Russia for space technology support and it has denied China a revenue stream to mitigate the high costs of space operations. An interesting sidebar to the ITAR issue is the apparent reliability of Chinese Long March launchers. China conducted 104 Long March launches between 1970 and 2007 with only one partial failure in 1996. There were 62 successful launches between 1996 and 2007[47], an amazing record not matched by any other state and yet none of those launches carried civilian satellites with US components.

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[46] Information Office of the State Council, *China's Space Activities in 2006,* (Beijing: October 12, 2006). http://news.xinhuanet.com/english/2006-10/12/content_5193446.htm

[47] Mathieu, 20.

The huge potential for economic return from GNSS receivers that are interoperable across systems has not been lost to China. One of its stated goals from a space activities perspective is to insure that any new space project will need to fully support the economic development of China. It is amazing to realize how prescient the 2006 White Paper on Space Activities was when it declared that one of the major tasks for the nation was "to develop independently application technologies and products in applying satellite navigation, positioning and timing service, and set up a standard positioning service supporting system and popular application terminus related to satellite navigation and positioning, expanding the application fields and market."[48]

China has set a course to develop all of the ancillary components required for the so far non-existent Chinese CNSS long before it was even off the ground. There is little doubt that China is determined to capture the huge and burgeoning Asian GNSS user equipment markets and prevent Russia or the EU from gaining a market share of any real significance. The Asian market is the largest untapped market in the world and it is led by pent up demand in China itself. A report in the China Daily reports that "statistics show that at the end of 2009, the COMPASS System had over 60,000 users and provided 330 million positioning services, 220 million communication services, and 30 million two-way timing services." [49] These numbers are miniscule when set against a population in excess of one billion people. China has become the number one new car and cell phone market in the world and the expansion of its civil air fleet is predicted to be

[48] Information Office of the State Council, *China's Space Activities in 2006,* (Beijing: October 12, 2006). Chap III, Major Tasks, 6. http://news.xinhuanet.com/english/2006-10/12/content_5193446.htm

[49] Zhou Chang, "The BeiDou Satellite Navigation System", *China Today* 59, no.12 (December 2010). http://www.chinatoday.com.cn/ctenglish/se/txt/2010-07/05/content_283194.htm

astonishing over the next several decades. There is no doubt that the Asian markets for GNSS services and equipment will be greater than has been seen before.

China went so far as to reiterate its desire to capture the user equipment market in that 2006 White Paper. Again putting the world on notice that China was serious about economic and industrial leadership, it stated that its major policies and measures for the present and near term in space were, among other things, "to promote space application and accelerate the industrialization of space activities...with emphasis on satellite navigation."[50] What is most interesting about this Chinese model is how much industrial flexibility and willingness to assume risk exists with the State's insistence on moving forward rapidly on the development of ground support equipment without having a comparably matured space vehicle component program. This is not the way business was traditionally conducted in the West and it has allowed China to gain a significant advantage on Western industrial concerns.

Another example in a move reminiscent of complaints against the EU in 2003-04 from US manufacturers, China has been slow to release the Interface Control Document (ICD) for COMPASS. This is the document that provides all of the system design information required for manufacturers to design and produce user equipment. Without the ICD, the system remains hidden from view. There have been complaints from manufacturers, mostly in the West, that Chinese manufacturers have received the ICD information early and are at work designing new GPS/COMPASS interoperable user

[50]China's Space Activities in 2006, Chap IV Major Policies.

equipment and will have a distinct advantage in sales and distribution by the time COMPASS becomes operational.[51]

Although the ICD was finally released in late 2011 it lacked a significant amount of design data making it difficult for equipment designers and manufacturers to design and build new equipment. It is unknown if China plans on releasing a completely transparent document on COMPASS any time in the near future. It is difficult to ascertain if any or how much advantage was gained by Chinese manufacturers at the expense of their Western counterparts.

5. RELATIONS WITH EU AND DECISION TO BUY INTO GALILEO

When China made the decision to expand its regional BeiDou-1 navigation system into a global system it realized it needed technology that it did not possess. It had options on how to acquire the necessary technology which included forming international partnerships that would include technology transfers, it could attempt to purchase the information from another space power, or perhaps it could gain the requisite knowledge through industrial sabotage.

China's White Paper on Space Activities from 2000 addresses these needs succinctly. It says that its space activities "uphold the principle of independence, self-reliance and self-renovation and actively promoting international exchanges and cooperation….and that due attention shall be given to international cooperation and exchanges in the field of space technology, and self-renovation in space technology shall

[51]Len Jacobson and Alan Cameron, "Compass ICD in October; Harmonizing GNSS", *GPS World*, September 29, 2011. http://www.gpsworld.com/gnss-system/compass-icd-october-harmonizing-gnss-12113

be combined organically with technology import on the principles of mutual benefit and reciprocity."[52]

As it turns out, the EU and China had found common ground in Galileo that dovetailed nicely with China's stated goals for space activities. In 2003 China was given the opportunity to buy into the Galileo project by the EU. China contributed over €200 million to the EU and in return, expected to have an opportunity to participate in the R&D of Galileo satellite design. They also expected to have an opportunity to manufacture components for the system. A sub-headline in an article published in the People's Daily from 2003 puts China's willingness to cooperate into clear perspective. It read "China is sure to become a space power in the 21st century, able and necessary to have its own global positioning system" The article goes on the explain that "China's participation (in the Galileo project) from the very beginning has made it possible to avoid the passive situation of knowing nothing about the GPS in the initial period."[53]

There seems to be little doubt that China was looking for avenues to import as much of the requisite knowledge needed to build BeiDou as possible. According to the terms of the agreement signed between the EU and China, it "provides for co-operative activities on satellite navigation in a wide range of sectors, notably science and technology, industrial manufacturing, service and market development, as well as standardisation, frequency and certification."[54] In short, this cooperative agreement would give China a complete overview of nearly every aspect of the Galileo project. It

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[52] Information Office of the State Council, *China's Space Activities, a White Paper,* (Beijing: November 22, 2000), Introduction, Aims and Principles. http://www.china.org.cn/e-white/8/index.htm

[53] "China Joins EU Space Program to Break US GPS Monopoly", *People's Daily,* (Beijing: September 26, 2003). http://www.china.org.cn/english/scitech/76116.htm

[54] Europa Press Release IP/03/1461, *Galileo: Loyola de Palacio welcomes the green light for an EU-China Agreement,* (Brussels: October 27, 2003). http://europa.eu/rapid/pressReleasesAction.do?reference=IP/03/1461&format=HTML&aged=0&language=EN&guiLanguage=en

also seemed apparent that China recognized the exact nature of EU motivations to enlist its cooperation.

The same People's Daily article makes clear that the EU is interested in working with China for two reasons. Firstly, it opines that "China's support and participation can facilitate EU's negotiation with the United States and Russia on cooperation. And secondly that China's huge market provides promising prospects for the program."[55] It does appear that China was prepared, at some level anyway, to sacrifice some percent of East Asia's future user equipment market share to the EU in return for active Chinese participation in Galileo.

Although the agreement between China and the EU was never actually cancelled, very little cooperation involving Galileo occurred because of security concerns over transfers of dual-use technology, conflict over work share partitions, and because of China's decision to become a direct competitor of Galileo with COMPASS/BeiDou-2.

One of the real prizes that the EU was anticipating when it brought China into the Galileo project was access to the huge Asian market for European built receivers and other user equipment. China, of course, also recognized the economic possibilities and took them seriously. Besides the economic boost, China has also harbored national security concerns about being tied to closely to Galileo.

China had a critical need for GNSS services capable of supporting its military force modernizing efforts and depending on any of the existing or planned GNSSs meant that China would have to depend on a critical military capability that was controlled by a potential adversary at some time in the future. This military necessity and the prospect of a strong economic return on investment weighed mightily on China's decision to build

[55] "China Joins EU Space Program to Break US GPS Monopoly".

BeiDou-2, to the great consternation of the EU. And what was more embarrassing to the EU was the announcement by China that their COMPASS/Beirou-2 system might reach full operational capability before Galileo nearly ensuring that the EU would be frozen out of the bulk of the Asian market for user equipment.

Another huge problem arose between China and the EU over China's determination to use a certain frequency for its encrypted military signals. The technical details of frequency selection are not important here but what is critically important is the fact that the frequency chosen by China is the same frequency that the EU proposed to use for its PRS or encrypted signals reserved for military, law enforcement and security forces. This has created a serious problem for Galileo because the ESA has published the Galileo ICD and it is too late in the process to change its PRS frequencies. And it also appears that the Chinese are unwilling at this time to alter their designs.

A published report in the International Herald Tribune from 2009 stated that "under the International Telecommunications Union's policies, the first country to start using a specific frequency is granted priority status, and later service providers transmitting on the same band must ensure that their broadcasts do not interfere with previously authorized signals. Because some of China's satellites are expected to begin transmitting before the Europeans can get to the frequency, China would effectively be able to gain ownership of it, meaning that Europe would be unable to use the wavelength unless it received China's permission."[56] The significance of this issue cannot be overstated because an overlap of frequencies will make it impossible for the EU or China

[56] Dan Levin, "Chinese wrestle with Europe in Space; Dispute about radio frequency is latest glitch for Galileo satellite project", *International Herald Tribune*, (Beijing: March 23, 2009). Finance, 10.

to jam or disrupt each other's signals without doing the same to their own. This condition has huge implications for national defense and security issues.

Informal Chinese comments suggest that China "considers GPS and GLONASS to be well-established 'legacy' systems that new arrivals should seek to avoid overlapping. On the other hand, Galileo and COMPASS are seen as having equal standing as new RNSS systems within the terms of the International Telecommunications Union (ITU).[57] One major argument that China is making regarding the overlap of frequencies is that it supports CNSS interoperability with other GNSSs and further supports development of the next generation of user equipment capable of processing signals from every global system.

Whether or not China's determination to overlap frequencies with Galileo is a result of the EU's reluctance to embrace China as a Galileo partner in 2003 is unknown. An argument can be made that China 'lost face' after signing on as a partner and actually buying-in with its €200 million ante and then having the EU do an about face on its agreement and minimize China's access to the system. This could be 'pay back' for previous slights or China may just be competing directly with another new entry into the GNSS club. In any event, diplomacy over frequency overlap has failed for the most part. There were six meetings between China and the EU between 2007 and 2010 seeking a solution to this issue with China showing no willingness to change its frequency plans.[58] The issue had not been resolved as of January 2012.

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[57] Scott Pace, "Expert Advice: The Strategic Significance of Compass", *GPS World*, December 1, 2010. http://www.gpsworld.com/gnss-system/compass/expert-advice-the-strategic-significance-compass-10826

[58] Ibid.

6. THE KNOWN FUTURE OF COMPASS

COMPASS is well on its way to becoming a reality. As of January 2012, China had 10 BeiDou-2 satellites operating in its constellation with six more scheduled to launch in 2012. The schedule calls for the system to be fully operational over the Asia and Oceania region by the end of the year. There is an expectation and it appears that the complete 35-satellite system will be operational on a global basis by 2020. China has also determined to maintain the operations and capabilities of its BeiDou-1 finding that the system has proven invaluable to the state in the case of natural disasters and emergencies. It seems that the two-way communication capability is responsible for saving many lives and allowing the state to respond faster and more efficiently to several recent weather related catastrophes.

D. QZSS

Japan is another nation with a space program that includes satellite based navigation capabilities. Traditionally allied with the US, Japan has been a strong proponent of GPS over the years and has been a major supplier of user equipment in support of GPS to the world. However, as more and more of Japan's economic well-being became tied to GPS services there were voices of concern related to the national security of the state in the event that GPS access was denied for some unforeseen reason. For the Japanese, like the Europeans, Russians, and Chinese, the time had come to wean itself off of the GPS diet and produce their own system in order to control their own destinies and limit their exposure to unnecessary national security risk.

Koji Terada, Project Manager of QZSS, expressed that sentiment clearly when he recently wrote "despite the fact that Japanese people have been familiar with GPS, such as in car navigation systems, since the 1980's, Japan has depended on foreign positioning satellites. It is high time we had a domestic satellite positioning system designed specifically for our life and society."[59]

Secondarily, Japan was interested in improving the availability and accuracy of GPS around Japan and its environs and could do it best with a locally built system. The satellites that were designed and built to support the system were named 'Michibiki' which means 'guiding' or 'showing the way' in Japanese.

1. EARLY DAYS OF QZSS

The idea was not to replace GPS but to augment it in such a way to be highly beneficial to Japan. Being an island nation that is densely mountainous and highly urban, Japan needed a GPS augmentation that would address the mountain canyon and urban canyon effect that tended to limit the accuracy of GPS.

A concept study was begun in 2003 to come up with the outline of a new navigation system. There were three basic requirements for the system. First, it would provide PNT services to users and would do so in concert with GPS. Secondly, it would have broadcast and communication capabilities somewhat similar to BeiDou-1 that could be used in emergency situations, in dense urban or in mountainous regions in a crisis situation. And third, it would improve GPS accuracy to the sub-meter range in Japan.

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[59] Koji Terada, *Establishment of a Seamless Positioning System,* Japan Aerospace Exploration Agency, (Tokyo: 2012). http://www.jaxa.jp/article/interview/vol41/index_e.html

The requirement for sub-meter accuracy was deemed particularly important from a safer operations perspective for Japan's high speed bullet trains.

The coverage area was to include most of East Asia and Oceania. Monitoring stations would be established throughout the coverage area. Most importantly, the system was designed to operate as a stand-alone system in the event GPS access was denied and accommodation was made for a complete system expansion in order to become a fully operational regional system consisting of a seven satellite constellation at some time in the future. The system was called QZSS or Quasi-Zenith Satellite System. Japan released the QZSS ICD to the world in 2007.

2. JAPAN'S INTENTION WITH QZSS

Setting aside the national security concerns regarding loss of GPS, the biggest issue facing Japan was the urban canyon effect that limited GPS accuracy. It takes four visible satellites in order to arrive at accurate PNT readings. In a built-up urban environment it becomes problematic for receivers to find four visible satellites because tall buildings block the horizon.

QZSS was designed to overcome the urban canyon effect by placing a constellation of three satellites in certain specific elliptical orbits that would position at least one satellite directly overhead of the Japanese mainland at all times. This would effectively reduce the angle of visibility to 0 degrees meaning the satellite is looking directly down into the urban areas. This design was the missing link in the equation that would provide the required PNT accuracies described in the original concept study. Figure 30 graphically depicts the urban canyon effect.

As an example, if there are nine GPS satellites visible at some location then four of them are required for an accurate PNT solution. However, because of tall buildings only three of them are visible to the receiver on the ground. The other six are blocked by buildings and their signals are reflected off of other surfaces rendering them inaccurate. QZSS will mitigate this effect by having at least one, and in most cases, two, satellites directly overhead at the zenith enabling an accurate solution.

The original system concept called for the system to expand to a seven satellite constellation providing stand alone service to most of East Asia and Oceania. However, the earthquake and tsunami that struck Japan's Pacific coastline in 2011 has forced the government to rethink the timelines for deployment of the extended system. A very tight economic picture will limit QZSS to three satellites for the near term.

There is a significant national security aspect to the development of QZSS as well. Battles have been raging for more than a decade in the Japanese Diet over Article 9 of the Japanese Constitution. This article prohibits Japan from engaging in an act of war, renounces war as a state, and bans the settlement of international disputes by force. A Diet resolution in 1969 defined its space policy to be one of peaceful uses of space only and that it would be independent, democratic, open, and support international cooperation. That resolution was replaced in 2008 by "The Basic Law on Space". This new law changed the notion of peaceful uses of space to imply that it doesn't mean without military application but something more like it can be military focused but at the same time non-aggressive or defensive in nature.

In the meantime, Japanese authorities have managed to skirt the literal meaning of the law using the "generalization theory" which means allowing 'dual-use' systems to be used by the Japanese Defense Force if those capabilities are also used by the civilian sector. For example, GNSS satellites are dual-use vehicles and they are being developed ostensibly to support the Japanese people and their society.[60] However, in the event of a national security threat Michibiki satellites could be used to support military operations but that is not their primary purpose.

This change in the space policy has also had a pronounced effect on the Japanese aerospace industry. Article 301 of the U.S. Trade Act was written such that Japanese commercial satellite procurement was required to be open for public tender. This put Japanese satellite manufacturers at an extreme disadvantage because they were not sufficiently large enough to compete with US companies. Consequently, most of the satellites being put into orbit by Japan had been purchased from US companies. This changed when Japan adapted a new space policy. From 2008 onward the Japanese government could privately procure space systems if they were linked to Japanese National Security interests.[61] This change opened the door for Michibiki.

3. DESIGN PARAMETERS

QZSS was designed and built under the auspices of a Japanese public private partnership consisting of four government ministries and several large corporations. A separate entity called the Advanced Space Business Corporation was created to be responsible for the communication and broadcasting services while the PNT component responsibility remains with the government ministries under an organization called the

[60] Maeda Sawako, "Transformation of Japanese Space Policy: From the "Peaceful Use of Space" to "the Basic Law on Space", *The Asia-Pacific Journal: Japan Focus* 44-1-09 (November 2, 2009). http://www.japanfocus.org/-Maeda-Sawako/3243

[61] Ibid.

Japanese Aerospace Exploration Agency or JAXA. This government organization is responsible for the system development and operations of the system.

Initially, QZSS will be broadcasting signals on the same frequencies as GPS making it completely interoperable and compatible with GPS by design. Although the Japanese Government touts QZSS as a system to improve the welfare of the Japan and its near neighbors through the peaceful application of system capabilities there can be no mistaking the fact that it is dual-use technology and can be used by the Japanese Self-Defense Force during its operations and especially in a ballistic missile defense scenario.

There is anticipation by JAXA that the system will broadcast on other frequencies as new applications are developed in the future. Koji Terada also stated that "we will try to establish next-generation positioning technology in Japan, not only with the same signals as GPS satellites but also with our own frequency signals. Having our own original system, even if the U.S. GPS service becomes unavailable to us in the future, we will still be able to manage, and even to create, new opportunities ourselves."[62]

Japan has been proactive in reaching out to other GNSS owners to work through frequency overlap issues that currently plague Galileo. Japan reached agreement with China on the interoperability between QZSS and Compass in 2007. There are no significant compatibility issues between GLONASS and QZSS as the two systems do not share frequencies. Negotiations are on-going between Japan and India on areas of cooperation and compatibility. There have been six working group meetings between

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[62] Terada

Japan and the EU to coordinate and to deconflict frequency overlap issues with most issues between them being resolved.[63]

The first satellite was launched from Japan on September 11, 2010, and currently remains in the testing and validation stage. When the three-satellite system is fully operational it is expected to increase the percentage of availability across Japan from a current GPS only 90% to a GPS+QZSS of 99.8%.[64] Japan expects to launch the remaining two satellites into orbit during 2012.

E. IRNSS

India is the largest democracy on the planet and has the second largest population after China, its immediate neighbor. It has a rapidly growing middle class and its economy ranks fourth in the world by GDP (purchasing power parity or PPP) right behind China and just ahead of Japan. However, Indian regional international relations present it with an ongoing security dilemma. It must remain strong enough to deter Chinese aggression along their common border and in the Gulf of Bengal and the Indian Ocean while not appearing to grow sufficiently powerful to cause Pakistan to either bandwagon with China against India or to increase its own military posture giving India a more dangerous two-front threat.

But the threats to India's national security don't stop at its borders. Consider the tone of a book written by the former director of India's military intelligence who presents

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[63]International Committee on Global Navigations Satellite Systems, *Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentations Systems,* United Nations Office for Outer Space Affairs. (New York: 2010). 49. http://www.unoosa.org/pdf/publications/icg_ebook.pdf

[64] Mikio Aoki, *QZSS Update,* Secretariat of Strategic Headquarters for Space Policy, (Tokyo: January 16, 2011). 5. http://www.oosa.unvienna.org/pdf/sap/2011/UAE/Presentations/06.pdf

a chilling scenario for India and its future national security. He opines that the US could attack India, in the near term, over the issue of Kashmir and that India must be ready to address conflict with any developed nation. The book states that the scenario is plausible because of the "propensity of the U.S. to act unilaterally against other countries in disregard of the United Nations."[65] If this is a major motivation for Indian ruling elite policy makers then they must be prepared for measured responses from China or Pakistan to account for the possibility of those states perceiving a higher threat to their national security from India.

Terrorist attacks on Mumbai in December 2008 galvanized India's military hierarchy into a review of its capability to protect the Indian sub-continent. One of the manifestations of that review was Vision 2020 – The Next Step for India's Military Space Program. The report calls for India to acquire an accurate and reliable navigation system by 2012 to support military and civil requirements. The report specifically suggests that precision ballistic missile targeting could be an important capability provided by the system.[66]

India is a nuclear nation and has a tested capability to launch intermediate range ballistic missiles at targets in Pakistan or China. Gaining access to encrypted military grade GNSS signals would provide a significant increase in precision targeting for its missile forces including launches from its nuclear submarine with target accuracies in the half meter range.[67] India also has a rapidly growing space system industry and has launched a number of satellites into orbit, the first in 1975 atop a Soviet launcher. It

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[65] Dikshit.

[66] Debajit Sarkar, *Vision-2020 – The Next Step for India's Military Space Programs,* Defense Update, (Kadema, Israel: December 20, 2011). http://defense-update.com/20111220_vision-2020-the-next-step-for-indias-military-space-programs.html

[67] Dikshit

launched its first satellite using an Indian launcher in 2001 ushering in a new chapter in space operations as a stand-alone space player.

India also has a critical need to incorporate GNSS into its transportation network. As a developing nation India's infrastructure lags its population growth and unfettered and reliable access to GNSS will allow India to improve the efficiencies associated with its highway, rail, air, and marine transportation systems.

1. EARLY DAYS OF IRNSS

With its huge and burgeoning transportation sector and a growing offshore fishing fleet and Navy, India determined it was in need of locally controlled PNT services. Therefore, India approved the concept for the establishment of the Indian Regional Navigational Satellite System or IRNSS in May of 2006. The concept was very similar in scope to China's BeiDou-1 system and would provide coverage to the Indian sub-continent to include a 1500 km buffer zone extending outward from the Indian mainland. The system would consist of seven satellites in GSO. The accuracy of the system is projected to be in the 20 meter range throughout the coverage area.

What is interesting about India's adoption of IRNSS is its partnership status with Russia and GLONASS. Indian interests specifically revolve around gaining uninterrupted access to the GLONASS military signals in order to support its military forces and improve the targeting accuracy of its missile and rocket forces. It is also anticipating future economic opportunities in the design and manufacture of GLONASS ground station and user equipment. Surprisingly, IRNSS satellite signals will also be broadcasting on co-allocated GPS and Galileo assigned civil frequencies making IRNSS interoperable and compatible with every GNSS except COMPASS.[68]

IRNSS is a seven satellite constellation with three satellites in GSO and four satellites in non-GSO. This system, like QZSS is designed to be a stand-alone system in the event that GLONASS access is denied for any reason. The original schedule called for the first satellite launch in 2009 and the complete constellation deployed by 2012. However, delays have set the schedule back by several years with the first launch expected sometime in 2012 and full operational capability projected for late 2015.

IRNSS coverage area encompasses South and East Asia as well as all of the Indian Ocean, Arabian Sea, and the Bay of Bengal to ensure complete PNT coverage for India's projected operating environments including most all of China and Pakistan.

2. INDIA'S AGREEMENTS WITH RUSSIA

India has traditionally been a buyer of Soviet/Russian arms and armaments. Although India officially remains a non-aligned nation, it has closed with Russia strategically in the political regionalism of South Asia. There are a variety of reasons for India's political affiliations not the least of which is the traditional support of Pakistan by the US and more recently, China. Another issue is the continuing border dispute with China on India's Kashmir border region. Even today, China is claiming 92,000 square kilometers of land along India's northern border. There are also reports that Pakistan would be willing to grant China a 50-year lease on areas along the its northern border and

[68]Hofmann-Wellenhof, 414.

that China is interested in building military bases in that region in order to exert more control on the disputed border territory.[69]

India signed its first agreement with Russia on GLONASS in December 2004. At the time Russia was looking for partners as it endeavored to resurrect its flagging GNSS. The agreement called for the two nations to cooperate in ground segment development and for India to assist Russia in satellite array sustainment.[70] India had also opened discussions with the EU during this same timeframe to explore the possibility of India buying into the Galileo project. Eventually, after several years of desultory progress, India cooled to the notion of being affiliated with Galileo just as China and Russia had done, and for the same basic reason. While advertising its desire for international cooperation in the development of Galileo, the EU was reluctant to allow other state access to the encrypted public regulated signals that could be used by the military. This reluctance did not sit well with the Indian government which pushed India into closer cooperation with Russia on the development of the IRNSS.

One year later in 2005 another agreement was signed that guaranteed Russia's intellectual property rights of GLONASS technology. This agreement also proposed for the first time that GLONASS satellites could be launched from India atop Indian GSLV launchers at some point in the future. There was also mention that India would eventually have access to all GLONASS signals and would be directly involved in the joint development of a new generation of commercial user equipment.

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[69] Vivek Raghuvanshi, "Experts: Land Deal Would Threaten India", *Defense News*, March 12, 2012, 16.

[70] Vladimir Radyuhin, "Russia's Glonass satellites available by 2009", *The Hindu International*, March 22, 2006. http://www.hindu.com/2006/03/22/stories/2006032206241300.htm

Another agreement was signed into effect in March 2006 that fully solidified India as a significant partner in GLONASS. First, it was agreed that GLONASS satellites would be launched atop GSLV launchers in recognition of Russia's inability to maintain its flight schedules due to launcher shortages caused by a large backlog of commercial orders. Secondly, India was to begin supplying the platforms, or chassis, for the upgraded GLONASS K satellite because Russia could not maintain the aggressive launch schedule called for by President Putin.

F. CONCLUSION

Thomas Freidman opines in "The World is Flat" that with increases in technology and communication capabilities comes more global interdependence among states and cultures. It is interesting that in the case of GNSS, there are several states that have chosen to reject the concept of interdependence in favor of unilateral actions that erect safeguards to protect the sovereignty of those individual states and use those increases in technology and communication capabilities to do so.

It has been demonstrated by the US and Russia that putting a navigation system into space and maintaining it is a very expensive and technically challenging endeavor. Russia tried and failed the first time because of cost and lack of internal will. Why is Russia trying again? President Putin has said it is important to Russia's future and to its standing in the world order. Right now Russia has the excess financial capacity to fund the system. It remains to be seen if it can sustain the system through the next 20-50 years especially considering the financial uncertainties that exist today.

India has also emerged as a top tier space player. It will have a captive system in place that is reliable and independent. Its system, however, will not provide the accuracy of other systems and India has made the decision to tie itself to GLONASS in order to improve its local accuracy and to have access to encrypted military signals. The IRNSS was designed to be fully interoperable with GPS and Galileo giving India other systems to coordinate with in the event GLONASS access fails to deliver for any reason.

Japan rolled out its regional system, QZSS, out of actual necessity. Time will tell if Japan continues to militarize but for now the country is truly in need of a system to improve the PNT capabilities available to the Japanese people. The efforts by the Japanese scientific community may have also supported the development of GPS III as well. Many of the system characteristics of QZSS have been adopted from the concept documents of GPS III and have been fully incorporated in the QZSS designs.

China's GNSS intentions remain the most opaque of all players. It spent time and Yuan toying with the idea of partnering with the EU in the Galileo project and then, growing tired of EU reticence, finally elected to go it alone. China is a member of every regional and global organization pertaining to GNSS and professes to promote international cooperation and the peaceful uses of space. However, it released an incomplete COMPASS ICD under pressure from the West in 2011 and has yet to provide the additional data expected from a state that promotes international cooperation. At the same time China has chosen to initiate a conflict with the EU over the use of signal frequencies that may impact the operations of Galileo.

There is no doubt that China has the will and the resources to deploy and operate COMPASS. It remains to be seen if the huge and burgeoning Asian market for GNSS user equipment opens up globally or if China's manufacturing sector gains the advantage and captures the bulk of the market. This is the biggest economic prize on the horizon and it could be that China is positioning itself into a position of making the most of it.

The US GPS is the gold standard of GNSS. US manufacturers will continue to provide user equipment because all other systems will work with GPS. However, the same cannot be said for the EU and Galileo. It very well could be that Galileo becomes the last system to achieve full operational status and the financial ramifications of that could seriously impact the costs and potential of Galileo. In this narrow example it could be that Europe might be left holding the bag and that would not bode well for European taxpayers.

CHAPTER V

ANALYSIS AND CONCLUSIONS

A. INTRODUCTION

The decade of the 2010's will likely see the greatest transformation of space based positioning, navigation, and timing systems in history. If current launch schedules are met then the PNT satellite population will exceed 120 by 2020. This represents a nearly four-fold increase in navigation space vehicles in just 20 years. At the same time three new states will have global PNT capabilities that rival the availability and reliability of the current GPS. So how is this transformation going to affect the way these states relate to one another and what are the implications for the future?

Three observations that have percolated to the top from the research that are significant relative to the expansion of GNSSs are the following: that the EU found it very difficult to act as a single entity throughout the project; that the US could be in great danger of losing its technological lead in GNSS space system design and manufacturing output to China; and that the EU may have squandered a tremendous economic opportunity by not getting Galileo off the ground in a more timely fashion. Each of these observations will be reviewed later in this chapter.

The research has shown that inter-state relationships have been politically contentious at times over the whole issue of competitive GNSSs. It is no secret that the creation of a GNSS from the ground up is a very expensive and complex endeavor and yet the European Union and China have elected to do just that. They are risking national resources to create global systems that already exist in GPS and GLONASS and have been offered free to the global population for the past three decades. The question has to be asked why a state would commit so much in order to get something that already exists as a free service and is considered a part of the global commons. The obvious follow-on question is why has it proven so difficult for the different states or entities to get along harmoniously in order to see these new systems built?

It would be easy to say that the EU, Russia, and China all decided to either build a new system or, in Russia's case reconstitute a decayed system, because they were tired of being beholden to US largesse. While it is apparent that each of those players identified dependency on GPS as a major national security concern it doesn't come close to explaining the actual underlying reasoning for their behaviors.

B. THE EUROPEAN UNION

The EU presents the most complex challenge trying to discern the underlying catalysts that compelled the Union to build Galileo. There were only 15 EU member states when the project was first approved in 2002 and it had grown to 27 by the time the PPP collapsed in 2007. The expansion of the Union introduced tension and uncertainty into the negotiations all by itself but this further expansion of the Union does not appear to be a major factor. The fact that the Parliament assigned the project to the European Commission proved to be fortuitous in the sense that EC work rules allowed for decision making by qualified majority vote and not consensus agreement and that did facilitate a less cumbersome decision making process..

The ESA partnered with the EC on the project and it operates as a one state, one vote, organization where financial contributions are mandated by state GNP and bigger donors theoretically don't wield more power than smaller donors. This seemingly simple departure from the norm in EU decision-making proved to be decisive on several occasions and allowed the project to keep moving forward in the face of member state intransigence.

The Transport Committee of the EC was the point where the GNSS question was first debated and negotiated. The focus of the committee was on improving transportation networks across Europe and therefore, the early debates on GNSSs were transportation centric. Interestingly, there was very little specific member state input into the debates until the outlines of the project had been approved and a governing body established with the GJU.

Neil Kinnock, a former Labour leader and former member of the UK Parliament, was the Transport Commissioner of the EC in 1997 when Galileo's future was first being debated. He became the champion of Galileo after the EU had been rebuffed by the US on a proposal by the EU to gain an equal share with the US in the control and operation of GPS. The US was firmly against allowing any third party having anything to do with GPS beyond having user privileges and refused EU advances. Kinnock looked at a GNSS as part of the global commons and believed it should therefore be shared and controlled internationally and should not be the domain of any one nation. Having no luck with the US, he then promoted negotiations with Russia with the intent of having Russia allow the EU to become a full partner in GLONASS. This attempt also proved to be a pie in the sky leaving Kinnock no choice but to promote Galileo as an internally created European system.

He was instrumental in the early days getting members of the Transport Committee to support the project as a distinctly civil operation designed to improve the welfare of the people. At one point in 1997 he said that:

> "The most basic strategic choice is whether we in Europe should develop our own independent satellite navigation system. Frankly, my preference - and I think that of many others - would be to develop a single global system with our international partners. Obviously, however, that course could only be followed if there was genuine collective control over the system; firm guarantees that the service could not be withdrawn under any circumstances, and an opportunity for European industry to compete in all segments of the market. If, after careful analysis, we in Europe are not convinced that such a global system is a realistic and dependable opportunity, I think that we in Europe will have to press ahead with our own system."[1]

The general attitude of the Transport Committee during this period was relatively narrow and apparently assumed that the US and/or Russia would be enlightened enough to recognize that their economic self-interests lay in full and equal cooperation with the EU on the GNSS issue. What was missing early on was a more holistic view of the impact that a GNSS was going to have on the international community in the near future. There were several obviously important matters such as international power and prestige, war and peace, arms and alliances that the Transport Committee was not considering because its focus remained primarily on transportation.

Kinnock's anticipated outcome seemed to suggest that an increase in economic integration would correspondingly increase economic interdependence and would help to diminish any propensity for conflict. It appears that he expected that any increases in economic interdependence would compel states to work closer together toward a common goal thereby relinquishing some amount of sovereignty in exchange for increased prosperity and security. Of course this would be the collectivized GNSS with

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[1] Lembke, 89.

each and every collaborator having equal access to economic gain without consideration of national security or military requirements.

Kinnock's arguments were persuasive and although his efforts to 'collectivize' GNSS generally failed, he was able to get Galileo approved by the EC along a very narrow transportation sector requirement by introducing, among other things, a sense of urgency into the proceedings.

The Directorate General of the EC Transport Committee, headed by Kinnock, argued for speedy approval of Galileo in a 1998 presentation saying flatly that "the window of opportunity is open now, it being understood that GNSS-2 (Galileo) needs to be operational before 2008, in parallel with the completion of the US GPS Block IIF. Any later start of GNSS-2 would put at risk the ability of GNSS-2 to conquer a reasonable segment of the commercial market and to protect overall European strategic interests."[2] This, then, was seen at the time as being the driving force behind the creation of Galileo. No matter what came later, the members of the Transport Committee saw the economic potential of the system well before many others in the EU governing ranks.

Unfortunately for Galileo, there ended up being a larger number of actors who entered the fray after the approval point who had many other interests in the project beyond the transportation sector. These new actors sometimes formed competing regimes based on economic issues or national security issues and often times worked against each other forcing delays and cost overruns.

What was missing during the early days was a one team - one fight mentality from the member states. Hence, the observation made earlier in the chapter that the EU

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[2] Ibid., 95.

found it very difficult to act as a single entity throughout the project. One could argue that the original 2008 date to have Galileo operational was overly optimistic but then John F. Kennedy suggested in 1962 that NASA would have a man on the moon by the end of that decade.

Kennedy said that "We choose to go to the moon. We choose to go to the moon in this decade and do other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."[3]

He managed to unite the people and their government in common cause to meet his stated goals by 1969. Conversely, the EU still continues to struggle with endemic delays and cost overruns with Galileo after more than a decade of effort. This lack of unity has had a deleterious effect on the project and its eventual success is still not a certainty.

Germany has been the economic engine of Europe for decades and rightly so. It is the manufacturing center of the EU. However, it had been focusing inwardly for a number of years at the turn of the century on its reunification efforts. The reunification had proven to be a much larger, more complex, and tremendously more expensive undertaking than expected and those efforts were consuming much of the external political vitality and discretionary resources of the state. Its space budget had been cut and there was little appetite for taking on new and costly projects like Galileo.

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[3] John F. Kennedy Moon Speech, Rice Stadium, (Houston: September 12, 1962). http://er.jsc.nasa.gov/seh/ricetalk.htm

This is the main reason Germany was not initially in favor of Galileo. When Germany finally engaged and supported Galileo it did so from the position of economic strength. But its actions were defensive in nature in that it was adamant about protecting its domestic space sector industrial capabilities against gains by other member states at its expense. Of all the member states, Germany was the most concerned about the welfare of its population and was somewhat indifferent to French or UK views on the military applications of the projects. France, on the other hand, was fiercely in favor of the project and its fervor was not diminished by a more liberalist Germany.

France, Italy, Spain, and several of the smaller member states recognized the future economic potential of the project but had another agenda that drove their politics. They were adamant about using Galileo as a strategic military and security asset and lobbied consistently for the project as a way of increasing the EU's independence on the world stage and, specifically, as a top-tier military power. This status had been an especially elusive goal for France and it saw Galileo as an instrument of power and prestige for itself and for the EU. France has been Europe's leading space state and, over the years, has spent more on space projects than any other member state. And it has also spent more on military space projects than all other member states combined. Finally, France has been the largest contributor to the ESA since its creation and is arguably, the leading space power in the EU.

France, Italy, and Spain were looking to gain economically from having ground support centers located within their borders and on the fair return on investment policies of the ESA. France had committed itself to bi- or multi-lateral agreements with Germany, Italy, Spain, the UK, and several other smaller states on dual-use space projects and has been the driving force behind most European space projects. It also has the most matured and experienced space related industrial base to capture future Galileo project contracts.

Galileo is too large of a project for any one member state to finance and build independently and France recognized that in order for Galileo to be successful it was going to need a collective effort from all ESA member states. Because member states retain ownership of their individually funded commercial and military space systems France could expect significant relative gains from having Galileo as a force multiplier for its large share of commercial and military space assets. There is no doubt that France focused on maintaining its industrial lead in space system expertise but it was also clear that there was a large and vocal realist sentiment in France that is offensive in nature and calls for autonomy and strength for France and the EU on the world stage.

UK support for the project was lukewarm from the beginning. The UK – US relationship has been considerably stronger than that of any other EU member state. The UK has also shared access to the GPS encrypted M-Codes when appropriate and there was little concern in the UK about possible conflicts between the two nations into the foreseeable future. Finally, the space system industry in the UK was not as firmly entrenched and matured as in other member states.

The UK complies with the mandatory contribution requirements to the ESA and concentrates other space spending on national projects that specifically support the welfare of the UK population. Consequently, there were few in the UK who could justify the costs associated with Galileo and the general sentiment was to continue to use GPS regardless of EU actions.

Member states spent seven or eight years maneuvering around each other trying to increase their relative gains at the expense of others. The UK, France, and Italy favored outcomes that improved national security, although for different reasons, while Germany and many smaller states favored outcomes that improved their domestic economic situations. What was not readily apparent during the run-up to the failure of the PPP was a unified effort that supported the greater good of the EU specifically. EU integration had not gained sufficient traction to compel the member states to relinquish some degree of sovereignty in support of a holistic approach to Galileo.

The situation changed dramatically in 2007 when the EU voted to support Galileo with public funds. All of the member states were forced to come on-board, ante up their share of Euros, and move forward in unison. What is not known is how much of the economic potential that was apparent to the Transportation Committee in 1998 was frittered away because of member state internecine conflict that was based on neo-realist concerns for border security, relative gains, and the presentation of a possible security dilemma if outcomes were not zero-summed.

There is most likely a multitude of reasons for the behaviors of the member states regarding Galileo. One possible reason is the absence of an EU centralized authority capable of trumping national assemblies. However, it is not the intent of this work to analyze the causes of the behaviors only to recognize the effects these behaviors had on the Galileo project.

It is interesting that the Transportation Committee, and the EC generally, knowingly promoted international cooperation and collaboration on the project early on and then, by 2006, had turned inward and away from international partnerships. This rejection of international cooperation by the member states is anathema to previous EU arguments and pronouncements and specifically, its condemnations of some aspects of the international behavior of the US.

The EU retreat from international cooperation on the project would have been difficult to predict. Member states recognized the huge economic potential to be derived from the next generation of GNSS and moved early with a plan (Galileo) to capture a large portion of it for European manufacturers. The EC extended invitations, signed letters of agreement and understanding, and even established centers of cooperation in an effort to create a truly global system in the reflection of the modern European social democratic tradition. And the effort mostly came to naught. It failed because the EU failed to deliver. In other words, the EU had buyer's remorse after the fact and realized that complete transparency and national security were immiscible on a global scale. Tip O'Neill, former Speaker of the US House of Representatives once said that in the end 'all politics are local' and that seems to be the way that the Galileo project is playing out.

The EU was not operating under a unified command structure in the early 2000's with regard to Galileo and that has proven costly in terms of lost opportunity. The EC was in an expansive mood when it engaged with Russia, China, India, and others to collectivize the project. Obviously, the major impetus for engagement was the potential for huge economic gain but the EU was also offering each partner significant access to the technological framework of the project which would have represented a huge leap forward in scientific knowledge for those partners. It became abundantly clear when the member states realized that a number of Galileo's critical components were on the US ITAR list and could not be transferred to those same states that were being courted as partners without US approval. This forced the EU to seriously reconsider its options. In this case, the EU blinked and backed away from close cooperation in favor of future negotiations on interoperability and compatibility. China's response to the EU behavior was interesting, and typical.

What is most surprising is the fact that China did not choose to immediately work cooperatively with EU on interoperability issues and frequency use issues after it announced COMPASS to the world. After all, China had contributed €200 million to the Galileo project in 2004 and then dropped out of the program in 2006 without gaining much advantage. It may have something to do with the basic relationship between the EU and China. In a 2008 report sponsored by the European Council of Foreign Relations (ECFR), the authors emasculate the Union and its member states for their inability to work together harmoniously and without unified leadership. The report states that:

> "The EU's China policy is trapped in a diplomatic vicious circle. European divisions reflect a lack of faith among Member States that the EU can act as an effective guarantor of their national interests. The EU has responded to the lack of direction from its Member States by clinging to a policy framework that dates from an era when China was the world's largest developing country. This encourages governments to pursue their relationship with China independently from Brussels, leaving the EU to deal with few matters of substance and to fight battles over largely symbolic issues. Arguments about language on Taiwan, Tibet, human rights or the arms embargo – which have little to no impact on the ground – are fought at the expense of progress on vital issues such as market access, African governance or climate change."[4]

If, as the authors suggest, China recognizes it is in a position to 'divide and conquer' by working directly with member states allowing it to bypass the EU generally then an argument could be made that it is in China's best interest to align itself with GPS

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[4] John Fox and Francois Godement, *The Power Audit of EU-China Relations,* (London: European Council of Foreign Relations, April 2009). 30. http://ecfr.3cdn.net/532cd91d0b5c9699ad_ozm6b9bz4.pdf

in order to, as Sun Tzu is rumored to have once said, that 'if you know your enemy and know yourself then you need not fear a hundred battles'.

Perhaps China agrees with the ECFR assessment that "today, feelings in China have soured and the EU's political significance has markedly decreased in Chinese eyes. The EU's failure to agree on a coherent foreign policy and the ongoing disputes among Member States has given currency to the Chinese analysis that an erratic EU is on a slide to irrelevance."[5] And this is from 2009! The unforeseen consequence of the uncoordinated decision making process of the EU continues to impact Galileo more so than COMPASS.

Offering cooperative engagement to those developing nations was going to put member state industries at risk of losing billions of Euros in lost US contracts because of violations of US law. This brings the conversation back to another observation that was made earlier that suggests the EU may have squandered a tremendous economic opportunity by not getting Galileo off the ground in a timely fashion. Economic growth opportunities for GNSS user equipment will be coming primarily from Asia and the Indian sub-continent. It seems that the EU missed several opportunities in its relations with China and India regarding Galileo. The potential losses in revenue from Galileo services and equipment sales could be in the hundreds of billions of Euros over the life of the system and right now, the research suggests that the EU is in danger of losing its opportunity to fully participate in that growth area.

In the end, the EU abandoned its plans to bring international partners into the fold and instead offered to have Galileo become interoperable with COMPASS, GLONASS,

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[5]Fox and Godement, 33.

QZSS, IRNSS, and of course, GPS. For now, the EU is working to maintain its build and launch schedules as it attempts to adhere to a 2018 full operational capability target date.

The research seems to suggest that the notion of space nationalism is emerging among states as an instrument of national pride, power, and international standing. There has been a period that began with the end of the Cold War where states were anxious to cooperate on a global basis with each other on space projects. The International Space Station and several of the deep space exploration missions are excellent examples of multi-lateral global efforts that have yielded positive results.

But the rush to build GNSSs may be a sign that states are moving away from the space cooperation model and back to individual efforts as realist sentiments of border security, nationalism, anarchy, and the balancing of power become more evident. The issue for the EU is that these issues exist on two levels. The first being the member state level where there is still a certain reluctance to freely relinquish sovereignty for the sake of the Union and then as it actually exists at the EU level where the EP is behaving as a recognized representative of the collective of states. Currently, the EU is under tremendous economic strain and the outcome could prove to define the future with a stronger EU or the weakening of EU institutions and a return to stronger state politics.

C. RUSSIA

Russia's behavior appears to be more predictable. It has suffered through several economic recessions since the end of the Cold War and the breakup of the Soviet Union and recognizing the economic realities of the times discovered that it could sell its space expertise for a profit. President Vladimir Putin has capitalized on Russia's space system expertise and the country is partnering with a number of states across the globe in support of space missions as a way of financing its own domestic space programs. Its Soyuz launcher reliability is almost legendary and Russia has maintained close ties with the US and the EU in support of the International Space Station and for providing launch services for Galileo satellites. There is no doubt that Russia is intent on maintaining its position as a global space power. What is new is the course it has taken to support those efforts. Russia's adoption of a more accommodating attitude toward international space partnerships has, to some degree, lessened the perception of Russia as a global aggressor nation to one with softer regional interests. The willingness of Russia to offer GLONASS to the global commons is an example of this new transparency.

However, there is still little doubt that Russia's military can and will take advantage of GLONASS's encrypted signals if and when it has sufficiently modernized its forces to actually integrate the system into its operations. The current state of Russia's military does not support GLONASS to any great degree and that fact was emphasized when Russian forces were compelled to try to use commercially available hand-held GPS receivers during the Russo-Georgian conflict in 2008.

A report on Russian military performance in Parameters Journal from 2009 said that "satellite-targeting support to artillery was woefully absent, thereby preventing the use of precision-guided munitions and the accurate adjustment of artillery fire. The Russian Army largely went into combat in August with World War II-era compasses and maps. Russian forces allegedly attempted to use the US Global Positioning System (GPS), but were thwarted in their attempts by the fact that the map of Georgia was blanked out for 48 hours. They were forced to resort to targeting conventional weapon systems through the use of vintage 1960s optical equipment."[6]

Russia has announced several initiatives aimed at integrating GLONASS services into its military forces in order to avoid the kinds of problems it experienced in Georgia. There is one other reason why Russia is accelerating the integration of GLONASS into its military forces. Russia is a major purveyor of arms and armaments on a global basis and counts on this revenue stream to support its military-industrial complex. Most new military hardware requires PNT capabilities and without those built-in capabilities, sales of that equipment would fall off dramatically. This is one of a number of economic imperatives that is forcing Russia to rebuild and integrate GLONASS as quickly as possible.

On another front, Russia is moving to improve its high technology manufacturing sector by partnering with India on GLONASS services and mandating the use of GLONASS receivers in all government applications across Russia in lieu of or in concert with GPS receivers. Russia has taken the precaution of having a backup system to GLONASS in the name of GPS but to the exclusion of COMPASS or Galileo. It remains to be seen if Putin is able to reinvigorate Russia's federal bureaucracy sufficiently to allow Russia's technology sector to become flexible enough to keep up with rapidly changing requirements and increased worker productivity in an era of declining demographics. There is no doubt that Russia's high tech sector has struggled to keep up with other world class manufacturers and if Russia does not figure out how to overcome shortages in the space technology sector it risks losing its place as a major space power.

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[6] Roger N. McDermott, "Russia's Conventional Armed Forces and the Georgian War", *Parameters*, Spring (2009): 70.

The biggest vulnerability facing Russia is its future ability to support and maintain a persistent space system like GLONASS and it needs to expand its user base in order to stimulate requirements for services and user equipment. This is the key to GLONASS' persistence. Russia is hoping that its relative gains in manufacturing and services will offset the transactional costs of maintaining GLONASS and have it join Soyuz as a mostly financially independent system. The future partnership with India should provide additional revenue to the program and may prove to be profitable for Russia so long as India remains a major buyer of Russia's arms and armaments.

Russia is a space power but not necessarily a space leader. Several of its legacy systems remain center stage but Russia is not currently in a position to introduce much in the way of next generation space navigation technology. As long as energy prices remain high and Russia continues to develop its infrastructure then Russia should easily be able to maintain GLONASS into the 2020's and beyond.

D. CHINA

It is hard to argue by nearly any metric that China is not the preeminent rising global power. Its economy continues to rapidly expand along with a corresponding rapid growth in its military expenditures. Conventional wisdom suggests that these trends will continue at least in the near term. China has the world's largest population and much of it is still rural so it is easy to understand that China could use a system like BeiDou-1. It can also be argued that China's BeiDou-1 program is the only true dual-use PNT system on the market today. It is dual-use in the sense that it is used for military and civil applications by the same user group, the PLA.

It cannot be denied that the two-way communication capability of the system provides China with a powerful tool for use in mitigating the effects of national disasters that occur out in the rural expanses of the country. The system has been used to save thousands of lives on numerous occasions and has proven to be an invaluable tool for disaster relief forces, most of whom are members of the PLA.

At the same time, that two-way communication capability provides senior military leadership the opportunity to move those same PLA troops around on the battlefield without the need of sophisticated communication equipment that does not currently exist in great numbers within the PLA. China's land forces are, for the most part, still in the developmental stage compared to Western forces but do have similar capabilities as other regional military forces.

BeiDou-1 is operational and covers that part of the globe that has sometimes been referred to as the China's Middle Kingdom. It encompasses much the area that China believes should be part of its regional economic and political sphere of influence. BeiDou-1 makes sense from the Middle Kingdom perspective. China can provide PNT capabilities to other regional actors and use it as a means of furthering economic integration and cooperation. It also provides China's maritime components, its fishing fleet and its Navy, with important PNT and communication capabilities as China continues to assert itself as the future regional hegemon.

BeiDou-2 or COMPASS is another matter altogether. Why is China building a GNSS? It makes sense militarily if China is interested in power projection on a global scale which it says it is not. However, it has commissioned a large aircraft carrier and has several nuclear ballistic missile submarines in service that are designed for blue water operations. It may be nothing more than another case where a state strikes out on its own to develop or acquire captive GNSS capabilities and simply desires to chart its own destiny in this critical area. Is it too much to ask of some nations to bank their treasures with an outside party (the US) and assume that GPS will be available into perpetuity and that their economies and their national security will remain protected? There are also compelling economic reasons for developing a GNSS. However, much of this economic argument is based on speculation and educated guesswork.

China has announced that its naval buildup is a defensive response to US actions in the region and nothing more. It could be that COMPASS is also a defensive response to the same stimulus. There is no doubt that China's military leadership is aware of the ease in which the US blocked GPS transmissions around Georgia in 2008 that impacted Russian operations. It was also impressed with the ease in which the US was able to block and defeat all Iraqi attempts to jam or spoof GPS during Gulf War I. It makes sense that China would feel somewhat constrained and vulnerable if they were forced to rely on some other GNSS for services in the event of a conflict especially considering the technological lead that the US currently enjoys.

That being said, Mongolia and Pakistan have been in negotiations with China for partnership roles in COMPASS that will include an unfettered access to COMPASS military signals. For Pakistan, this is an obvious balancing against India's recent agreements with Russia on GLONASS access and would also mean a closer alignment between China and a nuclear Pakistan that would further complicate US-Pakistan relations. In all of these instances China is making sure there exists a bridge between states to prevent a deadly spiral from developing.

The fact that China is ensuring that COMPASS be interoperable with GPS is an interesting turn of events in and of itself. The US is the regional hegemon that China seeks to supplant. It is also China's second largest export market. Why would China choose to align itself closely with its primary competitor in the GNSS arena? Although China has an abundance of labor its rapidly growing space technology sector is still generations behind the US space technology sector in terms of capabilities and output. In other words, it could be that it needs the US to ensure the persistency of the Chinese state and it will continue its efforts to increase the interdependence of the two states where that interdependency feeds the state.

However, it is not an easy question to answer from a purely GNSS perspective. Interoperability between GNSSs means that certain signals generated by satellites across more than one system can be processed by a single receiver appropriately programmed to receive multiple signals. Interoperability does not mean that states will be transferring essential technology amongst themselves. Therefore, China does not stand to gain significant increases in its technological knowhow merely by aligning itself with GPS. A simple out-of-the-box answer might be that China recognizes the US as a somewhat disinterested and credible third party to conflict resolution in that part of the world and China is using this behavior for future political gain.

The EU-China relationship as it applies to GNSS remains uncertain. The EU and China have become each other's largest trading partners which suggests that there have been considerable economic interdependencies created between these two entities. However, these interdependencies may exist at the member state level leaving a vacuum of sorts that exists between the EU specifically and China. If that is the case then any unresolved issues between Galileo and COMPASS could persist until it is in China's best interest to initiate resolution.

It appears that the economic stakes are high enough for China to make a stand against Galileo. Yin Jun, director of European affairs in China's Department of International Cooperation, Ministry of Science and Technology, stated in 2009 that "it is hard for Chinese industries to participate in Galileo FOC, even though China invested in the IOV phase; several [Galileo] IOV cooperation projects cannot be implemented smoothly, because of some barriers and obstacles; the Technical Working Group on Compatibility and Interoperability has not yet made concrete progress."[7]

It may also be that China is banking on GPS III to be operational before Galileo and will provide China an opportunity to capture a sizeable piece of the next generation of user equipment that is sure to follow GPS III. If that is the case then China will be competing directly with the US for market share in the huge Asian marketplace. Considering China's focus on economic growth and the need to provide jobs for its burgeoning urban population then it makes sense that China would launch COMPASS primarily to support its continued economic vitality.

E. INDIA AND JAPAN

India and Japan are regional players in the satellite navigation business and will remain so into the future. Both states have determined they have a need for captive navigation capabilities but for different reasons. Japan's geographical challenges exceed the capabilities of GPS and required a significant enhancement. The result is known as

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[7]Alan Cameron, "Asia-Pacific GNSS Roundup: Where Are They Heading?", *GPS World*, April 28, 2009. http://www.gpsworld.com/gnss-system/asia-pacific-gnss-roundup-where-are-they-heading-7264

QZSS. It is modeled after GPS and was built to be fully interoperable and compatible with GPS III. Its purpose will remain primarily to support the general welfare of Japan's population. However, it will have the capacity to fully support any future improvements in Japan's military capabilities including its growing missile defense capabilities.

India, on the other hand, has partnered with Russia and GLONASS for PNT services including the full suite of encrypted signals for use by India's military forces. At the same time, India is creating a separate and captive regional system that will be capable of providing PNT services to the Indian subcontinent on its own. India has also endeavored to ensure its IRNSS is interoperable with GPS, GLONASS, Galileo, and COMPASS giving India a very accurate and reliable system for domestic use in the event that GLONASS becomes unavailable for whatever reason. India's efforts fully support its non-aligned foreign policy practices of the past 60 years.

F. THE UNITED STATES

Today, GPS represents the gold standard of GPSS design and delivery. There is an expectation that GPS III will maintain that status in spite of new competition but the playing field has changed and the US is no longer the only game in town. How does this affect US foreign policy and what role might the US have in the future of satellite-based PNT systems?

Based on previous behaviors and the close relationship that the US has had with the EU it is hard to imagine any real conflict developing over the fielding of Galileo. There were several speed bumps early on that seem to have been resolved between both entities and the EU is well on its way to deploying their system. The major sticking point is Galileo's PRS signal. The EU did not make claim to its requested PRS frequencies with the launch of GIOVE-A and B and it does not expect to be ready to test the PRS until 2018. That has left the door open for China to claim those same frequencies for its encrypted signals and that will become a much larger problem for Galileo when it finally addresses the issue. In the meantime, NATO and all of the other EU member states will continue to use GPS for their military applications. That translates to 'GPS only' receiver equipment and the loss of economic revenue for EU user equipment manufacturers. Military budgets in the US and across Europe are in decline with all services trying to reduce costs and improve efficiencies. Losing the whole of the European military market to GPS will force the EU to remain dependent on the US in this important sector for at least another decade or more and that will be a favorable outcome for the US.

One large second order effect of not deploying PRS will be that EU armaments manufacturers will be building and selling their wares across the globe with GPS receivers in lieu of Galileo receivers which will further reduce the revenue stream from Galileo across member states. Other competitors present far different challenges to the US than Galileo.

China's decision to build COMPASS presents a larger political and economic challenge to the US than any other system. The 2010 National Security Strategy recognizes China as a rising regional power in the East and defines the US position. It states that:

> "We will continue to pursue a positive, constructive, and comprehensive relationship with China. We welcome a China that takes on a responsible leadership role in working with the United States and the international community to advance priorities like economic recovery, confronting climate change, and

> nonproliferation. We will monitor China's military modernization program and prepare accordingly to ensure that U.S. interests and allies, regionally and globally, are not negatively affected. More broadly, we will encourage China to make choices that contribute to peace, security, and prosperity as its influence rises."[8]

The passage makes clear the fact that the US would like to assume additional leadership duties in certain areas that support the global good but to refrain from entering into competition directly with China on a regional basis. The United States Military Strategy further reiterates and distills those concepts into the notion that the US:

> "Will continue to monitor carefully China's military developments and the implications those developments have on the military balance in the Taiwan Strait. We remain concerned about the extent and strategic intent of China's military modernization, and its assertiveness in space, cyberspace, in the Yellow Sea, East China Sea, and South China Sea. To safeguard U.S. partner nation interests, we will be prepared to demonstrate the will and commit the resources needed to oppose any nation's actions that jeopardize access to and use of the global commons and cyberspace, or that threaten the security of our allies."[9]

This passage leaves no doubt that the United States recognizes China as a potential threat to its national security in several areas including space. Looking at China's regional intent from the US perspective begs the question again. If the United States has put China on notice that it is a potential adversary why would China select GPS as its primary GNSS partner? The current US administration fully supports and encourages international engagement wherever and whenever possible as a means of lessening tension and increasing interdependence. There is no doubt that the US will work with China, and others, to ensure equal access to space for peaceful purposes. The US 2010 Space Policy clearly outlines the administration's vision on space. It states that:

> "The United States must maintain its leadership in the service, provision, and use of global navigation satellite systems (GNSS).To this end, the United States shall:

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[8]United States National Security Strategy, (Washington, D.C.: The White House, May 2010). 43.
[9]The National Military Strategy of the United States of America, (Washington, D.C.: Department of Defense, February 2011). 14.

—Provide continuous worldwide access, for peaceful civil uses, to the Global Positioning System (GPS) and its government-provided augmentations, free of direct user charges;

—Engage with foreign GNSS providers to encourage compatibility and interoperability, promote transparency in civil service provision, and enable market access for U.S. industry;

—Operate and maintain the GPS constellation to satisfy civil and national security needs, consistent with published performance standards and interface specifications. Foreign positioning, navigation, and timing (PNT) services may be used to augment and strengthen the resiliency of GPS; and

–Invest in domestic capabilities and support international activities to detect, mitigate, and increase resiliency to harmful interference to GPS, and identify and implement, as necessary and appropriate, redundant and back-up systems or approaches for critical infrastructure, key resources, and mission-essential functions."[10]

The US space policy has changed with regard to GPS since the last administration. The current policy now focuses on international cooperation and equal access and away from US dominance in manufacturing and design. The change has obviously been prompted by the realization of increased global competition coupled with decreasing space budgets. Although the specific 2013 GPS budget request of $1.26 billion has been cut from the 2012 budget request of $1.46 billion, the Air Force maintains that it remains on-target to launch the first of 32 GPS III satellites in 2014. The Nation's space strategy recognizes the huge economic potential associated with the modernization of GPS and the standing-up of competing systems. It calls for the US to "actively promote the sale of U.S.-developed capabilities to partner nations and the integration of those capabilities into existing U.S. architectures and networks. Posturing our domestic industry to develop these systems will also enable the competitiveness of the U.S. industrial base."[11]

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[10]National Space Policy of the USA, (Washington, D.C.: The White House, June 28, 2010). 5.

[11]National Security Space Strategy, (Washington, D.C.: Department of Defense, January 2011). 9.

The concept of international cooperation and increasing transparency are permeating the behavior and policies of the United States moving into the 2010's. There are several challenges facing the US that will require careful negotiation and strong leadership if the US is to persist as the world leader in GNSS technology. These policy changes and the aggressive action by China on COMPASS form the basis of the observation that the US is in great danger of losing its technological lead in GNSS space system design and manufacturing output to China. There are several strategies that could be adopted by the US in order to at least keep it competitive in the field.

First, the US could insure that its space sector industry has every opportunity to compete globally for GNSS components and equipment. For example, if China were to stack the deck and move to protect its domestic industry from external competition for the Asian GNSS user equipment market then that would be a significant financial blow to US manufacturers where they currently enjoy a healthy market share.

Because GPS has become part of the global commons and most of the globe currently depends on GPS it is imperative that the US optimize its position and continue to modernize the system in a very timely fashion or risk losing credibility and market share to foreign entities. The economic impact of lost market share would be significant and unrecoverable. It would also represent the loss of thousands of high tech jobs across the US.

It is important for the US to operate cooperatively on space projects but it is equally important for the US to stay ahead of the competition technologically in order to remain the leader in space systems. The US and every other country that is trying to build a GNSS should ask itself what is the relative weight of its resourcing versus the efficiencies of spending those resources; and of technological leadership versus the general opportunity cost? Or is this is only about economic growth and preservation of captive industry or is there more to it than that?

A GNSS is a persistent system that should continue to operate for generations to come. It can be a great source of pride and power for a population but if used improperly, will be a magnet for conflict and divisiveness. The very nature of the system guarantees that its impact will cross boundaries. The technological advances and industrial output associated with projects this large means that any state that attempts to limit access to some states in order to increase the economic relative gains of other states risks retaliation at the national level.

It really is about the money but each actor needs to understand the true value of money and how closely money is associated with the international and domestic politics of every state involved. Building a system of this magnitude merely for the sake of balancing power will probably not improve the efficiencies of domestic institutions because the system will not have sufficient internal focus to maximize the welfare of the population. Instead it could support a space race based on space nationalism that will ultimately destabilize the global order among its most technologically advanced states. The battle for GNSS leadership has been joined and the next decade will be decisive.

There are a number of predictions that can be made about the future of the GNSS. The research suggests that modern military forces will be forced to design and deploy a different system in the future to perform the varied and multiple tasks currently assigned to the GNSS. There are too many vulnerabilities extent and most of the scientific and technical details of these systems are freely available to anyone who desires them. It has been demonstrated over and over again that computer and satellite systems cannot be permanently hardened to prevent unauthorized hacking.

Even today, DoD no longer uses GPS to enable the targeting equations for its nuclear forces because of the potential for spoofing or jamming. There is no doubt that the first group of defectors from the ranks of GNSS users will be the military forces of the most technologically advanced states.

It would also be logical to assume that all GNSSs will eventually be moved to civil oriented departments or organizations that are not defense or security related. The growth of GNSS services is focused on civil applications and that growth will continue into the future. It could be argued that the time has come to privatize some of these systems and move the control out of direct government control and into quasi-government or PPP type organizations in order to improve the efficiencies of the operations and contribute to the continued growth and economic viability of these systems.

The research is clear on one thing. Every GNSS state is seeking the ways and means to ensure that their system is as financially self-sufficient as possible. There is a consensus among these states that the systems should somehow generate a revenue stream for the host state whether it is fees for actual services or industrial sector growth in support of the system.

It is still too early to know for sure where all of this is going because GPS is currently the only fully operational system. It appears certain that the situation will change dramatically when four systems are fully operational and competing with each other for services and user equipment.

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APPENDIX 1

DEPUTY SECRETARY OF DEFENSE

1010 DEFENSE PENTAGON
WASHINGTON, DC 20301-1010

DEC [illegible] 2004

The Honorable [redacted]
Ministry of Defense
[redacted]

Dear Mr. Minister:

I am writing you at this time to convey my concerns about security ramifications for future NATO operations if the European Union proceeds with Galileo satellite navigation services that would overlay spectrum of the Global Positioning System (GPS) military M-code signals.

Over the next several years, the U.S. plans a major modification to GPS to meet future military and civil requirements. One significant feature of the modernization is the spectral separation of the GPS military M-code signals from civil signals. Separating the signals will facilitate our ability to deny adversaries the benefits of these space-based navigation services in a local theater of operations without negating the military use of the system.

In a recent meeting in the U.S., a European Commission (EC) delegation indicated that a Galileo Public Regulated Service (PRS) was being considered for the same spectrum planned for the modernized GPS M-code signals. The addition of any Galileo services in the same spectrum as the GPS M-code will significantly complicate our ability to ensure availability of critical military GPS services in a time of crisis or conflict and at the same time assure that adversary forces are denied similar capabilities. Additionally, I am concerned that it is intended that the Galileo PRS will have the features of the military signals of GPS. If the future PRS is actually intended to serve such a purpose, I do not believe the current civil forum being used by the EC provides the proper venue to fully assess the security implications.

I believe that acceptable solutions can be found and that we can avert potentially serious impacts to future alliance operations that rely on GPS. To find such solutions, however, I believe we need to identify and establish the proper forum to discuss the security ramifications of this future services. In this regard, I urge you to consider two actions. First, convey these security concerns to your Minister of Transport in advance of the 6 December EC meeting to review the Galileo mandate. In expressing these concerns, I believe it is in the interest of NATO to preclude future Galileo signal development in spectrum to be used by the GPS M-code. Second, inquire whether the EC intends to develop a Galileo PRS that will have military features and, if so, we must examine in an appropriate forum the security implications of the proposed system.

Sincerely,

VITA

Robert F. Donnelly
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Robert F. Donnelly is a retired military officer. He has been assigned to a variety of positions throughout his career most recently to include military faculty member at the National Defense University, Operational Analyst at the Joint Center for Operational Analysis, Strategic Plans Officer at Joint Forces Command, and Human Terrain Team Leader in Helmand Province, Afghanistan. He has also served in Iraq.

Mr. Donnelly completed his B.A. in Journalism at The Ohio State University in Columbus, OH, and received his M.A. in American History from Virginia State University in Petersburg, VA.

His research includes issues relating to national security, US foreign policy, stability operations, and the role of the military in the political decision making process.