US ARMY LAND NAVIGATION IN THE 21ST CENTURY

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by

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US Army land navigation systems primarily rely on GPS-enabled technologies. The US Army has developed and integrated precision position, navigation, and timing systems into every aspect of operations from land navigation and unit position tracking to engagement of targets with precision munitions. This system has proved to be very reliable throughout the wars in Afghanistan and Iraq, but the vulnerabilities of this system present it as a target of opportunity for hostile states and organizations.

This research investigates US Army doctrine and training to determine whether or not legacy land navigation and unit position tracking remain in the curriculum for junior grade officers. ROTC, USMA, and OCS provided information pre-commissioning training. The infantry, armor, and engineer basic courses provided information about the initial training of company grade officers.

Basic map and compass land navigation training must continue if the US Army plans to continue dominance in ground warfare. Overreliance on the GPS signal may result in significant loss of life and equipment if the GPS signal is lost.

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

US ARMY LAND NAVIGATION IN THE 21ST CENTURY, by Major J. Mark Morgan, 75 pages.

US Army land navigation systems primarily rely on GPS-enabled technologies. The US Army has developed and integrated precision position, navigation, and timing systems into every aspect of operations from land navigation and unit position tracking to engagement of targets with precision munitions. This system has proved to be very reliable throughout the wars in Afghanistan and Iraq, but the vulnerabilities of this system present it as a target of opportunity for hostile states and organizations.

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ACRONYMS

ASAT	anti-satellite weapons
BOLC	Basic Officer Leadership Course
EMI	electromagnetic interference
EMP	electromagnetic pulse
EGNOS	European Geostationary Navigation Overlay Service
GAGAN	GPS Aided Geo Augmented Navigation
GLONASS	Russian Global Navigation Satellite System
GPS	Global positioning system
INS	Inertial Navigation System
OCS	Officer Candidate School
PNT	Positioning, Navigation, Timing
PPS	Precision positioning system
PTN	Personal Tactile Navigation
QZSS	Quasi-Zenith Satellite System
ROTC	Reserve Officer's Training Corps
SAASM	elective Availability anti-spoofing module
SPS	Standard positioning system
USMA	United States Military Academy

CHAPTER 1

INTRODUCTION

US Army communications and navigation systems rely heavily on Global Positioning System (GPS) technology. Lieutenant Colonel John A. Gentry, USAR Ret., an analyst with the Center for Integrated Intelligence Systems, the MITRE Corporation, stated that we should "alter doctrine and train forces to use information and IT [information technology] as aids, not crutches."[1] Vulnerabilities of the GPS system pose a serious threat to operations at the tactical level due to the heavy reliance on instruments and equipment that rely on a GPS signal. The loss of this capability in the tactical environment could seriously impair mounted and dismounted navigation and friendly unit position tracking. The loss of these capabilities would endanger the lives of the troops on the ground and the accomplishment of the tactical mission. U.S. forces must continue to train in a degraded GPS environment to succeed in a GPS denied conflict.[2]

The purpose of this study is to determine if company grade officers receive sufficient unit position tracking and land navigation training to conduct combat operations if GPS-enabled systems fail. The following issues prompted research into this topic: military training on electronic systems versus paper maps and compasses, recent successful destruction of a low earth orbit weather satellite by Chinese military forces, US military reliance on GPS enabled unit tracking and navigation systems such as the Defense Advanced GPS Receiver(DAGR) and the Force XXI Battle Command, Brigade and Below(FBCB2) system, and the alleged successful spoofing (re- programming) of satellite signals to commandeer a US drone over Iran. These issues inspired this study to

contribute to the situational awareness of unit commanders for continued legacy training on land navigation and unit location tracking skills.

Overreliance on any single technology can blind a commander to the need for alternatives, especially if the system is as reliable as the GPS family of navigation aids. This overreliance on a single technology presents that system as a critical vulnerability in conflict.[3] This study will address some of the issues associated with overreliance such as the vulnerability of the GPS signal and the continued need for training on fundamental land navigation methods with paper maps and compasses. The study also investigates the US Army's training of company grade officers to use legacy unit position tracking and land navigation skills. These findings will enable leaders and planners to explore contingencies and train forces to function in a GPS-denied environment.

Research Questions

Are U.S. Army company grade officers trained to successfully conduct combat operations that require land navigation and unit position monitoring in a GPS-denied environment? This question focuses the research on training in the Army officer commissioning programs at the United States Military Academy (USMA), Reserve Officer Training Corps (ROTC), and Officer Candidate School (OCS). The research also addresses training of lieutenants and captains at the U.S. Army Infantry, Armor, and Engineer Basic Officer Leadership Course (BOLC) and Captain's Career Course.

The following additional questions also support the research. Is there a credible threat to GPS technology? What land navigation training is the U.S. Army conducting without GPS? What unit tracking and monitoring training is the U.S. Army conducting with non GPS systems? What training is being conducted since 2001 that was not

conducted prior to the Operation Enduring Freedom and Operation Iraqi Freedom? What training is the U.S. Army conducting to ensure company grade officers acquire and maintain non-digital navigation and unit tracking skills? Each of these questions leads to direct conclusions about the importance and effect of continued training on basic land navigation and unit position tracking capabilities.

Assumptions

Several assumptions shaped this research. U.S. forces will continue to develop and rely on GPS enabled/dependent navigation and tracking systems. Enemies of the United States, both conventional and unconventional, will attempt to exploit the vulnerabilities of the GPS system through anti-satellite weapons, spoofing, and jamming. Future GPS technologies will account for and mitigate the deficiencies noted in this research. GPS will never be completely fail or fool-proof. These assumptions validate the need for a redundant, non-electronic, land navigation capability.

Definition of Key Terms

The following terms explain the acronyms and will give the reader a better understanding when reading this research.

ASAT–anti-satellite weapons–weapons designed to deny access or use of a satellite system

Beidou–Chinese Global Positioning System (GPS)–currently regional with plans for global capability by 2020. [4]

EGNOS–European Geostationary Navigation Overlay Service–relies on US GPS for current function, with plans for European Galileo constellation by 2020.[5]

EMI–electromagnetic interference–energy that can overpower or block a GPS signal.

EMP–electromagnetic pulse–generally used as a weapon to destroy electronics.

GAGAN (GPS Aided Geo Augmented Navigation)–India's GPS system.[6]

GLONASS–Russian Global Navigation Satellite System.[7]

GPS–US NAVSTAR global positioning system.

GPS-denied–environment where signal is unavailable for use.

GPS-enabled–devices that rely on GPS signal to function.

Inertial Navigation System (INS)–GPS alternative that relies on gyroscope, accelerometer, odometer, and compass for navigation.

Jamming–blocking the GPS signal from reaching the receiver.

Personal Tactile Navigation (PTN)–experimental system linked to GPS for personal land navigation in combat environment.[8]

Positioning, Navigation, Timing (PNT)–signals sent by GPS satellite to receivers.

PPS–precision positioning system–military accessible signal for precision navigation.

Quasi-Zenith Satellite System (QZSS)–regional Japanese GPS system

SAASM–Selective Availability anti-spoofing module–designed for future GPS receivers to reduce incidents of spoofing.

Spoofing–intentional blocking and reprogramming of a GPS signal sent to a receiver

SPS–standard positioning system–civilian accessible GPS signal

Limitations

This study is current for the year 2011and 2012. Research data from the past fifteen years differs significantly based on evolving technologies. Direct contact through email with subject matter experts at USMA, ROTC, and OCS organizations provided the training information for the commissioning sources. The programs of instruction for the U.S. Army Infantry, Armor, and Engineer BOLCs provided information about current land navigation training at each school and informed my conclusions and recommendations for further action. My training as a soldier from 1988 through 1996 to navigate with a map and compass, prior to Operations Enduring Freedom and Iraqi Freedom, may reveal some bias in the presentation of the information.

Scope and Delimitations

This research does not include any classified information, and as such, some points may prove irrelevant in light of a classified information study. The pre-commissioning training information comes from USMA, ROTC, and OCS programs. Additional research covers training primarily conducted in the U.S. Army maneuver and maneuver enhancement branches at the Infantry, Armor, and Engineer BOLC and Career Courses.

Significance

Results of this study can inform commanders and trainers about the need for additional legacy training in land navigation and unit tracking skills or the results may validate their current training plans and operations. This study recognizes the inordinate

reliance on a system that provides exceptional capabilities to every war fighting function, but it also points out its weaknesses and risks.

Summary

This study seeks to inform military planners about the need to ensure redundant land navigation capabilities if GPS-enabled systems replace land navigation training for company grade officers. It also investigates the effects that overreliance will have in a GPS-denied operational environment. The literature review investigated the information available and provided sources for further research. The sources of information increase daily as technology improves and countermeasures develop to protect current capabilities and exploit future possibilities.

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[1]John A. Gentry, "Doomed to Fail: America's Blind Faith in Military Technology" (Paper, US Army War College, Carlisle, PA, 2002), 101.

[2]William J. Lynn, "A Military Strategy for the New Space Environment," *The Washington Quarterly* 34, 3 (2011): 12.

[3]Michael R. McPherson, "GPS and the Joint Force Commander:Critical Asset, Critical Vulnerability" (Thesis, Naval War College, Newport, RI, 2001), ii.

[4]Andrew Czyzewski, "Satellite navigation systems are vulnerable, warns report," *The Engineer*, March 9, 2011, http://www.proquest.com.lumen.cgsccarl.com/ (accessed December 20, 2011).

[5]Ibid.

[6]United News of India, "Final Operational Phase' of GPS Aided Navigation launched," August 10, 2010, http://www.proquest.com.lumen.cgsccarl.com/ (accessed December 20, 2011).

[7]Czyzewski, "Satellite navigation systems are vulnerable, warns report."

[8]Linda R. Elliott, Maaike Duistermaat, Elizabeth S. Redden, and Jan Van Erp, "Multimodal Guidance for Land Navigation," Army Research Laboratory, October 2007, http://www.dtic.mil/dtic/tr/fulltext/u2/a473941.pdf (accessed December 21, 2011).

CHAPTER 2

LITERATURE REVIEW

The purpose of this study is to determine if company grade officers receive sufficient unit position tracking and land navigation training to conduct combat operations if GPS-enabled systems fail. This chapter details the literature reviewed for the study. This study investigates the national documents for U.S. policy including the *National Space Policy*, *National Security Space Strategy*, Government Accounting Office (GAO) reports, and Congressional oversight reports. It also focuses on independent, defense related studies and reports from the National Defense University and the George C. Marshall Institute. Army publications, theses from the Naval Postgraduate School and the Command and General Staff College provide additional resources for the research. Professional journals and newspaper articles, an experimental report from the Army Research Laboratory, and current (2011-12) programs of instruction (POI)s from the US Army Infantry, Armor, and Engineer schools complete the investigated works. Each source contributes to the overall understanding of the GPS systems, their limitations and impacts on US Army operations, and the training conducted to mitigate the loss of this capability. This study briefly highlights the main points from each for the purpose of this literature review.

National Policy Documents

The *National Space Policy* comes from multiple sources within the U.S. government. When signed by the President of the United States, it prescribes the end state for all policy related to space operations. GPS constitutes a large percentage of space

operations and consumes a significant portion of the overall space operations budget.[1] The 2010 *National Space Policy of the United States of America* states, "space systems allow people and governments around the world to see with clarity, communicate with certainty, navigate with accuracy, and operate with assurance."[2] This study focuses on the navigation portion of this statement. The GPS system is the primary supporter of the accurate navigation part of the policy and remains vulnerable to multiple threats. The 2010 *U.S. Space Policy* directs the space forces to maintain and enhance positioning, navigation, and timing by providing continuous global access to the free GPS signal. Initial tasks include engaging with other nations who provide global navigation satellite systems (GNSS), operating and maintaining the current GPS constellation, and investing in capabilities to counter the multiple threats to the signal.[3] Additional tasks assigned to the U.S government by President Obama include reducing space debris, training forces to operate in a degraded GPS environment, and partnering with other nations and commercial providers to ensure global continuity of the GPS capability.[4] The 2011 unclassified U.S. *National Security Space Strategy* addresses challenges to continued space operations based on the fact that space is congested, contested, and competitive.[5] Multiple states conduct space operations through GPS, weather, and communications satellites. This congestion only gets worse when satellites collide and break apart, contributing to the amount of space debris which presents hazards to all space vehicles. The Russian Cosmos satellite collision with an Iridium communications satellite in 2009 resulted in more than 1,500 pieces of trackable space debris in the low earth orbit.[6] In 2007, a Chinese anti-satellite weapon successfully destroyed a defunct weather satellite, which put an additional 3,000 pieces of debris in space.[7] The increasing number of states

investing in GPS and communications satellites contribute to the contested use of space. Adversaries look to space as a way of disrupting another nation's ability to carry out its economic and military plans. As nations continue to develop anti-satellite weapons and systems, U.S. efforts to protect its space assets will increase.[8] Competition for GPS and communication satellites continues to increase. China, Russia, the European Union and India continue to gain knowledge and expertise in space flight and operations. The technological advantage maintained by the United States is rapidly decreasing.[9] The 2010 *U.S. Space Policy* clearly directs U.S. forces to meet the need regardless of degradation, train to operate in a degraded environment, and research mitigation techniques to strengthen the architecture and survivability of our space systems.

Government Accountability Office Reports

GAO reports from 2009 and 2010 provide a history of the GPS system and delineate the need for anti-jamming and anti-spoofing technologies as well as security of the ground control stations to protect the assets.[10] A twenty-four satellite constellation constitutes the minimum required to ensure global coverage by the GPS signal and the probability that the United States will maintain a twenty-four satellite constellation through 2025 remains above 95 percent.[11] The April 2009 GAO 09-325, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities*, pointed out deficiencies in the anti-jamming and anti-spoofing capabilities of the current GPS receivers and recommended that these issues be resolved before issuing new devices to troops in a conflict environment.[12] The September 2010 GAO 10-636, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Capabilities Persist*, recommended fielding new user equipment through the military's

GPS user equipment program.[13] The equipment at the user level must contain the capabilities to resist jamming and spoofing as well as decrypting the new M-code (military) that will eventually be broadcast through the upgraded GPS satellite constellation.[14]

One concern specifically mentioned by the US House of Representatives Oversight Committee was a potential gap in service.[15] The April 2009 GAO 09-325, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities,* cast the probability of maintaining the twenty-four satellite constellation below 20 percent by 2018. The September 2010 GAO 10-636, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Capabilities Persist* showed significant improvement, but the May 2009 Congressional Hearing on G*PS: Can We Avoid a Gap in Service?* seriously questioned the ability of the Air Force to maintain the constellation.[16] A significant point of concern is loss of signal for military operations, because the military depends on the current system for navigation, target acquisition, and precision guided munitions.[17] U.S. Representative John F. Tierney (D-MA) asked, "how is DOD preparing for this potential occurrence (gap in service), and what impact may there be to users if a gap occurs?"[18] The GPS signal is not only a military concern, but an economic one as well. GPS currently provides navigation for shipping, air travel, and mechanized farming. USAF MG William N. McCasland, Director, Space Acquisition, Office of the Under Secretary of the Air Force, Washington, D.C, testified during the May 2009 Congressional Hearing on *GPS: Can We Avoid a Gap in Service?* that the United States intends to maintain its schedule to provide coverage above the 95 percent probability through 2025.[19] He informed the Committee on

Oversight and Government Reform that current GPS vehicles also transmit an additional civilian satellite signal as well as the military (M-code) secure signal.[20] MG McCasland also reassured the Committee on Oversight and Government Reform that acquisition of the new Defense Advanced GPS Receivers (DAGR), upgraded Miniaturized Airborne GPS Receivers, and Ground Based GPS Receiver Applications Modules remains on track.[21] The September 2010 GAO 10-636, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Capabilities Persist* offered a much more favorable assessment of the GPS program's viability and success for the future.

National Defense University Seminars

Proceedings from the National Defense University's *Securing Space Assets for Peace and Future Conflict* seminar held in November 2010 focused on the Space Policy's congested, competitive, and contested theme and provided recommendations to mitigate the threats.[22] These proceedings provided specific numbers for the congested and competitive aspects of space with more than 1100 active systems in orbit, 21,000 pieces of debris, and more than 9,000 satellite transponders expected by 2015, thus increasing radio frequency interference in space.[23] Ambassador Gregory L. Schulte, Deputy Assistant Secretary of Defense (acting) for Space Policy, stated "no matter what else, we must improve our capability to 'fight through' interference."[24] This statement sums up the concerns over signal loss and degradation and points to the heart of this research - the military must ensure it has a capability to navigate without a GPS system. The suggestions for mitigation included on-orbit spares (the USAF currently maintains three such satellites), interoperability with Europe's eventual Galileo system, land based backup systems (technology for this is evolving), and refresher courses in compass

navigation.[25] This point should be emphasized to every senior leader in the US Army. Leadership should ensure that every soldier understands the need for basic land navigation training and ensures training does not suffer due to reliance on the GPS enabled navigation instruments and technology. The NDU proceedings also categorized the threats to satellite systems as indiscriminate (nuclear detonation), reversible and or temporary effects (GPS jammers), minor damage (low powered lasers), and major damage (high powered lasers, direct ascent ASAT weapons).[26] Besides the threat of debris and weapons, this proceeding also pointed out the possible damage to unshielded electronics on the satellites that space weather and solar storms could inflict.[27] Solar events typically produce large electromagnetic currents that can destroy unshielded electronic systems in the same manner as an electrical magnetic pulse weapon. These proceedings mirror similar findings reported by the October 2008 conference at the George C. Marshall Institute, *A Day Without Space: Economic and National Security Ramifications.*

George C. Marshall Institute Seminars

The October 2008 George C. Marshall Institute's roundtable series discusses the issues surrounding space capabilities and specifically point to the fact that our success in space leads to complacency in users who take these assets for granted.[28] The successful implementation of satellite communications and GPS systems causes many to think that the United States always had them and that the systems magically continue to function. The report highlights the loss of capability of the Galaxy satellite in 1998 that crippled pager systems along the East coast for several hours.[29] With current dependence on GPS systems for basic navigation from home to the nearest mall, it raises questions as to how

much disruption would take place today if the systems were unavailable. The current modernization of the GPS satellite constellation intends to provide additional civil and military signals at greater power with less chance of jamming and spoofing.[30] General James E. Cartwright, during the February 2009 conference at the George C. Marshall Institute, pointed out the dangers associated with satellite collisions and the resulting space debris.[31]

The space debris issue stimulates debate over mitigation techniques from space vehicles designed to travel through space and catch pieces of debris, to laser shoot downs of individual pieces of debris. This threat continues to increase and shows no sign of subsiding in the near future. The U.S. Army has its own plans for space operations delineated in the TRADOC pamphlet 525-7-4.

Army Training Publications

TRADOC PAM 525-7-4 is the *U.S. Army's Concept Capability Plan: Space Operations 2015-2024*. This document provides guidance for future use of space assets focused primarily on supporting maneuver forces through voice, visual, and data communications and to provide accurate and timely positioning, navigation, and timing data to the user.[32] The updates and plans for future operations include new satellites broadcasting three unencrypted civilian signals and the military's encrypted M-code signal. The future GPS III satellites improve on current capabilities by transmitting a 500 times more powerful signal to better resist jamming, fixing current shortfalls and vulnerabilities, and extending the lifespan of each satellite.[33] The Army works closely with the Air Force to ensure the space capabilities planning includes the specific needs of the soldier on the ground. The soldier on the ground provides the best feedback for

planning and producing capabilities consistent with their needs. Many of these needs are addressed in Master's theses and professional papers written at the U.S. military field grade officer training institutes by United States Air Force, Marine Corps, and Navy officers.

Military Professional School Papers

Student research papers addressing GPS topics from the Naval War College, Naval Postgraduate School, US Army Command and General Staff College, and the United States Marine Corps Command and Staff College provide detailed information and analysis of the hazards associated with the GPS constellation as well as the dangers of overreliance on the GPS-enabled systems throughout the armed forces. The selected research papers focused on a particular threat, vulnerability, mitigation technique, tactical implications of signal loss, alternative solutions, or training plan.

Naval War College papers included in this study were written by two Air Force Lieutenant Colonels and one Air Force Major for the joint military operations department at the Naval War College. Their findings tended to focus on the benefits and vulnerabilities of the GPS system, but they also included a call for mitigation of threats, a need for training in a GPS-denied environment, and a caution against overreliance on the system.[34] The most thorough paper was written in 2001by Lt Col Michael McPherson. "GPS and The Joint Force Commander: Critical Asset, Critical Vulnerability," specified the overreliance on GPS, its specific effects on the joint Force commander and training in a GPS-denied environment.[35] In this paper, Lt Col McPherson recommended upgrading the current system to defeat anti-jamming and include inertial navigation systems as a backup to GPS.[36] He noted the difference between relying on GPS as a navigation and

targeting aid in Desert Storm in 1991 and total reliance on GPS enabled systems for navigation and targeting in the initial combat operations of Operation Iraqi Freedom in 2003.[37] The weak transmission signal for GPS operations reveals another shortfall in the current GPS system.[38] The fact that the GPS signal is weak leaves it vulnerable to jamming from multiple sources.[39] Economic factors when the satellites were first launched determined the payload. The heavier the system, the more expensive it was to get into orbit. The average cost per pound to get satellites into orbit from 1990-2001 was 12,000 United States Dollars (USD) per pound.[40] At around 2200 pounds per satellite, the total cost for each satellite exceeded 26 Million USD.[41]

The weaker signal was part of the trade off to get the satellite into orbit initially.[42] Weak signals will no longer be an issue when the upgraded system replaces the older generation satellites. These signals will need new ground receivers for maximum effectiveness and the Defense Advanced GPS Receiver (DAGR) fills this role. The DAGR incorporates an encrypted receiver that decrypts the M-code signal sent from the latest edition of GPS satellites to acquire precision positioning. The DAGR also incorporates selective availability anti-spoof module (SAASM) to further increase security of the system and integrity of the GPS signal.[43] The last Naval War College paper, *The Sun as a Non-State Actor,* was written by United States Air Force Major Brian W. Kabat.[44] Major Kabat focused exclusively on the effects of a solar weather event on the GPS satellite system. In addition to the earlier information about electromagnetic interference and destruction, another way that geomagnetic storms affect satellites is by actually changing their flight path.[45] While we have Air Force pilots assigned to navigate

the satellites via remote ground stations, there is no guarantee that these connections will survive the electromagnetic energy bursts from geomagnetic storms.[46]

The United States Marine Corps and United States Army staff college papers, written by USMC Captain J.W. Rooker, USAF Major Mark J. Walske, USN Lieutenant Commander Thomas M. McGrath, and Ms. Susan Ireland, respectively, tended to focus on the vulnerabilities of the GPS systems and the U.S. military's overreliance on the same. Captain Rooker's paper, "Satellite Vulnerabilities," notes that the ability to protect our satellites is limited and that there are very few means available to compensate for the loss of these systems.[47] Major Walske's paper, "Vulnerabilities of the Global Positioning System and the Impact on the Iron Triad: the AWACS, JSTARS, and Rivet Joint Fleets," provides a realistic description of losing our satellites to a direct ascent anti-satellite (ASAT) attack. The fact that US satellites fly at a medium earth orbit, above 11,000 km, makes it very unlikely that any terrorist organization or rogue state could physically engage or destroy them. [48] The most likely threat to this system is a solar event. The sun reaches its maximum solar activity every eleven years and the next expected event is in 2013.[49] LCDR McGrath's thesis, "What Happens if the Stars Go Out: US Army Dependence on the Global Positioning System," focuses on a perceived overreliance on GPS-enabled technology by the U.S. Army. His surveys queried US Army majors at the Command and General Staff College about their recent experience with training on map and compass land navigation. He also asked what will happen when the commander loses his Blue Force Tracker capability.[50] LCDR McGrath then reveals the fact that Chinese military space strategy acknowledges and focuses on the US vulnerability due to its overreliance on GPS-enabled systems.[51] His paper included information on a lack of

satellite coverage from the 2009 GAO report, Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities, Rep. no. 09-325. The 09-325 report has been updated to reflect a greater confidence in the availability of the GPS signal, but LCDR McGrath's premise remains, how will we operate in a GPS-denied environment?[52] The final paper written by Ms. Susan Ireland, "Dodging Bullets: the Threat of Space Debris to U.S. National Security," discussed the Chinese successful destruction of the Feng Yun-1C weather satellite on January 11, 2007.[53] This report corroborates and supports the initial Space Policy concerns over the congested and contested nature of space operations. Many sources point towards the dangers and warn of the hazards, but few point to the hope for future operations.[54] The review of the journal and newspaper articles answers some questions but raises several others.

Journal Articles

Various technical and industry journal articles address GPS issues and introduce new technologies designed to mitigate the loss of the GPS signal. The three primary categories of reviewed journal articles are threat, training, and new technology. The Chinese threat and their pursuit of ASAT weapons to affect US vulnerabilities provides an impetus for US policy makers to support upgrading and protecting our space assets.[55] Reports of a United States Central Intelligence Agency unmanned aircraft, allegedly captured by Iran, attribute the capture to jamming and spoofing. Iranian forces initially jammed the encrypted signal from the satellite to the aircraft and then sent a false signal that guided the plane to an Iranian landing strip.[56] If verified, this is the first successful case of spoofing by an adversary that resulted in a captured aircraft. While the details are not known, the basic idea of jamming and spoofing are valid.

An August 10, 2010 *United News of India* article reiterates the "congested" space premise set forth in the US Space Strategy by reporting on the additional systems planned or operational by other states. These systems include the Russian GLONASS, Chinese Beidou, Indian GAGAN, and Japanese XGSS. Another recent development involves a communications satellite company, Lightsquared, whose broadcast signal apparently interrupts or interferes with the GPS signal that is used by aircraft navigation systems.[57] The ramifications of this are not yet known, but it could limit the continued expansion and upgrades of some communications technologies.

A March 25, 2003 article in U.S.News and World Report, *The Global Positioning System,* outlined failed Iraqi attempts to jam GPS signals. It noted that a Russian firm allegedly sold GPS jammers to the Iraqi government. The article points out the failed attempt of the jammers to effectively counter U.S. forces operations, and that a GPS guided weapon destroyed at least one of the six jammers.[58] Lieutenant Colonel John A. Gentry, USAR Ret., an analyst with the Center for Integrated Intelligence Systems, the MITRE Corporation, appealed to US commanders to "alter doctrine and train forces to use information and IT [information technology] as aids, not crutches."[59]

Shielded receivers, stronger transmission signals from future satellite vehicles, and training in a GPS-denied environment lead the way in mitigation efforts to maintain information superiority in U.S military operations. Deputy Secretary of Defense William Lynn stated that "the US military is one of the few militaries today with the capability to operate in all domains on a global basis, and this ability provides a strategic advantage when space capabilities come under threat."[60] To maintain this advantage, the United States must continue to train its forces to operate without the benefit of GPS and invent

new technologies to counter the loss of GPS. The message seems to be that training and leadership can overcome the effects of a GPS-denied environment, but ultimate success depends on continued training at all levels.

There are a few journal articles written by USMC and US Army non-commissioned officers that specifically address training to operate in a GPS-denied environment. In a 2003 article in the *NCO Journal* written by Army Special Forces Sergeant First Class William Applegarth, "Rediscovering the Lost Art of Land Navigation," he states "Land navigation competency has severely declined in recent years due in part to soldier dependence on technological advances rather than the tried and true methods of map and compass navigation."[61] This kind of admonition seems to be making its way to today's force. USMC Sniper, Sergeant Matthew Cochran, wrote an article in 2009, *Land Navigation,* discussing the need to train marines on the task of land navigation by having them find real objects rather than hunting for engineer stakes with small signs attached.[62] USMC First Lieutenant Patrick Darcey wrote an article in 2010, *Old School Land Navigation,* stating that land navigation is "by far the most perishable military skill," but it does not remain on the annual training schedule for those who are not combat arms Marines.[63] The need for land navigation training in a GPS-denied environment is greater today than ever before.

LTC Raymond Millen, former US Army liaison to the German Infantry, Airborne, and Mountain warfare schools, writes in the *Infantry* magazine from 2000 that good leadership and close scrutiny drive successful land navigation, even if you are using electronic means to assist.[64] The emphasis must remain on training, if US forces intend to succeed in an era of overreliance on uncertain technology. LTG Joseph M. Cosumano Jr.,

former Commanding General, United States Army Space and Missile Defense Command/Commanding General United States Army Space Command, reflected on the effects of a GPS-denied environment when he said in 2002 that "all land, sea, and air vehicles leveraging the GPS for precise location and navigation would have to come up with another means to determine their exact location and navigate from where they are to where they want to go."[65] Twenty years ago this was normal, but much has changed since the invention of the GPS.

Training in land navigation basics will keep soldiers alive in combat, but their capabilities will be severely limited by the loss of GPS. Training can mitigate the effects of losing the GPS signal, but other ideas are surfacing that will protect the capabilities of our new systems and provide alternative navigation means in the event of a GPS failure.

Some of the new technologies designed to account for degraded or unavailable GPS include inertial navigation systems (INS), anti-spoofing and anti-jamming capabilities, and increased power of the GPS signal. The INS rely on gyroscopes, accelerometers, odometers and compasses to relay positioning and location to the user without susceptibility to electromagnetic interference.[66] While accuracy and size have been issues in the past, new gains in both limited size and improved accuracy appears to make this system a viable backup for navigation, especially on vehicles. It gives the position and location information without the vulnerability of reliance on GPS. Significant improvements to older inertial navigation systems offer a very good solution to operations in a GPS-denied environment without compromising efficiency and mission success.[67] Integration of INS and GPS technologies seem to provide the most accurate and reliable systems and currently lead the field for mounted navigation systems.[68]

Northrop-Grumman recently built a hybrid system for the South Korean Infantry Fighting Vehicle (IFV) that incorporates both the INS and GPS technologies to provide "uninterrupted three-dimensional position and attitude data for vehicle commanders and crews."[69] Vehicle mounted, integrated systems provide GPS backup systems for mounted navigation.[70] The recently fielded DAGR handheld device includes a selective availability anti-spoofing module and anti-jamming technologies for dismounted navigation that greatly improves its capacity to overcome jamming and spoofing efforts.[71] Upgrades to the satellite transmission signals as well as new capabilities on the ground contribute to the future, continued effectiveness of the GPS signal.[72] These journal articles caution against overreliance, but they also introduce capabilities that will mitigate the loss of the GPS. The following newspaper articles provide a glimpse into society's reliance on GPS and some proof that spoofing does exist.

Worldwide Newspaper Articles

The *Hindustan Times* of India reported that the "growing use of GPS is actually fostering hopeless dependency among drivers, reducing them to automatons."[73] The study actually reports that people are becoming so reliant on the flashing arrow of the GPS that they are not watching their surroundings to know where they are. While this report reports on results from India, there could be a parallel in U.S society as well. If this parallel exists, then it is cause for concern in the military. The eventual consequence of an overreliance on GPS technology could lead a unit right into a prescribed ambush set up by spoofing the GPS signal and routing them into a potential kill zone. Cornell researchers recently demonstrated the ability to spoof the GPS signal in a scientific experiment.[74] They sent a false signal to the GPS receiver and the display reflected the

incorrect coordinates from the spoofed signal. They focused on the civilian aspect of spoofing, but the intent of the research was to inspire the invention of safeguards for the system.[75] BAE systems claimed in 2008 that their system was able to function even in a multiple jamming environment.[76] Receivers that resist jamming also resist spoofing, because in order to send a false signal, the original signal must first be jammed or overpowered. These new technologies greatly enhance the survivability and continued use of the GPS system and provide consistent support for even newer technologies on the horizon.

One such technology is called a personal tactile navigator (PTN). The PTN is designed to interface with a computer that allows waypoints to be programmed for dismounted land navigation operations. The belt that a soldier wears includes eight miniature vibrating discs that are sewn into the fabric of a belt worn around the waist. As a soldier leaves his position, the disc closest to the destination will vibrate, indicating that the soldier is going the right way. When the front, center discs vibrate, the objective is straight ahead. If others vibrate, then the soldier is going the wrong way. This technology relies solely on GPS and provides an even more high tech means of navigating for future operations.[77] While its concept is solid, it could lead to serious problems if the signal is spoofed and soldiers relying on the false signals are routed into a possible ambush.

Service School Programs of Instruction

Training documents received from the US Army Infantry, Armor, and Engineer basic courses validate the need for continued legacy land navigation training. Each school continues to incorporate considerable time using paper maps and lensatic compasses in their training programs as well as a lesser amount of time devoted to the electronic means

of navigation.[78] Although they participate in a week long field training exercise that incorporates unit tracking and land navigation skills, the Maneuver Captain's Career Course curriculum does not include any specific instruction or testing in land navigation operations.[79]

Prior studies at the US Army's CGSC have addressed this topic from the viewpoint of a general question as to whether or not the Army is over reliant on GPS. This study assumes an overreliance on GPS based on personal experience and current data regarding training and reliance on GPS enabled systems. It will focus on the vulnerabilities of the GPS infrastructure, the navigation systems affected by it, and the current training program for US Army company grade officers to conduct land navigation and track unit positions using non GPS enabled methods.

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CHAPTER 3

RESEARCH METHODOLOGY

This chapter discusses the research methods used to gather information for this study. It covers the actual methods used to obtain the available information, the methodology of the research, the criteria used to determine relevance of the examples, and the strengths and weaknesses of the research. The purpose of this study is to determine if company grade officers receive sufficient unit position tracking and land navigation training to conduct combat operations if GPS-enabled systems fail. The primary methodology for this is a descriptive study which seeks to research the problem and report the current facts about it.

Available Information

The majority of the articles used in this research came from a request for information filed through the Combined Arms Research Library(CARL) at Fort Leavenworth, Kansas. Additional articles came from open source internet resources and the proQuest, and EBSCO host research applications on the CARL website. Additional information came via direct email contact with the Infantry, Armor, and Engineer schools. Each provided a program of instruction (POI) for their current, 2011, land navigation training requirements or a detailed email explaining the actual course requirements and training periods for the officer basic course and the Captain's career course.

Methodology

This research relied on information gathered through open, unclassified sources, personal experience through a three month tour of duty as a civilian contractor in southern Iraq from May through August 2003 and two military tours of duty in Iraq, 2004-2005, 2007-2008, and experience as a Soldier before GPS technology entered widespread service in the Army. The open source documents included in this research must address specifics regarding the GPS system to get included in this research. These include the vulnerabilities of the system to jamming, spoofing, debris field collisions, electromagnetic energy pulses, electromagnetic interference, and solar incidents as well as the lack of redundant land navigation training of the Army's junior officers to counteract the loss of the GPS signal. The breakdown of categories included the national level statements and policies, government/military think tanks and professional organizations, primary sources from training institutions, technical articles referencing GPS deficiencies, challenges and upgrades, professional journals from space and GPS fields, and newspaper and journal articles specifically focused on GPS related events. The descriptive study attempts to answer the primary research question while also answering the secondary questions by presenting the facts surrounding the question.

Criteria

The validity and reliability of the sources relies heavily upon the named institutions from which they came, i.e., GAO reports, Naval War College, Naval Postgraduate School, US Army and USMC Command General Staff Colleges. Each professional organization solicits research and articles from its members to improve weaknesses noted during combat operations or tests conducted in a tactical environment.

These sources lend credence to the research and support the foundational premise of professional sources. Sources outside official government proceedings, professionally affiliated seminars and conferences, trade journals, industry journals, and reputable newspapers did not meet the minimum requirements for inclusion in this study. Web logs (blogs) and opinion columns did not meet the minimum criteria for inclusion in this study.

Strengths and Weaknesses of Methodology

The strength of this methodology is its variety and depth of sources. The sources tended to be mutually supportive and many referenced the same professional organizations in their presentation of facts and conclusions. Another strength of this methodology is the reliability of the institutional sources for training documentation from the US Army Infantry, Engineer, and Armor schools.

The weaknesses of the study include some outdated resources, restriction on use of classified documents to supplement unclassified data, and the lack of personal interviews with unit commanders in the field. Some resources from the early 2000s lacked sufficient insight into the way things operate in 2011. Conclusions drawn from the unclassified document domain may lack credence in light of a more informed classified document study. Interviews with commanders in the field regarding their Soldiers' reliance on GPS could provide a more informed perspective for the conclusions of this study.

Overall, this study provides an update to other studies conducted without the most current information and should inform commanders in their planning for future training and operations. This research methodology depicts a current glimpse into the realm of

GPS reliance and its effects on the force. Analysis of the research will lead to clearer, more focused answers to the research questions.

CHAPTER 4

ANALYSIS

This chapter analyzes the data obtained and answers the primary and secondary research questions. The purpose of this study is to determine if company grade officers receive sufficient unit position tracking and land navigation training to conduct combat operations if GPS-enabled systems fail. This chapter categorizes the research information by current training at the three officer commissioning programs, training at the Infantry, Armor, and Engineer officer basic courses, threats to the GPS satellite systems and mitigation efforts to overcome those threats.

Current Training in Officer Commissioning Programs

The primary research question asks if the United States Army is training its company grade officers to succeed in land navigation and unit location tracking operations in an operational environment without GPS capability. The short answer is yes, they train all company grade officers on land navigation. Based on programs of instruction (POI) from the Infantry, Armor, and Engineer schools, no mandated training program exists for unit tracking during the early stages of officer training.[1]

The three primary sources for commissioning as an officer in the US Army include the Reserve Officer Training Corps (ROTC), United States Military Academy (USMA), and the Officer Candidate School (OCS). Each of these schools provides land navigation training for the candidates and cadets. OCS and ROTC require successful completion of the land navigation training and evaluation to graduate, but USMA does not.[2] Officers cannot get commissioned through the OCS and ROTC programs without

successfully demonstrating their proficiency in land navigation tactics using a lensatic compass and a paper map on a graded course that requires successfully finding five of eight points in a five hour time period.[3] In both the ROTC and OCS programs, cadets or candidates get at least two chances to succeed. If they fail the basic land navigation course, they do not qualify for commissioning.[4] COL Michael Hendricks, Geography and Environmental Engineering professor at the USMA, said that passing land navigation has not been a graduation requirement from USMA since 2009.[5]

Army ROTC programs follow guidelines published by the Department of the Army's Training and Doctrine Command to train cadets from the first semester in ROTC through their Leader Development and Assessment Course (LDAC) attended between the junior and senior year of college. This training provides classroom instruction to develop map reading skills including position plotting, intersection and resection, terrain association, and understanding the map legend and declination angles.[6] Students also attend practical laboratory classes to learn how to use a lensatic compass and apply this knowledge to actual navigation on the ground. Upon completion of the basics of land navigation they are tested through practical exercises to evaluate their skills and determine if additional training is needed. During the third year of the ROTC curriculum, cadets officially commit to become Army officers upon completion of their degree program and graduation from the LDAC. The third year program focuses on training cadets to pass the land navigation assessment portion of LDAC to qualify for commissioning as a second lieutenant. Multiple weekend field training exercises and a one week training and evaluation field training exercise period during the third year prepare cadets to navigate with maps and compasses.[7]

USMA, in West Point, New York, trains cadets on basic land navigation techniques during the summer before their freshmen year. They receive additional training in the summer of their second year on mounted and dismounted navigation. Cadets who fail the land navigation train again before their third year. Cadets who fail a third consecutive year continue through the course and graduate after completion of all other required coursework.[8]

The Army's OCS also trains candidates in land navigation with lensatic compass and paper maps. Candidates who fail the first round of land navigation tests receive additional training and a chance to retest. Students who fail the retest do not commission as second lieutenants.[9]

U.S. Army Centers of Excellence training

The U.S. Army infantry school at the Maneuver Center of Excellence in Fort Benning, Georgia and the U.S. Army engineer school at the Maneuver Enhancement Center of Excellence in Fort Leonard Wood, Missouri train their entry-level second lieutenants with three to four days of hands-on, paper map and compass, land navigation instruction including a practical exercise that evaluates proficiency. The infantry and engineer schools also provide a full day of training on the DAGR hand-held navigation device.[10] Second Lieutenants failing to pass the test are given opportunities to re-test if they fail, but they cannot graduate from the basic infantry or engineer officer's course without successfully passing the land navigation training. The basic armor officer's course at Fort Benning provides sixteen hours of land navigation training with paper maps and compasses. It does not mandate successful completion and passing of the land navigation tests in order to graduate nor do they offer training on the DAGR.[11]

LTC Mark Hollis, Commanding Officer at the 2-11 IN training battalion's Infantry Basic Officer's Leader Course (IBOLC), stated that:

> INF LTs need to understand how to navigate first w/ compass and map - then transition to technology. Therefore, IBOLC has been and remains set with 4 days of dedicated land nav training and weeks of integrated land nav. Integrated into field problems. . . . As for the 4 days of dedicated training, three are w/ map and compass - the last is with a Dagger (GPS).[12]

The training conducted at the Infantry school reinforces classroom training that the lieutenants received at their commissioning source–USMA, ROTC, or OCS. The land navigation training focuses on learning to read a map and using a compass to navigate from one point to another on the ground. It includes sixteen supporting tasks from identifying topographic features on a map to computing back azimuths to determine exact location on the ground.[13] This training provides a solid foundation for soldiers who may need to navigate without GPS-enabled technology and ensures that U.S. Army leaders have the necessary skills to train their subordinates in these tasks. One concern is that captains who return for the Maneuver Captain's Career Course do not receive training in hands-on land navigation. Land navigation skills are perishable and all leaders should receive periodic training to maintain or reinforce proficiency.

CPT Michael V. Trickey, the B team leader from the 554th EN BN's Engineer Basic Officer Leaders Course (EBOLC), noted that engineer lieutenants receive training on land navigation in a classroom setting prior to conducting dismounted land navigation exercises in a field environment. They also use a commercial electronic program for training that is available at 550cord.com to connect students with online technology and provide reinforcement training on the classroom instruction.[14] He also explained that "Standards are strictly enforced. No deviations to standards are tolerated and students

receive a NO GO for being over on time and/or incorrectly marking their score cards. The event is a critical event for graduation and is also used to rank students on an order of merit list."[15] Students complete both a day and night dismounted land navigation course, which is consistent with most pre-commissioning and basic course land navigation practical exercises. The standards include correctly identifying at least five of eight points during the combined day and night courses within five hours. The fact that the maneuver officers do not receive specific land navigation training at the Captain's Career Course is mirrored at the Engineer Captain's Career course. There is currently no specific land navigation training at the Engineer Captain's Career Course.[16] While the skills associated with map reading may be incorporated in the Career Course training exercises through the use of the electronic battle tracking and map systems, there is no physical testing or practical exercise focused solely on basic land navigation.

Major Matt Rawlins, Operations Officer, 2-16 CAV, Armor Basic Officer Leadership Course (ABOLC) confirmed that failing the land navigation course is not grounds for dismissal from ABOLC, but that failure to conduct land navigation operations effectively during graded missions adversely affects performance evaluations.[17] Armor BOLC includes sixteen hours of land navigation training and testing including basic map reading and an evaluated practical exercise using a paper map and compass.[18] The Armor school provides the fewest hours of training on land navigation of the three BOLCs addressed in this research.

Basic land navigation training continues to be a focus for pre-commissioning and Basic Officer Leadership Course programs in the United States Army. Successful completion of the proficiency exams validates the ability of junior officers to navigate

without a GPS-enabled system. The emphasis placed on land navigation in the pre-commissioning and BOLC programs establish its importance as a fundamental soldier skill. With a solid foundation in map reading and land navigation most junior officers can apply these skills to tracking units on the battlefield as they call in their units' grid coordinates. Senior leaders must ensure that this training remains in the curriculum for junior officers.

MG Robert Brown, Commanding General, U.S. Army Maneuver Center of Excellence, wrote an article about increasing the technology available to the soldier at the squad level in the November-December edition of the *Military Review*. MG Brown emphasizes and supports the expanded use of technology at the soldier level by equipping soldiers with greater access to real-time intelligence and video feeds during operations.[19] While the idea of using more technology at the individual soldier level has great potential, the fact that much of this technology relies on a functioning GPS signal cannot be overlooked. Soldiers in 2012 have sufficient understanding of digital interfaces to accomplish great technological feats, but what will they do if their technology fails?

During a lecture to students at the Army's Command and General Staff College on 10 January 2012 at Fort Leavenworth, Kansas, a student asked MG Brown about the reduced training on paper maps and compasses that increased training on technological systems would imply. He stated that this was an area where the Army would have to accept risk.[20] Significant risks exist for a unit or team unable to navigate without GPS-enabled technology. These risks should be considered when weighing the gains achieved through the increased use of technology. The risks include increased fratricide potential, inability to link up with rescue and medical evacuation resources, and inability to call for

accurate fire support. Technology can be integrated and incorporated to the greatest extent possible, but the basics of land navigation must never be neglected. The training required at the pre-commissioning level supports the understanding that there is a credible threat to GPS-enabled technology.

The threat to GPS technology

Existing and emerging threats to GPS-enabled systems require continued monitoring and training to mitigate the threat. The four most dangerous threats, as outlined in chapter two, are anti-satellite weapons, jamming or spoofing of satellite signals, space debris, and space weather events.[21] Anti-satellite weapons pose a formidable threat to destroy satellites in place, regardless of their orbit location or speed. Jamming and spoofing of satellite signals pose the second most dangerous threat because they deny signal to air, ground, and naval forces and provide a means of redirecting GPS guided systems from friendly use to hostile control.[22] Space debris threats are significant, but less specific for use by a hostile force, because they depend on an area coverage and probability of a hit, not on pinpoint accuracy. The final threat with the most disastrous potential and least predictability is space weather events.[23] The unknown quantity, time, and location of these events compel new GPS system designers to harden electronics and prepare future satellites for significant solar events.

Anti-satellite Weapons

Anti-satellite (ASAT) weapons emerged in design and initial production in response to the invention and deployment of the first satellites in space, starting with the Soviet Union's satellite, Sputnik I, on October 4, 1957.[24] The United States successfully

launched its first satellite, Explorer I, on January 31, 1958.[25] Technological advances in space and rocket employment spurred both the Soviet Union and the United States to invest in ASAT weapon research and development. Throughout the Cold War years, 1946-1991, both countries viewed space as the key to military superiority. After the collapse of the Soviet Union in 1991, the United States continued its development and deployment of satellite systems. ASAT weapon research and development by the Russian, Chinese, and Indian governments to counter the United States' technological superiority gives cause for concern.[26] Current variants of ASAT weapons include small satellites acting as space mines, conventional warheads with shrapnel, directed energy weapons (Laser and Microwave), and high altitude nuclear explosions (HANE).[27] China rightly surmises that the United States' advantage in the conventional fight can be greatly offset by eliminating or degrading its satellite capabilities and paralyzing its nerve center.[28]

The threat of ASAT weapons cannot be overlooked when planning for future military operations and training. The current lack of a serious ASAT threat to medium earth orbit satellites could lead to complacency in training and expose the vulnerabilities of U.S. forces. To believe that the United States military could conduct efficient and effective military operations without its GPS, communications, and spy satellites is both dangerous and irresponsible. If U.S. forces cannot use current satellite technologies they will need redundant capabilities to shoot, move, and communicate. Increased use of GPS guided munitions for precision strikes, GPS-enabled navigation systems in vehicles and aircraft, and GPS time synchronization for multiple frequency radio communications push current forces further from the map-based tenets of targeting and navigating. While

this study only addresses the moving portion of the equation, the potential threat bears out the need for continued training and diligence to prepare for such a contingency.

China's 2007 targeting and successful shoot down of its own communications satellite lends credence to the emerging ASAT threat.[29] ASAT weapons and technology, though quite expensive and highly dependent on technological expertise, continue to intrigue states looking to compete with the United States as a world military power. Chinese military strategy acknowledges and focuses on the perceived over-reliance of U.S. forces on GPS.[30] Without the current ability to match conventional force with the United States, China may look at reducing the effectiveness of U.S. military operations by targeting GPS and communication satellites. China's successful shoot down of its own satellite in 2007 proves that they have the targeting capability and the desire to produce weapon systems to engage satellites in space. The emerging capabilities and current viability of ASAT weapons underscore the continued need to train U.S. forces to operate in environments without a GPS signal.

Signal Jamming and Spoofing

ASAT weapons target and destroy satellite vehicles while jamming and spoofing weapons seek to mask or block signals and deceive receivers into validating a rogue signal. Signal jamming of radio frequencies for military purposes began soon after radio signals came into widespread use. The ability to jam selected radio wave frequencies helped military units as far back as World War II disrupt enemy command and control communications systems.[31] Basic GPS satellite signals operate at very low power levels and on publicly known frequencies.[32] Military GPS signals include encryption to combat jamming and spoofing, but the low power signal still suffers when receivers are in

buildings, in thick vegetation, or when the weather is cloudy.[33] Current upgrades in the block III GPS satellites include a stronger, encrypted signal to greatly reduce the risk of jamming by low power devices.[34] The inability to jam the improved GPS signal will limit the number of potential adversaries in the future. Only states or organizations that have sufficient resources and scientific knowledge to jam the improved signal can disrupt operations of U.S. forces that rely on GPS.

Spoofing, or deceiving, a broadcast signal with another signal allows the hostile actor access to the GPS receiver. This access gives the hostile actor a pathway to transmit a false signal to the receiver and thus spoof, or deceive, the receiver into transmitting a faulty location display. Iran's alleged spoofing of a United States unmanned aerial vehicle in 2011 raised the level of concern for anti-spoofing technologies.[35] A signal cannot be spoofed without first being jammed, therefore, the stronger signal on the block III GPS satellites also limits the ability to spoof a signal.[36]

Jamming and spoofing technologies exist in basic forms at reasonably low costs. The continued improvement of the GPS signal as well as efforts made to harden receivers to the effects of jamming and spoofing both reduce the ability of these low cost systems to effectively jam or spoof military GPS signals.[37] These technological improvements continue to keep the GPS signal available to military operators. Countermeasures and future innovations in jamming technologies merit continued diligence to ensure a redundant capability for U.S forces in an environment without a GPS signal. Continued training on paper map and compass land navigation and unit location tracking mitigate the risks associated with both jamming and spoofing technologies. The threats associated

with jamming and spoofing continue to decrease, while the threat posed by space debris increases.

Space Debris

Space debris continues to present problems as states increase funding for new satellite launches. Accidental collisions increase sheer numbers of pieces of debris, and states such as the United States and China target outdated satellites to test ASAT weapons.[38] The United States, China, Russia, India, Japan, and the European Union seek to exploit the commercial potential of satellite technology by increasing research and development of current and future technologies.[39] Accidental collisions of spacecraft compel states to prepare an international plan to ensure equitable access to specific orbits. The Russian collision of the Cosmos satellite with a United States Iridium communications satellite produced more than 3000 pieces of space debris.[40] China's testing of the ASAT weapon in 2007 left a total of more than 900 pieces of debris and showed the need for a plan to negotiate international treaties and agreements aimed at preserving the integrity of space systems.[41] Each of these events increased the amount of space debris and requires plans to mitigate the risk. As nations continue to launch new satellites or replace older ones, the potential for crowding increases. The new systems occupy a specified orbit, while the old systems become space debris and increase the likelihood of collisions.

GPS use has risen significantly since 2000 when the U.S. military stopped "fuzzing" the signals from the civilian channel of the satellite constellation.[42] The signal was originally degraded to deny its use to adversaries for military use, but the potential for economic gain outweighed the risk of allowing multiple users access to the signal.

This increased use and the financial impact it has already had across the world motivates other nations to invest in their own satellite constellation to compete with the United States commercially. The military advantage gained through the development and use of this technology also increases the incentive for other nations to invest in the system, because the United Sates currently controls the availability of the signal worldwide. Due to the increased commercial and military viability of GPS-enabled systems, Russia, China, India, Japan, and the European Union plan to launch additional satellites into space to increase their ability to compete. As global demand for GPS receivers increase, nations will continue to compete for worldwide markets.

There are currently more than 8,000 orbiting objects actively tracked by the U.S. Space Command's space surveillance network. Of these 8,000 objects, about 84 percent of them are within 800 km of the earth's surface in low earth orbit (LEO).[43] The GPS satellites occupy the medium earth orbit (MEO), approximately 20,000 kilometers above the earth's surface.[44] The limited number of satellites and pieces of debris in MEO coupled with its vast area make the possibility of an accidental collision almost non-existent. The minimal threat of space debris collisions requires close monitoring, but increased GPS constellations launched by Russia, China, India, Japan and the European Union add more satellites and pieces of debris which increase the possibility of a collision.

Accidental collisions threaten the GPS constellation of satellites by producing unaccounted for and uncertain sizes of space debris. Without an international effort to coordinate orbits and improved communication between all space capable states, accidental collisions could degrade the effectiveness of GPS-enabled technology.[45] The

threat of accidental collisions and ever increasing space debris both underscore the need for the U.S. military to maintain its redundant navigation capabilities, continue to enhance the GPS signal, and protect the satellite vehicle.

Space Weather

Space debris poses a limited, predictable threat, but space weather phenomena offer a less controllable and potentially more damaging threat. Solar events that produce large amounts of electromagnetic (EM) energy pose a significant threat to unshielded electronics on current GPS constellation satellites.[46] EM pulses tend to overload electronic circuits and render them useless. The current GPS satellites include hardening of the electronic systems to protect against EM pulses. The following mitigation paragraph details the parameters of this protection. Solar storm cycles peak every eleven years with the next major storm expected in 2013.[47] Future satellite systems contain enhanced shielding against EM threats, but the older systems that currently provide the GPS signal failed to include the enhanced shielding due to the high cost per pound to launch payloads into space.[48] The lack of enhanced shielding on the older systems shortens their lifespan and jeopardizes the continued availability of the GPS signal. While current research promises to help scientists accurately predict solar flares at least two to three days in advance, there is no reliable way to predict exactly when and at what strength solar activity will produce harmful EM pulses.[49] The unpredictable nature of this threat validates the need for the U.S. military to continue training its forces to navigate in an environment without the GPS signal. The existence of the threat requires continued research for mitigation.

Mitigation Strategies and Technologies

Recognition of the dangers posed to the GPS satellites drives preparations to mitigate the risk. Efforts to mitigate risk to the satellites include improving the physical structure of the vehicles planned for future use, strengthening the broadcast signal from these future systems, developing encrypted receivers to offset spoofing techniques, and developing alternate technology to assist with navigation apart from GPS.

Future satellite vehicles will include hardened electronics that are capable of withstanding bursts of EM energy from solar flares and directed energy weapons.[50] The current GPS satellites can withstand a million-rad dose of total radiation over a ten year lifetime which is roughly equivalent to 200 times the radiation emitted for a 10 minute period after the Chernobyl nuclear plant meltdown and explosion in April of 1986.[51] If satellite vehicle loses communication with ground control due to excessive exposure, it becomes yet another piece of space debris that crowds the orbit until it loses velocity and re-enters earth's atmosphere. Future GPS signals will increase more than 500 times the current strength to enhance signal reception and overcome low power jamming devices.[52] This capability also makes spoofing the signal more difficult, because the spoofing signal must be of a greater power than the original signal in order for the receiver to recognize and respond to it. Receivers that translate the encrypted military M-code signal in the DAGR also limit the capabilities of jamming or spoofing the signal.[53] The final mitigation technique involves developing INS capable of functioning with or without GPS.[54] These systems and instruments promise the best replacement for vehicle mounted navigation systems without GPS. Unfortunately, no hand-held version of this instrument currently exists for the dismounted land navigation mission. The fact that mitigation

strategies continue to develop does not negate the continued need to train junior officers to navigate in a GPS-denied environment.

Conclusion

Junior officer training on land navigation begins prior to commissioning and continues through the Officer Basic Courses, but the standards are not the same among the USMA, ROTC, and OCS commissioning sources or among the Infantry, Armor, and Engineer schools. The research shows that training on basic land navigation maintains a place of importance in the early phases of officer preparation and training. Training must continue in order to maintain a redundant land navigation capability especially with an ever growing threat to the GPS signal.

The current threats to GPS ranging from anti-satellite weapons to solar storms expose a critical vulnerability of over-reliance on GPS technology for moving on the battlefield as well as communicating and engaging targets. The unpredictability of nations seeking ASAT weapons, availability of conventional weapons able to reach low earth orbit, and the inability to predict the energy levels and damaging effects of solar flares accurately warrant diligence to ensure U.S. forces maintain redundant navigation and unit position tracking capabilities. Mitigation measures receive top priority for investment and research, but the high cost of some of these measures could make them untenable in times of economic woes. U.S. military strategists and planners continue to address the threats and provide funding to research countermeasures to maintain superiority in space. While the likelihood of losing the entire GPS signal is very small, a degraded signal could cause limited availability and limit the warfighter's ability to

conduct round the clock operations without a backup system in place for navigating and tracking unit locations.[55]

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[2]COL Michael D. Hendricks, Academy Professor (USMA), Geography and Environmental Engineering, email message to author, April 24, 2012.

[3]CPT Zachary Wiles, assistant S3 for the 3-11 IN training battalion, email message to author, March 12, 2012; and 2LT Joseph Thigpen, University of North Alabama ROTC department, email message to author, March 15, 2012.

[4]CPT Zachary Wiles, assistant S3 for the 3-11 IN training battalion, email message to author, March 12, 2012.

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[11]MAJ Matt Rawlins, S3, 2-16 CAV training battalion(ABOLC), e-mail message to author, April 2, 2012.

[12]LTC Mark Hollis, Battalion Commander, 2-11 IN BN (IBOLC), email message to author, December 3, 2011.

[13]LTC Mark Hollis, Battalion Commander, 2-11 IN BN (IBOLC), email message to author, December 3, 2011; and Powerpoint presentation received from LTC Mark Hollis through email to author on December 3, 2011.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

This chapter includes the author's conclusions and recommendations for this study and suggestions for further study associated with this research. The purpose of this study is to determine if company grade officers receive sufficient unit position tracking and land navigation training to conduct combat operations if GPS-enabled systems fail. This chapter first addresses the validity of the threats to the Global Positioning System (GPS) and current mitigation strategies and techniques to counter the threat. The second area includes conclusions from the research about the training given to future Army officers through the United States Military Academy, the Reserve Officer's Training Corps, and the Army's Officer Candidate School. The last section addresses training conducted at the Basic Officer Leadership Courses at the infantry, Armor, and Engineer schools for second lieutenants.

An interpretation of the data from chapter four connects the implications of data analysis to the practical application of training in the current operating environment. It defines the results in practical terms for current military operations. This section also addresses additional findings and discusses their implications.

The recommendations for further study include calls to further investigate areas outside the scope of this research. The author addresses any unanswered questions from chapter one and considers how things could have been done differently to improve the research. Recommendations for action, a summary of the research and a final conclusion complete the chapter.

Threats to GPS and Mitigation Strategies

The myriad of threats to the GPS system discussed in chapter four could impact future military operations. Direct attack by anti-satellite weapons requires extensive expertise, finances, and time making it very difficult, expensive, and unlikely in the near future. Current mitigation strategies from agreements to prohibit weapons in space to improving protection and signals from the satellite vehicles provide some assurance that the GPS signal will be available to military planners and operators for the foreseeable future. This research validated the threat and recommends continued diligence for U.S. forces to continue training to operate in a GPS denied environment. The research and development of new technologies to combat ASAT weapons, space debris, space weather activity, as well as spoofing and jamming continues to provide protection to the current GPS system. Additional technologies to replace or supplement GPS need to be developed to maintain the technological advantage U.S. forces currently enjoy on the battlefield. The basics of land navigation must remain in the current officer training programs to ensure a redundancy in land navigation capabilities.

Pre-Commissioning Training (USMA, ROTC, OCS)

The training given to the cadets and candidates in the USMA, ROTC, and OCS programs provides sufficient capability for the junior officer to navigate and report unit locations, effectively, in a GPS denied environment. While only USMA allows cadets to graduate and receive commissions without passing the graded land navigation course, the amount and level of training for all three programs is equitable and provides sufficient training to navigate without GPS-enabled technologies.[1] The impetus and motivation behind the relaxing of standards to graduate from USMA was not discovered during this

research, but it did not reveal any reduced training or standards of training on land navigation at the Academy. The ROTC and OCS programs continue to require graduates to pass the land navigation portion of training to receive a commission as a second lieutenant.[2]

Infantry, Armor, and Engineer Schools

The infantry, armor, and engineer schools train their lieutenants on paper maps and compasses with the infantry and engineer schools requiring successful passing of a graded land navigation course to complete the BOLC.[3] The armor school provides fewer training hours compared to the infantry and engineer schools and does not mandate passing the land navigation course to graduate, although failure in land navigation may lead to a written, negative evaluation for the student.[4] The training at the infantry and engineer schools continues to ensure lieutenants retain the skills needed to conduct land navigation and unit position tracking operations and functions in a GPS denied environment. The armor school also ensures a base level of understanding to operate in a GPS denied environment. The armor school should re-evaluate its current standard that does not require passing land navigation to graduate to ensure platoon leaders and company commanders maintain proficiency in land navigation. Continued training with current standards at the infantry and engineer schools provides the best contingency for operations in a GPS denied environment.

Data Interpretation

The research data from chapter four that addresses the training of junior officers and the threat against the GPS system provide direct links to the practical application in

the contemporary operational environment. The training of incoming second lieutenants through the USMA, ROTC, and OCS programs enables company grade officers to conduct combat operations without electronic assistance in any environment regardless of location. Maneuver is a critical requirement of any military and becomes a critical vulnerability when it depends on a single technology.

Reduced standards for graduation at the USMA and at the Armor BOLC indicate that the focus to maintain a basic skill set in land navigation may be waning. The USMA sets the standard for all other officer training programs and the relaxing of the land navigation standards could lead to future relaxed standards in the ROTC and OCS programs. Relaxed standards at the Armor BOLC could also lead others to follow suit, thereby diminishing the overall readiness of junior officers to conduct basic land navigation operations. In both cases, a diminished ability to operate in a GPS denied environment could expose a critical vulnerability in U.S. military operations.

Threats to the GPS system should motivate military planners to continue training and preparing soldiers to operate without this capability. ASAT weapons threaten the GPS signal by targeting the satellites, but the cost and expertise associated with researching, testing, and producing such weapons make them available to only the wealthiest and militarily advanced international forces such as the United States, China, Russia, India, and Europe. Space debris and space weather pose a lesser threat than ASAT weapons, but all are capable of damaging or destroying satellite vehicles and decreasing availability of the GPS signal. Jamming and spoofing technologies continue to adapt to stronger GPS signals and focus primarily on denying a GPS signal in a specific area or location.[5] The fact that China views the United States' over-reliance on GPS

technology as a critical vulnerability should motivate U.S. forces to continue training and developing mitigation strategies for operations without it.[6] These include current research and development of countermeasures for all threats to the GPS signal as well as continued training to ensure redundant land navigation capabilities. While the chances of a complete loss of the GPS signal are very low, the consequences of conducting U.S. military operations without it remain to be seen.[7]

The unexpected results discovered in this research were the relaxed standards at the USMA and Armor schools and the cost associated with developing and producing ASAT weapons. As discussed earlier in this chapter, the relaxed graduation standards at the USMA and Armor school could degrade the ability of future leaders to conduct land navigation during military operations without a GPS signal. Leaders unable to navigate during a combat operation jeopardize a critical requirement for military operations–the ability to maneuver.

ASAT weapons research and development require a significant financial investment. Greg Canavan of the Los Alamos National Laboratory presented a paper to the George C. Marshall Institute in 2004 that estimated developing and launching an area coverage, orbital, ASAT weapon at three billion dollars.[8] This financial constraint limits the number of nations willing or able to invest in the process to obtain the technology. This limitation improves the probability of a functioning GPS constellation for future operations.

Recommendations for Further Study

This research includes only unclassified information for the threats to the GPS and mitigation strategies. A classified study of the probability and likelihood of the loss

of GPS signal would benefit future planners by providing a detailed assessment of the current and future hazards to the system. A study of the active duty unit training plans within Armored, Infantry (mechanized and light), and Stryker Brigade combat teams could compare the priorities of different types of units in light of land navigation with or without GPS enabled devices. This study could lead to a standardized plan across the Army to ensure leaders are trained to conduct operations in a GPS denied environment.

The only question initially outlined in chapter one that is not covered in this research is the difference between training conducted on land navigation today versus training conducted on land navigation before 2001. The author's personal experience as an ROTC cadet from 1989 through 1991 shows no difference in the evaluation standards or amount of training conducted on land navigation from that time compared to post-2001 training.[9] The significant difference appears in the current training at the Infantry and Engineer schools with the hand held GPS devices compared to little or no training with these devices prior to 2001. One approach to making this research better would have been to conduct on-site visits with each of the BOLC schools and observe the training in a field setting instead of using the emails and POIs from the schools.

Recommendations for Action

The following recommendations for action provide suggestions for ensuring a redundant land navigation capability for future operations. The primary recommendation for action is to continue current training at the pre-commissioning courses and in the BOLC schools. The USMA and Armor schools should reassess their reasons for relaxing the standards for graduation and consider reinstituting successful passing of the land navigation course as a graduation requirement. All pre-commissioning programs and

BOLC courses should include a block of instruction within the land navigation training that outlines the threat to the GPS and emphasizes the importance of learning basic navigation skills as a redundant means to maneuver in combat. Army training doctrine should mandate land navigation training and successful passing of a graded course annually for the active force and bi-annually for the U.S. Army Reserves and National Guard.

Conclusion

Current Army training and doctrine ensures that junior officers acquire and maintain a basic knowledge and competency in land navigation using paper maps and compasses. There is a growing threat to the U.S. GPS satellites, and the military continues to partner with scientists to develop mitigation measures against ASAT weapons, space debris, space weather events, jamming and spoofing. While the future of ASAT weapons as well as the uncertainties associated with space debris and space weather phenomena currently pose a limited threat, jamming and spoofing technologies continue to advance. The necessity to retain a redundant capability to maneuver on the battlefield remains. U.S. forces cannot afford to overlook the real possibility that the critical capability of maneuver becomes a critical vulnerability due to overreliance on GPS technology. The future is bright for continued development of GPS based technology to offer more efficient and effective ways to conduct warfare. The caution associated with this research is to ensure redundant means of maneuver remain in the training and development of the Army's junior leaders.

[1]POIs received from each school via emails to author. CPT Michael Trickey, B Team Lead, B/554th EN BN(EBOLC), email message to author, November 28 2011;

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[5]Technology Quarterly, "GPS Jamming: No Jam Tomorrow," March 10, 2011, http://www.economist.com/node/18304246 (accessed May 9, 2012).

[6]Ashley J. Tellis, "China's Military Space Strategy," *Survival* (Autumn 2007): 41.

[7]"Ensuring America's Space Security," Federation of American Scientists, (September 2004), 35, http://www.fas.org/programs/ssp/man/wpnsinspacefolder/spacepnlrpt5.pdf (accessed May 3, 2012).

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[9]The author was an ROTC scholarship cadet from 1989-1991, and a commissioned second lieutenant in the Chemical officer basic course in 1992. Training in both the ROTC department and at the Chemical School reflect similar courses, time in training, and evaluation standards included in the current Programs of Instruction from the ROTC training and BOLC courses.

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