THE FINANCIAL FEASIBILITY AND MERITS OF THE SMALL LIGHTWEIGHT TACTICAL INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE SATELLITES COMPARED TO NATIONAL SYSTEMS

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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

THE FINANCIAL FEASIBILITY AND MERITS OF THE SMALL LIGHTWEIGHT TACTICAL INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE SATELLITES COMPARED TO NATIONAL SYSTEMS, by Major Donald M. Hodge, U.S. Army, 101 pages.

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LIST OF ABBREVIATIONS

AOR	Area of Responsibility
BOS	Battlefield Operating Systems
C^3I	Command, Control, Communications and Intelligence
C^4I	Command, Control, Communications, Computers and Intelligence
C^4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CINC	Commander-in-Chief
COTS	Commercial off the Shelf
DARPA	Defense Advanced Research Projects Agency
DCI	Director of Central Intelligence
DoD	Department of Defense
DoDSA	Department of Defense Space Architect (within the Office of the Under Secretary of Defense)
DSB	Defense Science Board
FIA	Future Imagery Architecture
GEO	Geosynchronous orbit
GMTI	Ground Moving Target Indicator
GPS	Global Positioning System
GSD	Ground Sampling Distance
IC	Intelligence Community: CIA, DIA, NSA, NIMA, and all national level intelligence producers
ISR	Intelligence Surveillance and Reconnaissance
JCS	Joint Chiefs of Staff

JTF	Joint Task Force
LEO	Low earth orbit
LOD	Launch on Demand
MTI	Moving Target Indicator
NASA	National Aeronautics and Space Administration
NCA	National Command Authority
NIMA	National Imagery and Mapping Agency
NRO	National Reconnaissance Office
NSA	National Security Agency
NSSMP	National Security Space Master Plan
OSD	Office of the Secretary of Defense
RAP	Record and Play
RISTA	Reconnaissance, Intelligence, Surveillance, and Target Acquisition
SAR	Synthetic Aperture Radar
Satcom	Satellite Communications
SR	Surveillance and Reconnaissance
Starlite	Surveillance, Targeting, and Reconnaissance Satellite
UAV	Unmanned Aerial Vehicle

CHAPTER 1

INTRODUCTION

Figure 1 appears on the back cover of the United States Space Command's *Vision For 2020* and reflects the dependency and emphases that the warfighter has on the United States space industry.

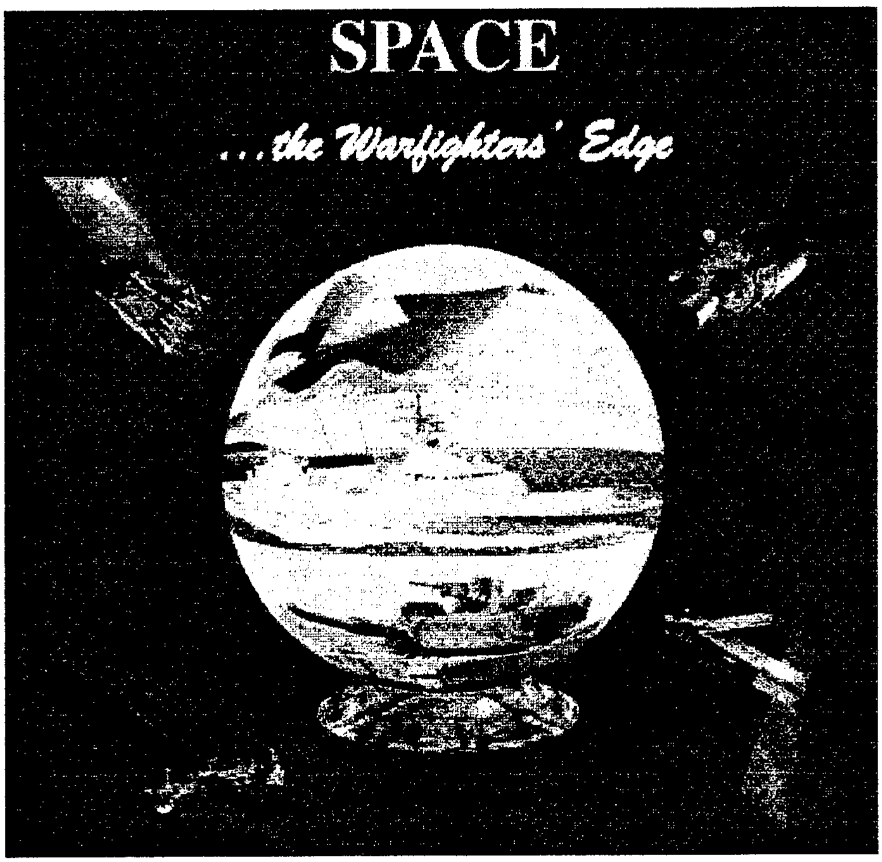

Figure 1. Back cover of US Space Command's *Vision For 2020*: Space: ... the Warfighters' Edge. Source: United States Space Command, *Vision For 2020*, 2nd Printing August 1997.

One of the primary tenants identified by President Clinton and the National Security Council through the National Security Space Guidelines for the intelligence space sector is improved space capability to support military operations worldwide.[1] The intelligence community is striving to determine the best method to answer a Presidential tasking which calls for more direct support to military operations for intelligence, surveillance, and reconnaissance (ISR) systems.[2] This Presidential tasking combined with an aging national ISR system and new technology illuminates the momentum behind many of the questions surrounding the future of ISR systems.

Problem Statement

Recent developments in technology, procedures, and approaches to problem resolution with regard to space systems are expected to have a profound impact on the cost effectiveness and merits of proposed future ISR systems[3] which will more directly support the warfighter. The challenge here is to determine if these recent developments significantly increase the merits associated with a small, lightweight tactical, ISR satellite program. If so, what implication does this have on the future of intelligence, reconnaissance, and surveillance support for the warfighter?

Limitations

Much of the literature on this topic is founded on an outdated vision of support to the warfighter. Technology and the capabilities of the theater warfighters have grown far beyond the ability to wait for the national intelligence community to digest and disseminate ISR.[4] The battlefield is so dynamic that this previous vision of support through national systems to the warfighter is antiquated. This body of research will have to be interpreted in the context of a much more technologically capable, faster, and demanding environment. This should not impact the validity of the discussion or results, although it needs to be acknowledged that this fundamental change in time sensitive support to warfighters is evolving. The need for decisive and instantaneous ISR will have a profound effect on the future systems.

This thesis relies on solely unclassified sources. Since there are volumes of significant research which is classified, this thesis is limited to only a portion of the total body of knowledge on the topic which is unclassified. Significant changes in security classification procedures since 1991 have enabled volumes of literature, system characteristics, and products to be more available at lower classifications and in many cases at unclassified levels. Since this thesis is focused primarily on the theoretical feasibility, practicality, and cost effectiveness of tactical ISR satellite systems, the classified technical details are not necessarily relevant to the conclusions. This will mitigate the exclusion of the classified information. The majority of the classified material concerns very specific and highly technical details. Keeping this discussion unclassified and open will help keep the audience broader and not channeled to only those who have access and a need to know.

Delimitations

This thesis is limited to examining the potential effectiveness of tactical space-based ISR imagery support to the warfighter compared to current and projected national support. Other types of intelligence sources may also be capable of providing significant and timely support to the warfighter, but will not be addressed in this thesis. Some of the results of this thesis may be partially or wholly applicable to other types of space-based or airborne systems. For example, the exploitation of enemy communications systems using the national systems, the use of satellites using SAR (synthetic aperture radar) or the use of UAVs (unmanned aerial vehicle) could produce similar results.

Background

> Probably the most far-reaching development in the area of military satellites is the trend toward smaller reconnaissance and surveillance satellites by the U.S. Air Force. There appears to be strong support for having the next generation of U.S. spy satellites be at least half the size and cost of current satellites. The loss of an NRO [National Reconnaissance Office] satellite on the failed Titan 4A launch last August may have been the straw that broke the camel's back. It highlighted the risks of launching a large, expensive satellite onboard a large, expensive launch vehicle.[5]
>
> Marco Antonio Caceres, "Launch Vehicles Steady Growth"

The European Space Agency (ESA), National Aeronautics and Space Administration (NASA), and the majority of the commercial space industry have projected that the cost of launching space systems will steadily decline in the next five-to-ten years. The space industry as a whole is moving to develop families of mass-produced mini-satellite platforms (100-kilogram to 500-kilogram range) which will serve a wide range of applications less expensively and more efficiently than their larger predecessors. NASA Administrator Daniel S. Goldin articulated this rubric as "smaller, cheaper, faster . . . with the aim of transitioning from traditional methods of tailor-made [and much more expensive] construction to the assembly line."[6] This shift in how satellites are designed and employed is expected to produce savings associated with the efficiencies of an assembly line approach as well as the launch cost of spacecraft purely as a function of its weight and volume.[7] This shift in cost and approach to construction methodologies has promising implications for the feasibility of small, lightweight, tactical satellites (throughout this thesis "tactical" will be used to differentiate between those systems that directly support the theater warfighter or the JTF (joint task force) commander and the national level intelligence community). Satellites could be built and launched at costs which would economically favor the launch on demand (LOD) of ISR[8] satellites with limited lifetimes, as opposed to the large, expensive, heavy, and long-lived satellites currently in use. This rubric has primarily revolved around the cost of launch, as a function of the weight of the satellite, generally speaking the more a satellite weighs the more expensive it is to put it into orbit.[9] This will be expounded upon and developed in more detail in chapters 2 and 3.

Recent developments have added to this discussion of the future of ISR support to the warfighter; these include: (1) the cost of launch services continues to decline based on commercial and international competition;[10] (2) the accelerating commercial satellite market has significantly changed the process and price of building satellites;[11] and (3) the recent launch disasters of several heavy expensive systems have forced the DoD and space industry to reexamine the prudence of launching single large systems.[12]

Since 4 October 1957, when the Soviet Union successfully launched the first object into space, the heavens have been open to imagination. The United States' exploration and exploitation of space has lead to systems and uses of the space environment that were not even contemplated forty years ago. The limits of the United States' imagination grew further and faster with manned space flight, men on the moon, routine space flights in the space shuttle, and the Hubble Telescope (equally important was the ability to retrieve and repair it). The development and use of communications satellites are now fundamental to the American way of life, delivering voices and images instantaneously around the world. These systems and the DoD's ability to plan, develop, deploy, and exploit them have become an essential part of what the country is today.[13] Indeed, DoD's ability to protect the country and stabilize the geopolitical environment of the future depends on these systems.[14]

Space systems provide the nation with vital intelligence, communications, weather, navigation aids, and indications of threat at nearly all levels of national defense. These systems include the National Command Authority's (NCA) use of real-time information (information that is provided instantaneously to the actual event) with little or virtually no delay of the actual event, video teleconferencing to communicate virtually face to face instantaneously to nearly any place on earth. Video downlinks that provide real-time live action video to report or record events as they develop are the standard now. A soldier marching in a desolate region of a foreign land can get a precise fix on his location within a meter and use SHF (superhigh frequency) satellite communications to relay critical information to any other location. All this is possible because of the United States' dominance of both space technology and its exploitation.[15] It is through this technology that America can develop and leverage space assets, which enable the nation to earn the ultimate strategic position--the high ground.

Success in the next millennium's conflicts will demand that the United States continue to lead with information dominance through technological advances and exploitation of space by providing critical intelligence to friendly forces and denying essential information to the opposing forces. Key to this dominance is the "evolution of technology (i.e. sensor development, computation power, and miniaturization) to provide a continuous, real-time picture of the battle space to war fighters and commanders at all levels."[16]

United States space assets are an essential support structure to the terra firma forces, enabling more efficient and effective use of the increasingly limited forces. Key among these assets is the ability to provide near real-time (NRT which is defined as transmission of useful information within seconds to minutes from the actual event) images of targeted locations. Additionally, surveillance and reconnaissance systems can help uncover what is not known and assist in making predictions about what may happen in the future. It is imperative that the United States is able to see the other side of the battlefield, enabling the warfighters to reach out to the enemy long before they are within reach of the enemy.[17]

Likewise, the national intelligence community (strategic intelligence) must be able to provide the NCA with intelligence that paints the picture of current situations and developing conflicts. Challenges to the United States national interests that these organizations will face include proliferation of "weapons of mass destruction (WMD), unconventional warfare, and sophisticated enemy countermeasures, surveillance and reconnaissance. These advances are . . . essential for achieving the 'high ground' in information dominance, conflict management, and war fighting."[18]

Given the worldwide advance of technology particularly with regard to computers, space systems will undoubtedly increase their capability to function more and more effectively.[19] The United States, European, and Russian space industries, both commercial and government sponsored, are continually making advances that will enrich the United States' ability to develop and launch systems more expeditiously and simply.

These systems will have a more significant impact on the United States' ability to conduct surveillance and reconnaissance. Considering the intelligence community's (IC) and the Department of Defense's (DoD) responsibilities to the country and its commitment to world stability, the IC and DoD must exploit the continuing advantages that are developed to ensure domination of information and space. "Our space capabilities are a strategic advantage for the United States, but they are perishable and need to be protected and renewed accordingly."[20]

With the rapid advance of the technology comes the development of equipment that is smaller and more capable than each previous generation, with decreasing intervals between generations. These improvements suggest that the ability to inexpensively develop and implement programs that more directly support the tactical users of space-based intelligence is economically feasible, advisable, and necessary.[21] Like the computer industry today, the designers have to build the best system possible, both technically and financially, and move forward from that point. Waiting for the ultimate machine will stagnate and jeopardize the national security and international position.

For the sake of this thesis, it is assumed technology will continue at previous paces and that the United States will continue to be the leader in space development, exploration, and exploitation. Today, there are primarily seventeen countries and organizations with proven abilities and committed interest in putting and maintaining objects in space: Australia, Canada, China, Egypt, France, Germany, India, Israel, Italy, Japan, Norway, Russia (CIS), South Korea, Sweden, Spain, United Kingdom, United States, and the ESA (European Space Agency which is comprised of several European countries banding together).[22] There are many other countries which have either launched objects with the intent to put them into space or which have actively sought or are developing programs to do so. Similarly number of countries seeking space capabilities is expanding rapidly.

This proliferation of space powers, both government and commercially sponsored, although initially cost prohibitive for the smaller less-determined investors, will be easier and more imperative for their growth and sustainment in an ever increasingly technologically dependent world. Historically, the space industry was driven at least in part by the cold war, which drove adversaries to attempt to gain a strategic advantage chiefly between the United States and the Soviet Union. This competition between the most capable and determined space powers seemed to polarize the development of space systems, that is, each of the two countries invested huge sums of political will and capital into the development and exploration of space systems. The countries that were allied with the two superpowers saw secondary and tertiary benefits from the competition, without having to spend the huge investment on the initial research and development. These countries were able to come into the development at a much later date, realizing the benefits from the early groundwork laid by the Soviet Union and the United States.[23]

During the early development of space systems, it was projected that many of the space systems of the future would be too expensive for any one country to complete. The projects would move far beyond the resources both financially and technologically and beyond the feasibility of any one organization or country. The perception seemed to be that competing countries would have to join forces to continue the pace of exploration and development of space. Indeed, today there is significant evidence of this cooperation, which can be seen with the development of the international space station. Arguably, the United States has reached the point where joining forces financially and sharing technological advances are far more common and seem to be the norm. These joint efforts between countries and industries have resulted in greater cooperation, which result in greater research and development efforts, more efficient production procedures, and reduced costs.

As this process becomes the industry standard and the United States realizes some of the benefits of the thaw of the cold war, greater government-to-government cooperation will enable the speed of advancement to increase more than would have been possible prior to these changes. Government deregulation has also had a significant role in the record growth. These advancements have significantly lowered satellite construction costs and reduced time to market, serving to greatly expand the variety, availability, and potential uses of satellites.[24] This explosion in technology and cooperation, has enabled more countries and commercial ventures to realize that space assets are not only more achievable economically but necessary for future survivability.

As more and more government and private ventures sponsor space systems development, the natural tendency will be to increase research and development, causing increased competition which will result in increasingly cost efficient development and deployment.[25] As these space systems increase in capabilities, there is a corresponding decrease in their size. Size and weight have historically been major considerations for deployment of space systems,[26] since the means to get the systems and components into space used huge amounts of fuel and since the payload space on board was limited. Additionally, the costs of insuring these systems were included in the total package cost.

These limitations provided the gravity that pulled the systems weight and size to be as small and lightweight as feasible,[27] while at the same time ensuring that the systems were robust enough to withstand the rigors of launch and the space environment.

Putting these systems into orbit is expensive and has dictated that they be extremely reliable and have multiple backup systems which would ensure that once placed in orbit they would last as long as possible to ensure that the expense was not wasted.[28] This drove the weight of the systems higher than would have been otherwise necessary. Failure with one of these systems was nearly catastrophic to the program. The expense of the layered backup systems both added weight and increased the cost, which accentuated the risk. The designers build redundant systems and multiple work-around solutions so that nearly every contingency and possible failure would be avoided, resulting in higher costs overall.[29]

Record growth in computer technology and composite designs has spawned so many advancements that the satellites can do far more with significantly lighter weight systems. This growth in technology and design coupled with current and anticipated advancements in the launch systems that actually deliver the payloads into orbit will significantly reduced the cost to put systems into orbit.[30] These reductions in cost of delivery and production enabled more countries and commercial ventures to examine the benefits of these systems and begin development.

Smaller, faster built, and more economical space systems will become the standard. A prime example of the tremendous growth of these new smaller, more-powerful satellites is a recent contract between Teledesic's (the ambitious "internet in the sky" joint venture) telecommunications pioneer Craig McCaw and Microsoft Chairman

Bill Gates. "Telledesic recently selected Boeing to coordinate the $9 billion project, including the construction of approximately 288 satellites."[31] This number of satellites would have been inconceivable for a government let alone a commercial venture only a few years ago.

There is also a fundamental shift from primarily government-sponsored (typically military) development of high-speed secure communications systems capable of carrying high-capacity connections worldwide to commercial ventures. A recent contract between the United States DoD and Iridium to purchase gateway (high-capacity connection) to the Iridium network for about $14.5 million will support the continued development of these types of systems.[32]

The shift to smaller, more-numerous satellites for a number of different purposes could provide the military forces and the intelligence community with significant cost savings not to mention much quicker revisits of the targeted area. It is even possible, depending on the number of satellites used, to have near continuous coverage. Conversely, the gaps in coverage by today's few megasatellites make it easier for potential targets to calculate when the satellite is overhead and to plan their activities accordingly. Some predictions of when United States surveillance and reconnaissance satellites are passing over can even be found on the internet. Any reasonably sophisticated adversary could adopt routine countermeasures enabling him to mask his intention. The ease and efficiency of implying masking procedures was illustrated by "the apparent failure of the NROs low altitude imaging spacecraft to detect preparations for India's [and Pakistan's] recent nuclear tests angered the Clinton Administration and congress."[33] This failure has highlighted a weakness with the ISR systems currently in use today.

Launch disasters involving many of the huge systems of the past have had a significant impact on past programs and will continue to be of concern. This is especially true with many of the planned launches having up to twelve satellites in one delivery system. Globalstar is a new satellite-based mobile communications system that is similar to Iridium, in that it also plans to orbit a significant number of low earth orbit (LEO) satellites. However, the primary orbits that are being considered for this communications system are also the most common orbits for imaging satellites. GlobalStar plans to do this by packaging five to twelve satellites per launch. The company recently lost one of these systems with twelve satellites on board just after takeoff.[34] This loss illustrates the risk associated with larger launch systems.

As the systems get smaller, the increasing tendency is to group more systems together in the delivery system in order to realize some of the cost benefits. This retains some of the same hazards of yesterday, that is, the inherent risk still associated with launches and the impact of a failure on the program. Formerly, the problem was failure with one single larger satellite mission that was custom made, took years to conduct the research and development and to construct, while now these systems can be built much quicker, smaller, and cheaper. However, the United States is not alleviating the financial risks when the systems are packaged and delivered together in multiple payload launches. Most experts conceded that to launch orbital assets on multiple launches holds the least risk when compared to putting all the assets onto one launch.[35] To protect system capabilities from total loss in the event of a launch failure, the classical approach was to invest in duplicate systems and launch vehicles. This combined with insurance cost drove the price of the system prohibitively higher. It is the apparent failure of a few huge systems, launch disasters, and delays getting information down to the lowest levels of warfighters, that is part of the motivation for this thesis.

During the Gulf War, a relatively small group of large expensive systems exploited by highly trained, diverse, and dispersed array of national and allied forces significantly delayed dissemination of intelligence unnecessarily. Admittedly, some of these delays were related to the level of security of the information or sensitivity of the source. A significant change in both the handling and classification of the intelligence has addressed some of these problems. However, most of these systems were designed for fixed site national and strategic long-term support, not fast paced dynamic tactical situations. These national systems are also expensive to maintain and are used continuously and so have to be designed so that they give general worldwide support and coverage as opposed to specific support to a specific geographical region.

With the advent of smaller, cheaper, and faster built systems the possibility of having some small ready made systems on the shelf [36] ready to launch when the situation dictates has become more realistic. This process of quickly producing satellites using proven state of the art technology would save money from the maintenance of systems that are in orbit for long periods and allow the small tailor made systems to be quickly put into the most advantageous orbit for the crisis. This process of launching the satellite quickly, only when necessary, is called launch on demand (LOD), and the time that it takes from making the decision to launch and the actual launch would vary from a few days to a month or more. Launching on demand can provide significant improvements from the current standard that takes months in the best cases to years in the typical case. This is one alternative to the more expensive national systems currently in use. Another is to simply orbit more, cheaper, smaller systems to achieve more world wide coverage and faster revisit times.

A recent information paper by the Office of the Under Secretary of Defense for Space Architect lists some of the possible applications for LOD missions as:

1. Monitor Terrestrial Manmade Phenomena: Launch quick response, multispectral sensor satellites to observe and collect detailed data on theater warfare related phenomena

2. Surge and augment satellite communications: upon demand, launch satellites to increase EHF, SHF, or UHF availability to the theater CINC

3. Temporary ISR: Increase and tailor imagery in conflict area, launch special imaging satellite (s) to quickly image an area where the military forces are deploying.[37]

There are many other potential missions for the LOD type of systems described; however, the three listed are the purposes that are of primary interest to this paper.

Normally, these systems have significantly shorter operational ranges or life spans than the traditional custom built expensive single purpose systems, which typically have life expectancies of up to ten years or more. Where as most of the systems being considered for Launch on Demand are planned to be in much lower orbits and have much shorter life spans (from a few weeks to months giving tailored support just when needed). The vision for these systems is based on mutually supporting concepts: Dominant Maneuver; Precision Engagement: Full-Dimensional Protection; and Focused Logistics.

1. Dominant Maneuver: The multidimensional application of information, engagement and mobility capabilities to position and employ widely dispersed joint air, land, sea and space forces to accomplish operational tasks.

2. Precision Engagement: A network of systems enabling forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess the level of success and retain the flexibility to reengage with precision when required.

3. Full-Dimensional Protection: Control of the battlespace to ensure the forces can maintain freedom of action during the deployment, maneuver and engagement, while providing multi-layered defenses for United States forces and facilities at all levels. This concept will enable the effective employment of forces while degrading opportunities for the enemy.

4. Focused Logistics: The fusion of information, logistics and transportation technologies to provide rapid crisis responses, to track and shift assets even while en route, and to deliver tailored logistics packages and sustainment directly at the strategic, operational and tactical level of operations. This will enable joint forces of the future to be more mobile, versatile and able to project power and influence from anywhere in the world.[38]

All of these functions could be accomplished using tactical satellite systems.

Certainly some of these functions could be accomplished with systems based here on the ground, for example UAVs (unmanned aerial vehicle) could fly over target areas minimizing the risk to soldiers, less expensively. Many other systems are currently in use to do these missions, however, none of the ground based systems offers the unrestricted access to terrain that is currently available to space platforms.

In light of the advances and risks that have in many cases proved to be cost prohibitive and recent disasters the questions become:

1. Would it be more effective to launch small dedicated tactical satellites on demand, allowing commanders to see satellite observations of the battlefield and leaving national systems to provide the strategic picture?

2. Should national systems lean farther forward with the systems they have planned for the next generation giving quicker, more accurate and decisive intelligence to the commanders on the ground?

3. Should DoD and the IC do a combination of national development of its own dedicated systems in concert with the tactical systems providing the warfighters with the required systems?

Operational Terms and Key Definitions

It is important at this point to define a few key words and phrases in use throughout this prospectus. They will provide the working vocabulary for a discussion of the usefulness of tactical satellites for the warfighter. A more comprehensive list of definitions is included in the glossary.

Bus. Everything on a satellite except the payload(s). The bus includes the structural frame, power, attitude control, thermal management systems, tracking, telemetry and control subsystems. The bus supports the payload, but the payload performs the mission of the satellite.

Constellation. A system of like satellites. Constellations are usually designed to provide increased coverage and redundancy for essential mission functions.

Geostationary Orbit (GEO). A Satellite that has a period of one day and orbits the equator. To a ground-based observer, the satellite appears to remain in the same fixed location in the sky.

Launch on Demand (LOD). The launch of a satellite into orbit in response to an unscheduled event or developing situation.

Low Earth Orbit (LEO). A satellite rapidly orbiting the Earth at a low altitude (approximately 200 to 1200 kilometer) is said to be LEO. Satellite imagery comes almost exclusively from satellites in LEO orbits.

Multispectral. A means of subdividing the light spectrum into smaller bandwidths. Adding or subtracting these subdivisions can be useful in terrain or target analysis.

Payload. The portion of a satellite that performs the satellite's primary mission. A payload must be supported by a bus. There can be multiple payloads on a bus, thus giving a satellite a multipurpose role.

Reconnaissance. "A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy."[39] The primary difference between this and surveillance is the target of the focus being enemy or not and the regularity of the focus.

Space System. This term will generally refer to all of the elements required to build, launch, fly (orbital platform), sensors, and the support infrastructure necessary on the ground to control and exploit the sensors.

Surveillance. "[The term used to describe] the systematic observation of aerospace, surface or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means."[40] It is the "systematic" that is the difference between surveillance and reconnaissance, it requires periodic or aperiodic observations of the target.

Tactical Commander and Warfighter. These terms will be used synonymously and generally used to refer to the CINC, JTF or below military commander in the theater.

Tactical Satellite. Are those satellites whose primary purpose is to provide direct support either real-time or near real-time, to the commanders in the field, either the CINC or the Joint Task Force commander. Tactical satellites may have dual national and tactical missions; however, the emphasis will be on timely support to the warfighters without stove pipes. This would ensure priority dedicated direct support to the warfighter.

Thesis Question

Have recent developments made the cost effectiveness and merits of the small, lightweight tactical intelligence, surveillance and reconnaissance satellite argument more compelling, and if so what implications will it have on the future of intelligence, reconnaissance, and surveillance for the warfighters?

Subordinate Questions

Are the tactical ISR satellites projected to be less expensive relative to the systems of today? The United States can build ISR satellites that can accomplish just about what ever the tactical commander needs, however, if the cost is prohibitive the argument becomes mute, especially given the imperative that DoD control and when possible decrease spending. Alternately, if using tactical ISR space systems is less expensive than the continued construction and operation of the national systems in support of the warfighter then this would be advisable.

Would the tactical ISR satellites be significantly more beneficial to the warfighters? Building systems that more directly support the tactical commander is commendable, however, if the systems are not a significant improvement, would the cost be worth the investment? This thesis will make an assessment as to whether the projected advancements in the literature are consistent with the warfighter imperatives. The difference between ISR space systems that the national and strategic community are projecting to develop and those systems that are projected for tactical use may be closer together than would have been thought. They may be able to perform the same mission using one system to accomplish both objectives. Additionally, the differences and improvements in new systems will be identified.

Is a new dedicated system needed by the warfighter? With the anticipated technological improvements, is there a need for two separate systems: one for the warfighter and one for the National and Strategic community? There may be procedural or technical methods to support both customers at the same time with the same system. Ultimately the end state for both levels are linked. It is not inconceivable that as the United States moves into the twenty-first century the line between the two levels will become even less defined, enabling single systems to meet the needs of both.

Underlying Assumptions

The warfighter will continue to be the focus of the intelligence community during crisis and he will be a priority during daily operations. Accordingly the IC will be able to decisively leverage national systems to affect the battlefield to United States advantage. The ISR requirements stipulated by warfighters can be achieved with the proposed systems.

Technology with regard to ISR capabilities will continue to evolve. Enabling the payload on future missions to actually be much smaller and provide more accurate and timely information.

A launch on demand capability will exist in the 2010 timeframe. Accordingly the discussion is centered on LOD utility and impacts, rather than launch vehicle and associated infrastructure.

Significance

Every great military mind from Sun Tzu to Clausewitz, Alexander the Great, Napoleon, and the military leaders of today has recognized the importance of deception, and hence the necessity to employ and deploy assets to see through feints, and the prevention of surprise attacks. These leaders have also recognized the United States' dependence on these systems. If the DoD is to be successful on an ever increasingly complex battlefields that are fought in ever increasing dimensions, it is imperative that the warfighter be able to quickly see and control the battlefield. The eyes and ears of the commander, especially during the early stages of a developing crisis, may mean the difference between decisive success and costly failure.

Currently, the warfighter depends on the national intelligence community support during crisis situations to provide timely ISR. Admittedly the quality of support that is available from the IC has significantly improved in the last ten years. However, these systems are not primarily dedicated to the warfighter nor quick enough to provide the commanders in the field with the vital vision of the battlefield. Nor are the national level products as specific as the commanders need.

Both the United States Army and Air Force have cycles that describe part of this process. The Army uses "Decide-Detect-Deliver-Assess" (D3A) cycle where timely reconnaissance assets are clearly needed to perform the detect and assess phases in the cycle. The Air Force also recognizes the importance in the "Observe-Orient-Decide-Act" (OODA) loop theory governing combat. The theory suggests that the combatant that can accomplish the functions of the loop first will be the victor.[41]

The ability of the United States warfighters to see the battlefield is essential to the successful prosecution of United States military strategy. The ever-increasing capabilities of new systems, both governmentally and commercially sponsored, and significant cost reductions projected over the next ten years suggest that new more capable space based ISR systems that directly support the warfighter are advisable. The CINCs and JTF Commander's ability to fight and win will depend on their ability to see the battlefield and enemy before he can see them.

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CHAPTER 2

LITERATURE REVIEW

The United States space systems support provided to the warfighters during Desert Shield and Desert Storm brought many intelligence issues to the forefront. One of the most significant of these issues concerned the examination of the role of national systems and the priority of support.[1] Many in DoD called the Gulf war "the first space war,"[2] although the more accurate description would be the first "information war."[3] Commanders were literally inundated with intelligence information, so much so that much of the information was not screened or fully analyzed. The flood gates were opened, and technology enabled the collection of huge volumes of imagery to be sent to the field. The problem became one of getting the right image at the right time to the right commander who needed it most and had the correct clearance.[4] The intelligence community (IC) as a whole has refocused its support to the warfighter since the Gulf war. Every agency and department that has intelligence as a primary role or as a support role have as one of their fundamental mission statements "support to the warfighter."

The role of space support to the warfighter has undergone dramatic evolutionary changes following the end of the Gulf War. The Gulf War demonstrated the potential of fully integrating space systems into the U.S. joint doctrine and operations. Some of the lessons learned in the war identified shortfalls[5] in planning, doctrine, experience, and operations, many of which remain to be addressed.[6] The National Security Space guidelines clearly indicate that intelligence support to the military is a priority:

> 1. Timely information and data to support policies, military operations, diplomatic activities, indications and warning, crisis management, and treaty verification.

2. Advanced technologies to respond to threats and support national intelligence priorities.
3. Improved intelligence space capabilities to support military operations worldwide.
4. Protection of the nature, attribution and operational details of intelligence space activities, plus provisions for release.
5. Classification of other collected information according to its content.
6. Protection of imagery product (per Executive Order 12951).[7]

To address some of these concerns, DoD initiated central and multi-agency planning processes to ensure that the space goals of both DoD and the IC programs are properly developed. To this end, an interface was formed called the National Space System Master Plan (NSSMP), which is charged with development of "Guidestars" as top-level goals for both DoD and the IC. The NSSMP task force reports to a Senior Steering Group (SSG) with the representation in figure 2.

<table>
<tr><td>Co-Chairs

Ass't DUSD (S)
Dir, NRO Plans and Analysis (PandA)</td><td rowspan="2">Flag-Level
Representatives

Each Service (USA, USN, USAF, USMC)
Joint Staff
USSPACECOM
National Imagery and Mapping Agency (NIMA)
DoD Space Architect
Defense Intelligence Agency (DIA)
Central Intelligence Agency (CIA)
National Aeronautics and Space Administration (NASA)
National Security Agency (NSA)
Community Management Staff (CMS)</td></tr>
<tr><td>Adjunct Members

Dept of Energy
Dept of Commerce
Dept of Transportation
Dept of Interior</td></tr>
</table>

Figure 2. Senior Steering Group Membership

As can be seen from the membership on the SSG, it is a joint and national effort to ensure that all agencies concerned have input into the development and coordination of space intelligence support systems.[8]

In support of the effort to ensure that DoD is moving in the right direction, the *Joint Vision 2010* was prepared and is the DoD vision "designed to guide the Service force development efforts to support joint warfighting in the early twenty-first century. It includes space as an operating environment on par with land, sea, and air."[9] Accordingly, there are a number of studies and proposals that offer possible solutions to some of the shortfalls identified following Desert Storm. The changing space environment is of primary interest to many of these studies.

The dramatic increases in commercial space applications and commercial launches of space systems created an increasingly competitive environment for nearly all space systems, ultimately driving prices down and capabilities up.[10] The NRO (National Reconnaissance Office), Defense Advanced Research Projects Agency (DARPA) and the DoD Space Architect office have published various studies and papers examining a variety of ways to better support the warfighters with space assets in light of this rapidly evolving and dynamic environment.

Historically, the national ISR (intelligence, surveillance and reconnaissance) space systems were designed to provide intelligence to Washington decision-makers. This list included the "White House, the Secretaries of State and Defense, and the Joint Chiefs of Staff."[11] Although the raw intelligence was very timely, the decision cycles were lengthy, and there was opportunity for exhaustive studies and voluminous national intelligence estimates. These systems were more NCA, NSC, and State department support than support to the warfighters. Although today the view is markedly different, the bulk "of the Nation's intelligence effort is concentrated in the Department of Defense."[12]

One of the programs proposed by DARPA, called surveillance, targeting and reconnaissance satellite (Starlite), would consist of from twelve to twenty-four tactical satellites that would operate in three mutually supporting orbits (four to eight satellites in each of the three different orbits). The three different orbits would enable the systems to cover nearly the entire globe within minutes. This coverage enables the user to image nearly any likely target area within minutes of the recognition that an image is needed. Figure 3, below compares the increase in coverage with the associated increases in the number of satellites in orbit.[13]

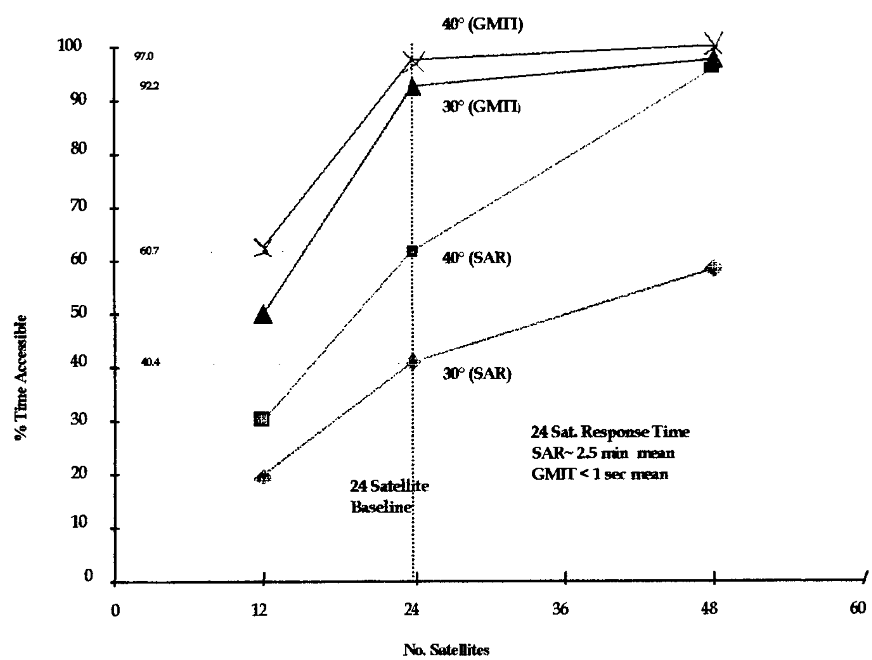

Figure 3. Number of Satellites to Accessibility

This comparison uses ground moving target indicators (GMTI) and SAR (synthetic aperture radar) focusing on the regions of the globe that account for 98 percent of the world's population. This is generally considered to be plus or minus 65 degrees latitude, resulting in coverage of the vast majority of the world's inhabited areas.[14] The inclination angle of 30 to 40 degrees would give the best coverage over the most inhabited areas of the globe. Although the routine operation and maintenance of a system like this would be far more expensive than a LOD system, the information that would be available from a Starlite-like system would be far superior to that provided by a typical LOD system. A system, such as Starlite, could provide excellent IEW (indications and early warning) support to the CINCs, JTF commanders, and the national intelligence community.

This program would launch two to four satellites at a time and have an expected life cycle of ten years. Significant savings would be realized with the use of heavily modified off-the-shelf technology. Additionally, savings would be generated by building the systems in an assembly-line fashion and by adopting commercial business practices.[15] Industry wide efforts are being expended toward this end. It is almost as if the theory of the assembly line were just being put to practical use in the space industry.

Within the last year the Defense Science Board (DSB) completed a report on space surveillance. The report was initiated by a request from the directors of NRO and DARPA to review the operational, technical, industrial, and financial aspects of the future imagery architecture (FIA) effort and DARPA's proposal to demonstrate a space radar surveillance system (Starlite). This report addresses several issues germane to this thesis.

The first issue raised by the DSB report concerning space assets for warfighters concerns future needs of commanders during military operations. The reports states that future military operations will need the combination of day, night, and all-weather access, the rapid revisit of imagery and broad-area search (BAS), and moving-target surveillance. It is the view of the DSB that these objectives are best achieved through the proliferation of low-orbit satellites that must and can be greatly reduced in cost from past practices.[16]

The DSB goes further by saying that FIA should incorporate some of the attributes emphasized by the Starlite proposal including the application of MTI and reduced revisit times, reduced classification of systems and product information, and increased attention to integrating FIA systems with military operations. All of which are issues that have historically been areas of concern when national systems support the warfighters.

The third point of interest from the DSB report is that the DoD should pursue a program to create a military surveillance program that loosely resembles Starlite and would seek to achieve broad area coverage in all weather conditions, and near continuous radar access for integration with military operations. Whether this is accomplished with national systems or with tactical systems is not specifically addressed, so long as the system is fully integrated into the warfighters operations.

Both DARPA and the NRO have vested interests in the outcome of the Starlite proposal. NRO proposed an " . . . evolutionary system of three to four imagery satellites rather than the twelve to twenty-four spacecraft that could provide the U.S. military with dramatically improved revisit times and world-wide coverage."[17] This type of system proposed by the NRO is more of a status quo, since current systems are similar to the proposal, in terms of complexity, expense, size, weight, and numbers of systems. The proposal has many of the same risks associated with it. Each of the armed forces is also weighing into the debate with input into the future of the surveillance and reconnaissance systems. The trend among the services' for these systems is that they be dedicated to the warfighter and not national systems that are able to support the warfighter. This is a common visceral response by commanders that are reluctant to rely on systems that are not under their direct control. The rationale is that if the services have to compete for the asset, either with other units or services, then the system can not be counted on. With the prevailing attitude being that "if I do not own it I can't count on it."[18]

The DoD Space Architect (DODOSA) office within the office of the Under Secretary of Defense has explored options for LOD capabilities and the implications that such a capability could have on the support provided by space assets to warfighters. One of the methods that is used to develop the vision of the future system requirements and capabilities is the *Joint Vision 2010*. This method is a "template for how U.S. armed forces will channel the vitality and innovation of the American people and leverage technological opportunities to achieve new levels of effectiveness in joint war fighting. . . . [LOD] is one such technological opportunity."[19] This vision could lead to systems that are built around the "Just in Time" availability rather than forces and assets deployed more or less continuously on a "Just in Case" basis. That is not to say that these systems can only be used during a crisis situation or during hostilities. Rather this option would allow the use of fewer satellites during routine operations then augment them with more satellites during crisis. A fundamental assumption of this study is that the future will include resource and policy constraints and certainly new methodology that would both save limited resources and provide better support that would be welcomed.

This type of design would assume a certain amount of risk in the beginning. One risk is whether there is sufficient warning to ramp up to the LOD decision. The potential cost savings associated with routine operations with a LOD system could be significant. However, LOD systems would depend heavily on all the various sources of intelligence and systems that routinely monitor worldwide activity and could provide early indications of problems. Also as with any new system, especially unproven new launch platforms, the risks would be high initially, and there would likely be a corresponding increase in the launch failure rate.[20]

In 1996, the DSB completed a report on C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) which concluded that the CINC needs better support and input both for the concept, design, and control of ISR assets. "Adequate support [would] enable the CINC to stay abreast of ongoing and potential development of capabilities that can significantly influence the ability to perform the missions."[21] The DSB was looking at the assets that are in place now and looking to the future. Any future systems must make this support better and less complex to the customer. To add another highly complex system to the picture would exacerbate the already complex environment.

The Air Force sponsored study by the National Security Industrial Association entitled "Spacecast 2020" looks forward to what the United States may be capable of in the next twenty-five years and what some of the operational requirements may be given by those capabilities. This study was undertaken to determine the most prudent direction and path to be taken given those capabilities. It also attempts to anticipate and define some of the warfighter needs for the future. This study presents the technological vision for the Air Force with regard to space systems. Essential to this vision is the ability to maintain and continue developing the United States leadership role in information dominance.[22] Advances in surveillance and reconnaissance capabilities are essential to their forecast, particularly the ability to provide real-time, sensor-to-shooter information and one-shot, one-kill technology. Society has become accustomed to wars that are in their living rooms each evening and are decisive. If warfighters are to maintain the continued support of an increasingly impatient society conditioned to very short wars, quick decisive action (which has its obvious advantages from a military view point), minimal casualties, and low collateral damage, it will "require a system and architecture to provide high-resolution pictures of objects in space, in the air, on the surface, and below the surface--whether they are concealed, mobile or stationary, animate or inanimate."[23] The future systems that need to be developed to support the warfighter will have to provide the intelligence near real-time, with quick revisit, near all-weather, and day or night coverage.

This study by the Air Force also suggests that there may have to be a fundamental shift in how the United States currently uses imagery. "Spatial resolution should not be the only criterion for evaluating the value of surveillance [and reconnaissance] systems. Future systems may instead produce target information by coupling low-resolution position information with large amounts of spectral data about the target."[24] Ultimately, most of the current Air Force studies conceive of systems that will provide nearly instantaneous world-wide coverage by linking geosynchronous (GEO) and LEO satellites, manned aircraft, and unmanned aerial vehicles (UAV) to provide a synergistic net. The U.S. Space Command is a wealth of both basic information and near-term and far-term technical and conceptual proposals that should be of further use as the scope of this thesis develops.

The U.S. Army Space Command and the Space and Missile Defense Command have vision statements and proposals for future systems that will be illuminating for both the potential for systems to come and the proposed systems that are planned to replace the current systems. These systems would be designed to significantly enhance military operations by employing leading edge technology to a force that is increasingly asked to do more faster with fewer assets. For these reasons, the U.S. Army (and certainly the rest of the DoD and IC) views these advances in capabilities to be fundamental to the future of the armed forces.

The Department of Defense Space Program Office is perhaps the best source for the focus both for the near term and long term outlook of space support to the war fighter. There are web sites and on-line services that provide the user with up-to-date space systems direction and planning guidance.

On the commercial side of the space industry, the market is extremely optimistic about the development of newer and better systems. These space systems will be developed using market-based techniques and efficiencies.[25] Two projects that are using this approach include Iridium and Globalstar systems.[26] Each of these systems are designed to orbit up to sixty or seventy satellites forming constellations that blanket the central region of the earth's orbit enabling the respective companies to provide nearly world-wide cellular telecommunications.

Aviation Week and Space Technology, *Janes Defense Weekly*, and *International Defense Review* are among some of the numerous excellent publications from the non-governmental side of the future satellite architecture. These sources provide a superb sanity check and a balance to some of the systems proposed by the various departments and agencies of the U.S. intelligence and defense community. It is precisely because of these sources and especially in light of the increased commercialization of space that much of the information that is available for this topic is available in an unclassified format. The increased demand for benefits provided by systems that use space has enabled commercial markets to develop where formerly only dedicated government programs could afford to venture.

Summary of the Literature

The review of the literature has suggested that the capability to accomplish more with increasingly sophisticated space systems and the United States' dependence on these systems will increase dramatically over the next ten years. The warfighter continues to be at the forefront of the support effort as the new systems are designed and programmed. Official U.S. policy has been clear on the need for these systems to be useful to the warfighters. As these space assets become more sophisticated and more numerous, the relative costs associated with them have been declining. The cost savings coupled with the increase in capabilities suggest that the development of these systems is not only possible given the constrained resources, both in terms of forward-deployed forces and in terms of funds available for other defense-related expenditures, but necessary if the U.S. is to maintain the leadership role in the world community. Additionally, the U.S. public is increasingly concerned about the expense of new systems and the deployment of U.S.

troops, looking for the apparently mythical and elusive peace dividends. As the U.S. government endeavors to address the public concern over these expenses, it is also challenged with meeting the very real demands of national defense into the twenty-first century.

As the U.S. strives to maintain global reach and power, the tools that enable this projection of U.S. resolve are the ability to maintain a global view coupled with power projection. This ability to monitor worldwide events and project power is especially critical as DoD moves to further reduce the cost of the force projection. The global view becomes more vital as DoD transitions to an environment of "just enough, just in time." U.S. resolve can ensure that less expensive, resilient, reliable, and flexible space lift and systems will become a reality. Without assured access to space, the global power projection will be increasingly cost prohibitive.

Another result of the literature review suggests that tactical systems and national systems may merge and the information that is used by one can be simultaneously used by the other. This could save a great deal when compared to two separate mutually exclusive systems. This would not be what many of the warfighters have viscerally demanded, that is a separate dedicated system for their support. This demand that the systems be dedicated to the warfighters comes from generations of playing second seat to the national community and commanders in the field wanting to control that which will have direct impact on their operations. This would suggest that as long as the new systems give the commanders what they need, it should not matter whether the system is a tactical system or a national system.

As future space assets come on line they will become the force multipliers that enable success on future battlefields. The last four decades of experience in space have lead to incredible breakthroughs for the United States and the world. The use of space has become critical to the performance of the defense of this country, greatly improving the ability to prevent conflicts and when necessary fight them and win. The challenge will be to build on the accomplishments to date, and leverage the emerging technology to dominate the global battlefield of the next century.

This thesis will explore the various options given the direction of technology and priority for support to the warfighter. The result should illuminate some of the advantages of the various options and highlight the most advantageous tactical satellite option.

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CHAPTER 3

RESEARCH METHODOLOGY

The design of the research methodology focuses on the primary question: Do the recent and projected developments in space technology, changes in the developmental and construction procedures, and launch approaches make the argument for a new dedicated tactical ISR satellite system more compelling? Is the promise of new technologies and innovative techniques offering an opportunity to significantly improve ISR support to the warfighters? Are these new advancements cost effective? If so what implications do they have on the future ISR capabilities for the warfighters? Do the warfighters need a dedicated ISR system or can they continue to be supported by national systems?

The literature review has suggested that the advance of space technology and procedures will make it technically possible and possibly economically feasible to LOD or have on orbit systems that would provide tactical satellites in direct support to the warfighters. Making it possible to have dedicated satellites that provide the warfighter quicker revisits of the target area and NRT target identification in all weather, day and night. Defining the warfighters needs with the anticipated capabilities of future systems will permit clearer exploration and focus on the system requirements.

As a result of the review of the literature, the supporting questions have become: is a separate tactical ISR satellite system required, and can the same system serve both the national or strategic community and the tactical commanders?

This chapter will define how the thesis question will be answered. This will be done by phase:

I. Defining the warfighter needs

II. Defining capabilities of the ideal system and review in general terms the capabilities today, and what the projected capabilities are for the next ten years.

III. The general cost of these systems: current and projected, although the specific details are not available, general assertions from reliable sources will give a general picture about the most likely costs relative to current systems costs.

IV. The final phase will define how to determine the best solution for all of the different proposals and current systems.

Phase I

The first phase of research will define the current and anticipated information needs of the tactical commanders. This will be done in concert with a thorough understanding of the capabilities today, what the United States expects to be able to do in the near term, and what the vision is for the next twenty years. This understanding of the United States' current and projected capabilities should not obscure the discussion of the actual needs of the war fighter, rather provide a framework to build and expand. The requirements generated by the tactical commanders should drive the system requirements, not system capabilities driving requirements, as has often seemed to be the case. Historically, part of the problem associated with a system that took years to design, build, and launch was that the needs of the consumers evolved and changed by the time the system was fully operational. Similarly, by the time the system was in operation, the technology had advanced so quickly that the system itself could be outdated.[1] For example, a notional communications system designed to pick up two way radio transmissions conceived of twenty years ago, designed, built, and finally launched ten years ago, could not have fully appreciated the advancement and proliferation of mobile phone systems. Additionally, the system would likely have been designed to last ten to fifteen years. The majority of its life cycle would have been wasted, unless the system was designed with alternate capabilities.

The warfighters' needs today will have to be articulated in such a way that the systems that are being sketched on the drawing boards tomorrow will still satisfy the requirements when they are flying over head in five years and throughout the systems life cycle. Military commanders need to be more directly involved in the system requirement process to ensure that as the systems are designed, built and launched they are there to ensure that the system is still relevant.[2] This is another compelling reason for the faster design to launch cycle that is making such an impact on the space industry. Procedures that can improve this time line from identification of the needs to solutions will not only save considerable expense but more importantly improve the warfighters ability to quickly and decisively win battles of the future.[3]

The warfighters needs do not prescribe that the source is from space, air or ground, so long as the information meets the requirements. What the commander wants is the answers to his questions. How the questions are answered is largely irrelevant, so long as the answers are factual, and can be disseminated to the level that can leverage the information to win on the battlefield. Towards this end DoD can take the warfighters needs and apply them to whatever system or group of systems that can best meet them.

Whether the system is space or ground based, and in many cases it will be a combination of both systems, will not matter. An example of this combination and reliance on both space and ground based systems is being used in the Balkans today with SFOR (Stabilization Forces). There the United States has the Predator (UAV) flying over a target linking live video feed to an F-15E via satcom. That video is linked with NRO imagery to give pilots as they are flying to the target area not only images with precise location information but what the target area looks like from their approach real time.[4] However, for the sake of this thesis the focus will be on the space-based systems portion of the process and the unique capability of these systems to contribute to the needs of the warfighters. It would then be up to the collection managers to decide which asset could best answer the CINC's questions at a given time and circumstance.

The warfighters objectives for the future systems generally can be summarized as those systems that will integrate space assets across all functions of the Battlefield Operating Systems (BOS) and enable precision strike, dominant maneuver, force projection, information dominance and force protection.[5] Likewise, the warfighters' needs can be defined as the answers to the questions that can assist them in anticipating what the potential or actual intentions of the enemy are prior to the execution of those intentions and the precise location of both mobile and fixed targets. The answers to these questions must be provided in sufficient time to allow the warfighters to act decisively to either prevent the conflict or when necessary to fight and win.

Phase II

The next phase of research will discuss the capabilities of the national ISR space systems and tactical systems in place today and expound on the benefits and the problems associated with them. Desert Shield/Storm will be used as an example, although there have been significant improvements to the dissemination process since 1991. Those improvements will be noted and explored. The requirements of warfighters and Joint Task Forces will also be reviewed to better understand the benefits and challenges that the ISR systems currently provide. Then examine the capabilities that are desired and finally to review some capabilities of the proposed systems.

In order to compare the national and tactical systems available today, it is useful to think of the systems as a whole rather than as individual assets that collect the ISR information. To successfully conduct intelligence surveillance and reconnaissance it is necessary to have access to the target area. This can be accomplished remotely through electronic means, by direct over flight of the target area either from space or in the air, or lastly by a source of information actually on the ground in the vicinity of the target. Historically, the national systems were the space systems, and the systems that would fly over denied territory. When a conflict or crisis dictated, the warfighters systems could then be used for over flight of hostile areas (none of which were space systems). Hence, the comparison between national space systems and current tactical systems will not be completely fair on a system per system basis. That is, comparing a system that is designed to support the national community and collect from space to a system that is used within thousands of feet of the target area. However, the comparison will highlight the significant the differences between the systems and provide some basis for comparison to the possible future system's contribution. Ultimately, it is the end product that is most important to the customer, so whether this paper compares national space systems or tactical air breathing systems it is the end support that matters most.

The research methodology will analyze each of the two different grouped systems capabilities, national and tactical in place today according to the different aspects of its contribution to the tactical ISR needs. The results will be evaluated by the primary criteria that are derived from the answers to the questions from phase II. The results will be given a numerical score based on the answers to specific tertiary questions defined in this chapter. The results of these numerical ratings will then be graphically illustrated in a Decision Matrix according to the format in U.S. Army Command and General Staff College Student Text 25-1.[6] An example of this format is shown on Table 1.

TABLE 1. EXAMPLE OF DECISION MATRIX

Characteristic	National Systems	Tactical Systems
1	5	2
2	2	4
3	5	5
4	3	4

Phase III

The purpose of third phase will be to compare the general cost of the ISR program as it currently exists against the projected costs. This will, to the extent possible, look at each part of the process, the construction of the satellite, the launch, and the operation that controls the satellite once on station. Because of the sensitive nature of some of these programs, these figures may not be available in detail but will be described in general terms. The goal will be to determine the cost per pound for the launch and operations historically and to project them for the new systems. This cost comparison should enable the current and older systems to be evaluated against the projected cost of the future systems. Admittedly, the costs that are associated with the future systems can not be defined as accurately as current or older systems.

The cost per pound criteria is an industry standard that acknowledges that this method does not take into account how well the system performs but rather is a straight forward measurement of weight as correlation to cost to orbit.[7] The system qualities have to be compared separately, not as a function of weight. All things being equal the less an object weighs and the smaller in volume the easier it is to get into orbit. If the satellite weighs less, but can not perform the mission, obviously that would be unacceptable. Weight will be used as an indicator benefit not as a mission enhancement quality.

Once the relative costs have been estimated, the cost will be compared with some of the qualities discussed in phase I. These will yield a general cost linked to the effectiveness of the system which will precipitate phase IV.

Phase IV

The fourth phase will be to determine which current or projected space systems could best satisfy the current and anticipated requirements most efficiently. It may be that none of the systems discussed will be recommended. The results will be rank ordered with the system that can best accomplish the support to the warfighter getting the highest ranking, although the anticipated cost will be weighted.

Conclusion

The methodology encompassing the review of various literatures on ISR satellites, highlighting significant improvements to warfighter support by the various options proposed with current capabilities will enable conclusions to be draw about the merits of the various ISR satellite programs. The results will illuminate the best course for the improved warfighter support in a resource-constrained environment.

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[1]U.S. Air Force Air University, "Spacelift: Suborbital, Earth to Orbit and On-orbit" Federation of American Scientists [database on-line] October 1997, available from http://www.fas.org/spp/military/docops/usaf/2020/app-h.htm; internet; accessed 1 February 1999.

[2]Thomas G. Behling, and Kenneth McGruther. "Satellite Reconnaissance of the Future." *Joint Force Quarterly* 18, Spring 1998, 26.

[3]Richardo de Bastos, "Think Small: Solving problems for commercial communications customers with lightweight spacecraft." *Satellite Communications*, June 1997, 3.

[4]U.S. National Reconnaissance Office, "NRO Provides Support to the Warfighters," National Reconnaissance Office press release 28 April 1998[database on-line]; available from http://www.nro.odci.gov/index3.html; internet; accessed 3 January 1999.

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CHAPTER 4

ANALYSIS

> In an era of limited resources, government is depending more heavily on small spacecraft to attain important civil and military space goals . . . . The Air Force, Navy, and the National Reconnaissance Office are all exploring ways to shift assets to smaller platforms that can be deployed more rapidly at lower cost.[1]
>
> Liam Sarsfield, *The Cosmos on a Shoestring*

Introduction

In this chapter, each of the criteria introduced in Chapters two and three will be closely examined and evaluated. From this examination a determination will be made of the feasibility and prudence of developing a tactical ISR satellite system that would provide dedicated support to the warfighter. This determination is based on how well the various systems are anticipated to meet the warfighters needs along with the other evaluation criteria discussed in chapter 3. This is primarily a comparison of the proposed tactical systems versus the current and likely capabilities of national systems. The results will determine if a new dedicated system for the warfighter will be more effective than the current method of national systems in general support.

The thesis question will be answered by identifying the short falls in current systems, illuminating some of the likely capabilities of the future and relative costs associated with both present systems and future systems. This will yield recommendations for future systems in the final chapter.

Currently the warfighter depends on national systems to give timely coverage of denied areas. The United States has largely led the technology drive that has enabled an unprecedented level of information support for the battlefield commanders through the leveraging of national systems that have routinely been in support of the national policy makers and the IC.[2]

As the Department of Defense plans the next generation of ISR satellites it will seek to exploit the many advancements in technology, production, and design procedures while meeting or exceeding the warfighter's needs.[3] Given the changes in capabilities and the likely improvements, should satellites be dedicated to direct support of the warfighter? Given the current and projected financial constraints, where decision makers may have to take one or the other of the options--support the Warfighter or support the policy makers, this issue is of vital interest to each side. This choice of national or warfighter support is not as clear or divisive as it may appear on the surface. National systems can and do support warfighters now and a future system that is dedicated to the warfighter could support the policy makers. It is primarily a question of who gets routine priority and who controls the system. Historically, service planners were very resistant to dependence on national systems that were not controlled by the service, the services reasoned that the individual services could not depend on the national systems to respond to the individual needs in a timely and predictable manner.[4] This issue of trust is being exacerbated by the declining and therefore fiercely competitive defense budget.[5]

The four phases of this evaluation will focus the process and yield answers to these subordinate questions and ultimately the thesis question.

Phase I: Defining the Warfighters Needs

Defining the warfighters needs, both present and future, is absolutely vital to the development of future systems. Under current and historical design and development procedures for ISR systems, it has taken and still takes years to go from concept to the drawing board to construction to operation.[6] Once in operation, the operational life span of a system would be expected to be from a few years to ten or more, depending on the mission and orbit[7]. If the DoD is to expect the systems to be responsive to the needs of the warfighter, those needs must be clearly articulated. The warfighter must be included throughout the concept, design, production, and deployment of the system.[8] Instead of engineers and researchers coming to the warfighters with capabilities, the warfighter must address his needs up front in concert with a firm grasp of the design capabilities, and to the extent possible, these needs must drive the development process. The warfighters needs must be defined up front, prior to the design and development process.[9] Once the design and development process has begun, adjustments to the system will either delay it significantly or may not be possible after it is launched.[10] Either way the adjustments will be expensive.

Most of the current and future warfighter needs fit into one of the following criteria:

1. World wide coverage
2. Detection of enemy force posturing
3. Weapons and equipment: movement detection – conventional and WMD[11]
4. Contribute to information dominance
5. Target ID equipment and operational status, BDA
6. Quick revisit time

7. NRT data speed
8. Control and tasking process
9. Dissemination
10. Multi-role for conventional or unconventional action

The sources for these needs include input extrapolated from publications from DoD, DARPA, NRO, and JFQ and from historical problems faced during previous conflicts such as Desert Shield and Desert Storm. Further explanation of each of these criteria will illustrate its importance to the success and impact of the program on the warfighters' ability to fight and win using this system. Each of these needs has a direct impact on the level of support that the warfighter will receive and on the extent that the system can provide this support will help in clarifying the best system to provide that support.

Worldwide Coverage

Worldwide coverage is the ability of the satellite system to image any given location on the globe,[12] so the system would be able to image a target during different portions of its orbit for all of the CINCs. The more coverage of the earth's surface the better the worldwide coverage. Keys to worldwide coverage include the number of satellites in orbit, the type of orbit, inclination, and the system capabilities.[13] Given that the satellites under consideration are in LEO orbits, the best way to achieve worldwide coverage is to have the satellite in a near-polar orbit. Satellites in polar orbits (those satellites whose orbits pass near the south and north poles) will regress to the west on each pass. With the average altitude of 300 to 500 miles, a complete orbit is achieved about every two hours. This near polar orbit with the westward regression combined with some flexibility of the sensor to look forward, aft, left, and right ensures that the satellite will have a ground track that covers nearly the entire earth.[14] Current systems can provide this capability and it is important that future systems maintain or improve upon this capability and nearly all of the proposed systems do.

Detection of Enemy Force Posturing

Detection of the enemy intentions is key to both national and tactical ISR systems. It is the ability to detect enemy activity that could be the precursors to hostile actions that can enable both the policy makers and the warfighter to take action to either prevent the conflict or fight and win.[15] An example would be the movement of Iraqi forces to the border of Kuwait. It is the critical piece in the early warning capability both to the NCA and to the warfighters. The failure to stop Iraqi forces from invading Kuwait in late July/August 1990 was not a failure of the space intelligence systems. Rather it was a failure of the senior intelligence advisors who did not sound the alarm loudly enough and the policy makers who did not leverage the intelligence available to them. This is a policy issue and must be addressed by the senior policy makers.

Weapons and Equipment: Movement Detection

The detection of weapons and equipment movement including both conventional and WMD is key to knowing the enemy. The ability to detect the type of enemy force is critical to meeting the enemy with the right force at the right time and place. Change detection is an integral part of this equation. Change detection in terms of equipment located at a target area, the ability to detect the addition of new equipment or simply the movement of key equipment.[16] Change detection could for example detect the movement of testing equipment at some of the nuclear storage and testing facilities in Pakistan and

India, providing the NCA with indications that a test was about to be conducted. This capability must be sustained and where possible improved.

Contribution to Information Dominance

The data provided by the satellite system must be capable of being integrated into a system of systems that will be linked synergistically to provide a clearer picture of the enemy situation. The ISR satellite system would be a vital link in the formation of networks leading to information dominance.[17] In an environment that envisions increased lethality of systems and greater stand off distance from the shooter to target and the concept of one shot one kill precise timely intelligence is even more critical. This capability must be developed and fully integrated into the warfighters situational awareness.[18]

Target and Equipment Identification

Target and equipment identification are key components of the old adage "the right system for the right target." The ability to determine of the nature of enemy intentions will enable the warfighter to leverage the right asset for the right mission.[19] The system should also be able to detect the operational status of equipment or facilities. Currently this capability exists but is not fully incorporated into the warfighters systems.

Revisit Time

The revisit time is the time it takes from one image of a target to the next opportunity that targets can be imaged at a subsequent time. This is primarily a function of the number of satellites in orbit and to a lesser extent the type of orbit.[20] Although the latter reason can be discounted since the primary orbit of consideration is LEO. The greater the number of satellites in the system the more frequent the opportunities for acquiring the target area. Thus a shorter revisit time can be achieved with more satellites. This frequency of re-visits becomes more critical as we get closer to the modern battlefield that is believed to be more lethal and faster paced.[21] Generally each satellite in a LEO orbit has about two passes over the same area per day.[22] A DARPA study has shown that a constellation of 24 satellites orbited at 477mile altitude would offer 90 percent probability of delivering an image to a warfighter within 15minutes, for any given spot on the Earth (between 65-degrees north and south).[23] Expanding the constellation to 37 satellites would allow revisit times of 8 minutes. Forty-eight spacecraft would further reduce the interval to 5 minutes.[24] Figure 4 illustrates the relationship between the number of satellites in orbit and the time that it takes to get visibility of the target.

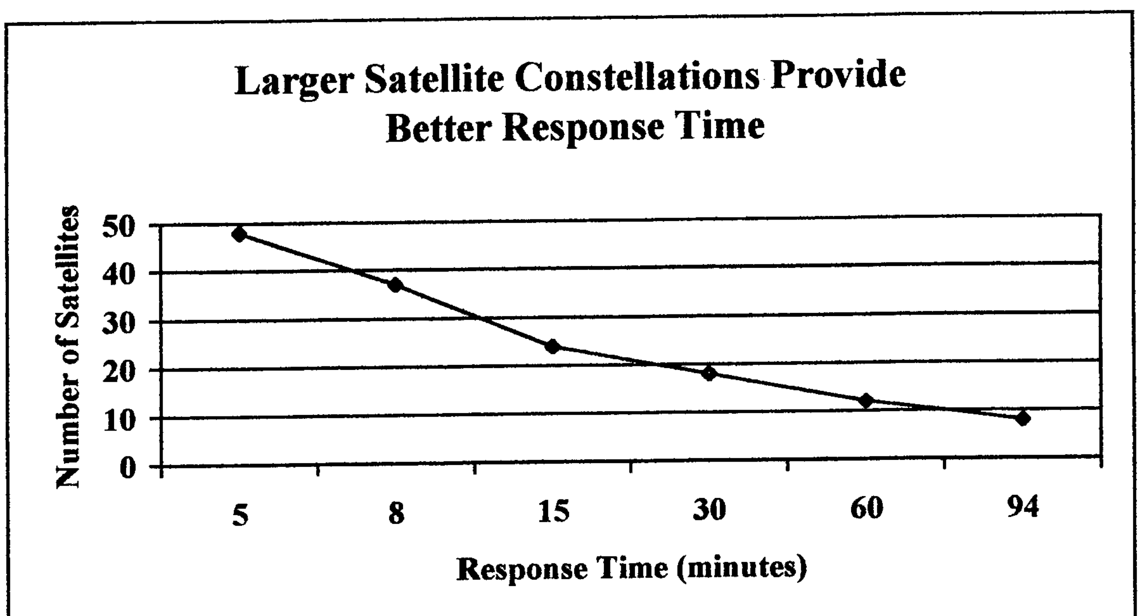

Figure 4. Satellites to Response Time

NRT Data Speed

Along the same lines as the revisit times is the amount of time that it takes to get the data from the sensor to the warfighter. The sensor can be at the right place at the right time but if the data does not make it to the warfighter in time for action then the data will be marginalized at best and at worst a waste of a very expensive asset. There are numerous systems that can receive data into the warfighters AO from national systems today so receiving the feeds from the satellites would not be a problem.[25]

Control and Tasking Process

Control of the satellite and the process tasking the system have traditionally been accomplished by the national IC. Warfighters have historically demanded that they control and own the systems that they depend on, this is fundamentally an issue of trust.[26] Warfighters have been and still are resistant to depend on the senior leadership to support them when and how they need it. Another contribution to this reluctance to depend on a system that the warfighter does not control is that they believe that with limited assets their AO will be a lower priority than is warranted. For these reasons the more control over a system the better the warfighters confidence and reliance will be on the system. Controlling the system is essentially being able to select the target area and direct the sensor at will, without prior approval or control by the national IC. Historically, particularly during Desert Shield and Desert Storm this process for the warfighter was not easy or straightforward. It was both bureaucratic and time consuming.[27] Today this process has been streamlined considerably, although the warfighter still does not control the sensor.

Dissemination

Dissemination of the information must be to the lowest levels that need to take action with the information. For this to happen the classification of the data and the ability to receive and process the data will have to be addressed. Sensor data is capable of drowning the warfighter with the sheer volume of data,[28] for example in Desert Shield/Storm:

> Over 500,000 photographs were processed. . . . Over its 14 year lifetime, the Pioneer Venus orbiter sent back 10 terabits (10 trillion bits) of data. Had it performed as designed, the Hubble Space Telescope was expected to produce a continuous data flow of 86 billion bits a day or more than 30 terabits a year. By the year 2000, satellites will be sending 8 terabits of raw data to earth each day.[29]

As demanding as these figures are the computing power seems to double every few years and will likely be able to handle this data.[30] So the mere collection and passing of information is not sufficient. The information must be focused on the needs of the warfighter, and provide that information to the right place at the right time.

Multi-role Information

The system must be able to support all levels of military action including peace keeping and enforcement, humanitarian assistance, terrorist actions, full scale major regional conflicts and asymmetric warfare of the future.[31] The current systems can support this in a limited way, however given the current theories about future conflicts asymmetric aspects the traditional threats will not be the most commonly faced threat. The more likely threat is one that is:

> ASYMMETRIC foes seek offsets against stronger, more technologically advanced countries by indirectly attacking things that are both strengths and weaknesses, e.g., the openness of our culture. They will attack to upset our

> capabilities to synchronize things we are doing (that's *ASYNCHRONOUS* warfare). They will operate in both physical and moral domains of war, using terror to affect aggregate psyches of the American populace.[32]

These are the primary reasons that support must be capable of reaching whatever level necessary to provide the warfighter with the decisive information in time to decisively accomplish his mission.

Phase II - Defining Capabilities: Present and Future

The capabilities of the current systems will establish the minimum standard for future systems and establish a baseline for comparison. The primary characteristics that will be reviewed include:

1. Orbital consideration
2. Revisit times: function of number of satellites, and type of orbits
3. Spatial resolution: target detail, detection capabilities - what can be sensed with the system
4. Ability to disseminate the information
5. Launch capabilities: current and future
6. Control: tasking of system

Orbital Considerations

In the model tactical satellite reconnaissance system rapid revisit of point targets is a priority, more specifically looking for a specific target at a specified location and possibly at a specified time. Imagery satellites are generally in Low Earth Orbits (LEO) which are typically less than 1,000 km above the Earth's surface.[33] The fundamentals of orbital mechanics explain why satellites cannot simply hover over one geographic area, rather they are generally designed and programmed for a specific orbit, each of which has specific characteristics and advantages. These fundamentals will be briefly reviewed here to provide a clearer picture of the systems optimal configuration, which will provide the best support to the warfighter. The three primary orbits of importance for this discussion are highly elliptical orbits (HEO), geosynchronous orbits (GEO), and LEO.

HEOs are elliptical in shape and enable the satellite to spend more time in one extreme portion of the orbit than in the opposite side of the orbit. That is to say at apogee the satellite is travelling the slowest (relative to the ground) and when at perigee it is traveling the fastest.[34] In an average twelve-hour period for a satellite in a HEO orbit, it can spend eleven hours with access to the same geographic area and only an hour in the

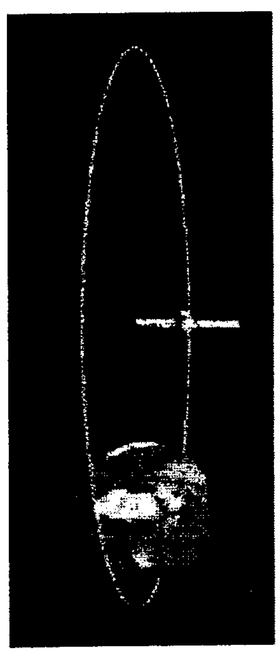

Figure 5. HEO orbit

opposite side of the orbit. Figure 5 illustrates the position around the earth of a satellite in HEO orbit. The disadvantage of this type of orbit is that the distance from the earth at apogee is relatively high, up to thousands of miles and perigee is relatively close, as low as a hundred miles.[35] The higher altitudes of apogee will preclude its use for current and anticipated imaging technology in support of the tactical warfighters.

GEO orbits are generally circular and are far enough above the Earth's surface to appear to stay in the same place relative to the Earth's surface. In reality the satellites in this orbit are traveling approximately 6,900 miles per hour relative to the earth, this is necessary to keep pace with the earth's surface as it rotates.[36] Generally the geosynchronous orbits are about 22,000 miles above the earth and are particularly useful to the communications, missile warning, and weather reporting satellites. The physical limitations of current and anticipated future imaging systems generally preclude the use of higher resolution imagery from the higher altitudes of a GEO orbit. This is particularly true for systems that would be in direct support of the tactical users. Figure 6 illustrates the orbital path of a GEO satellite.

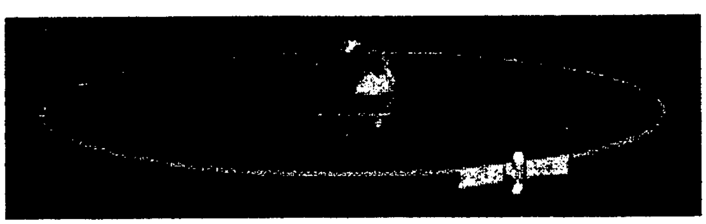

Figure 6. GEO orbit

LEO orbits offer quicker revolutions and there for the possibility for faster revisits of the target area. LEO orbits also have the advantage of being closer to the earth and can there fore expect better resolution than the higher orbits. A LEO sunsynchronous orbit is generally lower than 1,000 kilometers from the surface of the earth and passes over the same spot on the earth at approximately the same time each day. This is the preferred orbit for most satellite imaging systems in use today, and of particular use where frequent revisit and high quality resolution are important.[37] Figure 7 illustrates the position of a satellite in a LEO orbit around the earth.

Figure 7. LEO orbit

Generally speaking, the higher the orbit the more expensive it is to get the satellite into the orbit. However, the lower the orbit the shorter the theoretical orbital life of the satellite, that is the length of time until the gravitational pull of the earth drags the satellite into the earth's atmosphere.[38] Theoretically all of the satellites in orbit around the earth will eventually be pulled by gravity to the earth, however the length of time that it would take a typical GEO satellite is estimated to be thousands of years. LEO orbits have a much shorter orbital life; with out routine station keeping orbital adjustments they could re-enter the earth's atmosphere (depending on the altitude) within a few weeks or months of launch. The typical LEO in an orbital range of 250 to 500 miles, if left unattended, would be expected to re-enter the atmosphere within a few years.[39] The US Space Lab was an example of a LEO satellite that had a decaying orbit that ultimately brought it back into the earth's atmosphere, destroying it.

Given this basic understanding of the orbital considerations the LEO orbit is the only orbit relevant to ISR systems under discussion for this thesis. The intended purpose of the satellites will generally define which orbit is best. Another consideration is the inclination of the orbit, which will define how far north and south the satellite will travel relative to the earth's surface.[40] The inclination will also define the coverage of the earth's surface, the more inclined the orbit (up to a polar orbit) the more coverage of the earth. Although there is not much interest in the system that is designed to support the warfighter being able to cover the extreme northern and southern areas of the earth's surface. So by using an orbit that is only inclined as far north and south as there are areas of concern you can increase the time that the systems spends in the inhabited regions. During each of these orbits the satellites must receive new imaging and system instructions both in terms of what to target with the sensors and general system maintenance instructions called station-keeping instructions.

Revisit Time

The length of time that it takes to reacquire a target is the revisit time. This revisit is vital to timely ISR systems both for its ability to quickly ascertain change and monitor activity.[41] Many of the other factors important to the revisit time include the number of satellites in the system, the orbit for each satellite and the inclination. All of these aspects have been discussed in earlier chapters and portions of this chapter.

Spatial Resolution

Spatial resolution is the ability to discriminate between two separate and distinct objects. This is for practical purposes the detail that a sensor can detect on the ground from the space sensor. The following table illustrates some general examples of the detail that the satellites would have to be able to distinguish at various spatial resolutions.

As table 2 illustrates the amount of spatial resolution necessary depends on which target is to be imaged.[42] Does the system need to see the fine detail so that technical analysis can be completed or is it sufficient to simply identify the type of equipment? For example are there aircraft on the runway or are the Armored Personnel Carriers in the garrison parking areas or deployed. In most cases the warfighter would generally need to simply identify the type of equipment, numbers, change detection and operational status. Of course the more information and target detail that can be determined the better the system. With so many of the future warfighter weapon systems counting on increased knowledge of the enemy and information dominance the more that can be determined from the space based ISR systems the clearer the picture that the intelligence system will be able to construct. Spatial resolution is provided by the current national systems, however with the design of new systems that may provide dedicated support to the warfighters coupled with the pressures to reduce cost spatial resolution must not be sacrificed. Emerging technology and launch reduction costs could be the best source for reduced costs.

Table 2. Examples of Spatial Resolution

REQUIRED GROUND RESOLUTIONS FROM COMMERCIAL OBSERVATION SATELLITES (in meters)					
Target	Detection	General ID	Precise ID	Description	Technical Analysis
Bridges	6	4.5	1.5	1	0.3
Radar	3	1	0.3	0.15	0.015
Troop Units	6	2	1.2	0.3	0.15
Airfield Facility	6	4.5	3	0.3	0.15
Rockets/Artillery	1	0.6	0.15	0.05	0.045
Surface Ships	7.5-15	4.5	0.6	0.3	0.045
Vehicles	1.5	0.6	0.3	0.06	0.045

Detection: Location of a class of units, objects, or activity of interest
General Identification: Determination of general target type
Precise Identification: Discrimination within target type of known types
Description: Size/dimension, configuration/layout, components construction, equipment count, etc
Technical analysis: Detailed analysis of specific equipment

Source: Ann M. Florini, "The Opening Skies: Third Party Imaging Satellites and U.S. Security," International Security, Fall 1988, 43.[43]

Dissemination

The process of dissemination is currently handled by multiple systems (for example the Army's TENCAP system) that are designed to take the national systems technology and provide it to the warfighters.[44] This simply is a matter of providing the warfighter data that has been approved by the strategic/national community. This process needs to be stream lined to ensure that the warfighter gets the information as soon as possible--as quick if not quicker that the national community in NRT. This concept is part of the effort to get the information direct to the warfighter that can most quickly leverage systems to impact on the enemy. This is what has come to be known as the "sensor to shooter" time. The quicker the key information is collected and delivered the better the warfighter can respond.[45] Future systems will have to be nearly instantaneous, getting the information as it happens to those that need it most and providing a nearly seamless picture of the battlefield. Historically national systems have significant security considerations that have precluded timely dissemination to the lowest levels of warfighters.[46] Although significant improvements by the national IC have been made in the last ten years, if there were a system that was dedicated to supporting the warfighter this problem would be substantially reduced. Although at all levels these systems have to be protected and safeguarded to protect both the vital capabilities and the technology.

Launch Capabilities

The ability to get satellites into orbit is obviously a key aspect of the entire program. Currently the ISR systems are placed into orbit with the use of rockets based out of Vandenburg Air Force base, California or Cape Canaveral, Florida, the two primary United States launch facilities. The process of scheduling a satellite for launch on one of the current systems is both time consuming and competitive. If for example we decided today that we need to launch a typical satellite (on the shelf ready to go) because of the failure of a satellite in current use it is estimated that it would take from six to nine months to launch.[47] Future launch systems will need to be more responsive to short notice requirements, either because of failures, damage (either intentional or accidental) or land based situations that demand support from a space based system. The development of a LOD capability would significantly improve our ability to provide tailored support at the right time and place. With a LOD capability, the tactical satellite system could be a deployable system used only when it was needed.[48] The warfighter could work with a reduced number of systems until the full system was needed, for example during a crisis situation a series of small satellites could be launched into the correct orbits to maximize the capabilities of the satellites. This could save valuable resources, both in terms of ground control and actual satellites. It would have the added benefit of being much more flexible with the design. Allowing the warfighter to adjust his needs as the situation develops and allows the engineers time to make the changes and upgrades before the system is fully deployed.[49] As discussed in chapters one and two, there are numerous proposals for systems that will likely be coming on the market in the next 5–15 years. Some of current proposals envision systems with an inexpensive LOD capability.[50] This would revolutionize the market for space systems and especially the ability to launch the right systems into the right orbit at the precise time that the warfighter needs it, while saving the resources until the are needed.

Control and Tasking

Control and tasking of the asset is currently firmly in the control of the national IC. That is not to say the warfighters needs are not met with the current systems, it is that the warfighter is reluctant to count on the current system since he does not control them. The systems that support the warfighter must either be under his direct tasking control or there must be a fundamental change in the warfighters mindset with respect to the national systems. That shift would have to be trust that the national systems would be there to support them when they need it. This trust is not without risk, and the national intelligence community will have to earn the trust of the warfighters[51]. This trust already exists with many other programs and facts of military life, but for many complex and historical reasons the willingness of the IC to quickly pass and support the warfighter timely information has not met the warfighters expectations. This trust could be earned through exercises and small crises support that reflects the unity of effort that is necessary to win decisively on the modern battlefield.

These capabilities will be measurements that will assist in the evaluation of national systems and proposed tactical systems. This evaluation process will be part of the answer to the question about the need for a dedicated tactical space based ISR satellite system.

Phase III – Relative System Cost: Present and Future

The general cost of these systems: current and projected. Although the specific details are not available in an unclassified forum, general assertions from reliable sources will give a general picture about the most likely costs.

National ISR systems in current use are the result of the cold war mentality. During the cold war the cost of a system was not a significant factor in its construction. The most significant factor was can the system help the United States prevent war and if not can it help us fight and win? If these system could answer yes then cost was largely not a factor. The United States developed concepts on theoretical drawing boards then began to build them and launch them. Each system was tailor made with the latest technology and built to have multiple back up systems so that should there be a failure in the system there would be options for work around.[52] This mentality was typical of the 70's and 80's, which is when most of systems around today were constructed. Consequently the systems that we have today are very technologically advanced, especially given their time. However, the expense can no longer be justified in the same fashion. Cost is a factor in a fiscally constrained environment, the following all impact on the direction and momentum on the topic today:

1. Historical costs of National ISR systems: tailor made custom systems, cost was not a significant consideration

2. Efficient vs. effective debate--namely which should be more important and the primary consideration, the warfighter position has historically been that effective needs to drive this debate and efficiency should be a very distant ancillary consideration.

3. Will always need/have national systems--so tactical will be in addition to the National Systems

4. Cost development and advancements: smallsats, cheepsats, and future technological advancements

5. More systems equal more expense versus better systems, pros cons: Future requirements: information dominance, fast paced environment, one shot one kill, and increased lethality

The cost of the actual systems are expected to come down slightly or remain approximately level in terms of today's dollars.[53] With the expectation that technology will continue to provide improved capabilities coupled with the design and production improvements, the construction and assembly process the future systems will provide increased capabilities.[54] Technology advancement is normally an expensive process, especially when accomplished in a closed vacuum of classified defense programs. With the advent of commercial space development some of this advancement will be accomplished in a much more competitive open commercially driven environment.[55] This should reduce some of the associated costs traditionally linked with the development of one of a kind, one-purpose systems.

Similarly the cost and ability to rapidly launch these systems is expected to improve. This improvement will be driven by similar factors that are effecting key elements of the space industry today. Namely, the technological improvements to the launch platforms themselves[56] and then to the commercialization of the space industry at large.[57] These two factors will keep prices in check and in some areas reduce the cost.

Phase IV – Results: Best System and Approach

Preference Chart

The Preference Chart (table 3) is the method by which criteria are ranked and assigned a weight relative to their importance to the system overall. The criteria listed in the table are standard dimensions used to evaluate the characteristics of current systems and will be used to rate the relative worth of potential systems designs. National and the proposed tactical systems will be evaluated against the criteria in order to determine the best alternatives.

Table 3. Preference Chart

CRITERIA	Timeliness Revisit	Worldwide coverage	System control	Cost	Spatial resolution	Total	Weight
Timeliness Revisit	/	<	>>	>>	>	12	3
Worldwide coverage	>	/	>>	>	>	13	3.25
System Control	<<	<<	/	=	=	4	1
Cost	<<	<	=	/	=	5	1.25
Spatial Resolution	>	<	=	=	/	8	2

NOTE:
Vertical axis criteria compared to horizontal axis such that:
>> is much more important (4 points)
> is more important (3 points)
= is relatively equal (2 points)
< is less important (1 point)
<< is much less important (0 points)

Timeliness/Revisit Time

The first criterion in the table is timeliness and revisit time. This criterion represents two functions. The first function is the amount of time it would take the system, once the information has been collected, to get the data to the warfighter. Things that can affect this are whether the satellite has onboard data storage or a record and play (RAP) relay system, the data transfer rates, and where the warfighter is located relative to the downlink. The alternative systems are evaluated on how quickly the data can get to the customer. The faster the better, the concept of sensor to shooter is one of the ultimate goals and real-time data is the endstate. The second function is revisit time. This is the time that the system can be in position to perform a subsequent mission of the same target area. For example the time that it would take to conduct RS of a target area then to perform a similar mission on the same area or target either with the same satellite or another one. The shorter the re-visit times the better.

Worldwide Coverage

The second criterion is worldwide coverage. This criterion looks at the overall systems ability to image any place on the earth that would be of interest to the war fighter. The more coverage of the earth provided the better the system. For example most of the imaging systems today can image approximately 95 percent of the populated areas of the earth. Those areas that are not covered are in the extreme north and the extreme south.

System Control

The third criterion is control of the system. The warfighter historically has not had control over space-based ISR systems. Historically CINCs and JTF Commanders were very reluctant to depend on systems that they did not own and control.[58] The more control they have with these systems to direct the sensor where and when they want it the better the systems. This criterion also takes into account the time it would take once the warfighter determines that coverage is needed to the time that the system is imaging his target. Historically the process that warfighters have had to go through to get national systems coverage was not as expeditious as desired[59]. The quicker this processes the better. The fewer layers of validation and checks that the warfighters are required to go through the more timely the product would be.

Cost

The forth criterion is cost. The relative cost of the system historically has not been a major consideration.[60] However with the budget constraints, efforts to "do more with less" are increasing and even more fundamental is our fiduciary responsibilities to the American public. The cheaper the system the better, acknowledging that the system has to be able to perform its fundament task first then cost will be a consideration.

Spatial Resolution

The fifth criterion is spatial resolution. This is the ability of the system to discriminate between objects. For example the ability to distinguish between two objects on the ground as being two different objects.

It is obvious that some potential criteria are not stated in the table. Since the orbit is considered to be LEO for this paper that consideration has already been discussed it will not be addressed further. The systems ability to perform wide area searches and point targets is considered to be a difference between the national systems and the warfighter systems. The wide area criterion will be left for the national systems. Wider area coverage also takes an extensive amount of time to search and evaluate, which the national agencies would handle. The warfighters needs are generally more pressing and time sensitive, so the long term studies and searches would be the responsibilities of the national IC in conjunction with the services.

The relative importance between criteria is read from the criteria on the left as it relates to the criteria across the top of the table 3. This relative importance is taken from a national war college paper, discussions with NIMA, and personal experience with space-based and air-based ISR systems. The criteria weights were determined by dividing the lowest score into all the scores. These weights give the overall relative importance of each criterion and will be used in evaluating the alternatives.

Systems Utility Function

The measure defining the expectations of the systems performance for each of the criteria is outlined in the Systems Utility Function (see Table 4). This table displays the performance requirements of a system in each of the criterion categories, which are considered to be either exceptional, above average, average, below average, or barely acceptable.

The range of "performance" is listed in the table for each criterion. Under the criteria of Timeliness/revisit, performance is the opportunity that the system will be able to revisit the target area in a given amount of time. Under Worldwide coverage, performance is the system's ability to have access to a given percentage of the earth's surface. Under System Control, performance is the level at which inputs to the satellite are controlled. Under the cost, performance is the cost of today's systems relative to the anticipated systems of the future, including both current capabilities and providing the warfighter with a dedicated system. Under Spatial Resolution, performance is measured by the spatial resolution that the system is capable of producing in meters.

The rating is a numerical value assigned to each alternative's criteria performance. This number will relate how the systems expected performance measure up with the desired performance. This will be used in evaluating the alternatives.

Table 4. Systems Utility Functions

Weight	Rating	0 1	2 3	4 5	6 7	8 9
	Criteria	Barely Acceptable	Below Average	Average	Above Average	Exceptional
3	Timeliness/ Revisit	Daily	Twice daily	4 – 6 /day	Hourly	15min
3.25	Worldwide Coverage	70%	80%	90%	95%	99%
1	System Control	IC only	IC	IC support	CINC/JTF	BDE/BN/ SQDRN
1.25	Cost (relative to current system)	Much More than current	More than current	Equal to current	Less than current	Significantl y less than current
2	Spatial Resolution	3m	2m	1m	0.5m	.025m

Systems Simulation Table

Expected performance of national and tactical type of satellite system is given in the Systems Simulation table (table 5). Since one alternative is a completely developmental system and will likely have similar features (likely with improved capabilities) in future proposals, future performance can be estimated based on current assessments of its capabilities. The other system is proposed future system and there fore assertions will have to be made about a generic systems proposals believed to be comparable based on the most commonly believed future capabilities within the satellite community. These estimations are tempered with a level of confidence assigned each value. Again, this level of confidence is a "best guess" based on systems complexity, level of advanced technology that is to be incorporated, and the typical scenario in which the system will be used.

Table 5. Systems Simulation Table

CRITERIA	SYSTEMS	EXPECTED PERFORMANCE	CONFIDENCE
TIMELINESS/ REVISIT	NATIONAL	80%	VC
	TACTICAL	90%	VC
WORLDWIDE COVERAGE	NATIONAL	90%	VC
	TACTICAL	90%	VC
SYSTEM CONTROL	NATIONAL	70%	C
	TACTICAL	90%	VC
COST	NATIONAL	80%	LC
	TACTICAL	80%	C
SPATIAL RESOLUTION	NATIONAL	90%	VC
	TACTICAL	80%	C

NOTE:

Code	Level	Factor
VC	Very Confident	0.9
C	Confident	0.6
LC	Little Confidence	0.3
NC	No confidence	0.1

The factor is the correction to the rating from the systems utility function for the level of confidence. This correction will be used in evaluating the alternatives.

In summary, this chapter established system requirements and limitations, listed system options, weighted criteria, established desired performance standards, and expressed the confidence of expected performance, all of which will be in the final evaluation.

The final phase will define how to determine the best solution for the different proposed and current systems, and yield the results from this evaluation.

The tables and charts will represent the various criteria from the three previous phases.

Summary and Conclusion of the Analysis

This chapter examined different characteristics associated with national ISR satellite systems and proposed tactical ISR satellite systems and the ability of these systems to provide support more effectively to the warfighter. The results of these evaluations are in the evaluation matrix, which is summarized below and will provide the bases for the conclusion.

In the Systematic Systems Approach, the Evaluation Matrix takes the criteria weights from the Preference Chart, the ratings from the Systems Utility Function, and the confidence from the Systems Simulation Chart and determines a ranking between alternatives.

Evaluation Matrix

The Evaluation Matrix takes each alternative and measures it against each criterion (table 6).[61] The first column under each alternative is Relative Rating. This value represents how the alternatives expected performance compare with desired performance for each criterion. This value comes from the Systems Utility Function (Table 4). The second column shows the level of confidence, from the Systems

Table 6. Evaluation Matrix

Criteria (Weight)	Feasible Alternative							
	National				Tactical			
	R	C	U	D	R	C	U	D
Timeliness Revisit (3)	3	VC	6	5.4	7	VC	21	18.9
Worldwide Coverage (3.25)	5	VC	16.25	14.63	6	VC	18	16.2
System Control (1)	4	C	4	2.4	7	VC	7	6.3
Cost (1.25)	6	LC	7.5	2.25	3	C	3.75	2.25
Spatial Resolution (2)	8	VC	16	14.4	6	C	12	7.2
Total Value (total U's)	49.75				61.75			
Discounted Value (total of D's)	39.075				50.85			
Overall Confidence	78.5%				82.3%			

NOTE:

R= Relative Rating VC = .9
C = Confidence C = .6
U = System Utility LC = .3
D = Discounted Utility

Simulation Chart (Table 5), that the alternative system will meet its expected performance standards. The third column is System Utility and measures the contribution to the overall utility of the system for each criterion. This value is determined by multiplying the relative rating by the weight of the criteria. The last column under each alternative is discounted utility. This value represents the criteria's contribution to the system utility tempered by the perceived accuracy of the expected system performance. This value is determined by multiplying the system utility value by the factor associated with the level of confidence (factors are listed under tables 4 and 5).

With these utility values determined, a ranking is possible between the alternatives. The Total Value is the overall relative utility of the system and is the summation of the values in the System Utility column. The Discounted Value is the overall utility of the system tempered by the accuracy of the expected performance of the system. This value is determined by adding the values in the Discounted Utility column. The Overall Confidence represents the overall perceived system accuracy of the expected system performance. This value is determined by dividing the Discounted Value by the Total Value of each alternative system.

Conclusion

The Tactical system has the highest Total Value (61.75), the highest Discounted Value (50.85), and the highest Overall Confidence (82.3 percent). The National System scored last in all three values. Therefore the system which can best satisfy the warfighters needs is the tactical ISR satellite system.

Cost

A detailed cost analysis is left for another classified study. Further, costs associated with the equipment discussed in this study are variable due to the level of technology and future production costs. Therefore, realistically pricing the total systems is difficult given the complexity and uncertainties of technology advancements and improvements. Yet a general appreciation of the relationship between the alternative systems in terms of cost is desirable. Additionally the cost of an additional system will be more expensive than the current type of system. An ISR space-based system dedicated to the warfighters will not replace the current type of national system, and there fore is an additional expense, above and beyond current systems.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

Thesis Question

The primary question this thesis seeks to answer is have recent developments made the cost effectiveness and merits of the small, lightweight tactical ISR satellite system versus the current national systems argument more compelling, and if so, what implications will it have on the future of ISR for the warfighters? This study also seeks to answer the following subordinate questions:

1. Are the tactical ISR satellites projected to be less expensive relative to the systems of today?

2. Would the tactical ISR satellites be significantly more beneficial to the warfighters? Building systems that more directly support the tactical commander is commendable. However, if the systems are not a significant improvement, would the cost be worth the investment?

3. Is a new dedicated system needed by the warfighter?

Conclusion

Recent developments and anticipated improvements in the space industry and DoD have made the merits of small, lightweight tactical ISR satellite systems more compelling. These evolutionary developments and proposals include improved design and construction procedures, use of off the shelf technology, reduced launch costs, and LOD capabilities. In addition to these cost savings, there have been and likely will continue to be significant improvements in technology that will enable systems to be reduced in size while increasing capability. The combination of increased capabilities and the potential for reduced costs coupled with the warfighters dynamic world-wide missions, increased lethality of weapons systems, and dependence on improved battlefield awareness dictates that the warfighter have a dedicated space based tactical ISR system.

The proposed addition of tactical ISR satellite programs is more expensive than the current national satellite systems in use. This is in a large part because of a basic assumption that the national systems that support the national policy makers and NCA will have to be maintained and even improved. This national system is the baseline, and any other warfighter-dedicated systems would not be a replacement system. They would function as a complimentary system that more directly supports the warfighter. Thus, the addition of a dedicated space based ISR system for the warfighter would be more expensive than current systems, although slight reductions to some of the national systems could enable the addition of tactical ISR satellite systems without significant increases in overall costs. The result is in significantly improved complimentary systems. National systems provide one part of the picture, and the tactical systems provide another. When the warfighter leverages these systems, a synergistic effect enables him to achieve improved information dominance.

A tactical space-based ISR system would significantly improve support to the warfighters. A basic tenant of all of the proposed systems is that they have the capability to rapidly revisit areas of interest. This gives the warfighter a significant improvement over current systems. Additionally, all of the proposals give improved control over the system and direct tasking of the asset as well as improved response time.

A dedicated system is needed for the warfighter. The increased need for NRT integration of information into ever increasingly fast paced systems that will decisively engage and destroy targets in an asymmetric battlefield, demands that the system in support of the nations strategic objectives be as fast and responsive, as technically possible, to meet the warfighters requirements.

In summary, the alternative tactical space based ISR systems have a wide range of capabilities that are reflected in a broad expanse of costs. If the current projections for the tactical systems are taken to be the baseline in comparing costs and capabilities, national systems will cost significantly more than the baseline system of tactical satellites. If it is accepted that the national systems will have to be the baseline for future support as a minimum to the NCA, policy makers, and the IC, then any dedicated support for the warfighter would be an additional system and therefore an additional expense. Given the imperatives for information dominance and needs of the warfighter, the system or systems of the future must provide both the warfighter and the national policy makers with timely and accurate information that can be used to better achieve the national strategic goals.

Given the apparent conflicting goals of reducing spending while improving our ability to leverage our technological preeminence to better support the concept of information dominance, there will have to be some fundamental changes to the way the space based ISR systems are designed, constructed, and employed. As reliance on ISR satellite systems increases, the impact of the sudden loss becomes more traumatic and therefore our vulnerability to attack is more dangerous. One of the DoD's most important challenges will be to advance ISR systems to better support the warfighter while balancing the requirements to reduce costs and realize some of the mythical cold war victory dividends.

The difference between ISR space systems that the national and strategic community is proposing to develop and those systems that are projected for tactical use may be closer together than previously thought. They may be able to perform the same mission using one system to accomplish both objectives. Additionally, the differences and improvements in new systems should be researched and identified.
There may be procedural or technical methods to provide improved support to both customers at the same time with the same system. Ultimately, the goals for both levels of ISR have similarities that are common and linked. It is conceivable that as the United States moves into the 21st century, the line between the two levels will become even less defined, enabling single systems to meet the needs of both users.

Whatever direction global change ultimately takes, it will affect the view and conduct of both joint and multinational operations well into the 21st century. How the United States responds to dynamic changes of potential adversaries, technological advances and their implications, and the emerging importance of information superiority will dramatically impact how well the armed forces can perform its duties in the next millennium.

The United States' space-based capabilities are a national advantage.[1]
The national policymakers must review and revise national space policy to ensure that DoD and the IC are guided to plan and implement appropriately sized and dedicated missions. The focus on the policy should be in achieving the synergistic fusion between national and warfighter needs at the best balance of cost and risk.[2]

One of the most important challenges is to advance small spacecraft performance and reduce mission cost by incorporating advanced technology. National space objectives increasingly rely on successful small missions, which, in turn, rely more heavily on higher-performance systems and components. This is especially true given the larger complex systems that were destroyed during launches in August and October 1998. Effective means of planning and implementing an aggressive technology program is therefore, essential.

The ability of the United States warfighters to see the battlefield is essential to the successful pursuance and execution of United States military strategy. The ever increasing capabilities of new systems, both governmentally and commercially sponsored, and significant cost reductions projected over the next ten years suggest that new more capable space based ISR systems that directly support the warfighter are advisable. The CINC and JTF Commanders' ability to fight and win will depend on their ability to see the battlefield and enemy before the enemy can see them.

Recommendation for Follow-on Research

While researching this topic, it became obvious that the complexity of the systems and demands for cost savings are complicated. This will be a fundamental crossroads for the United States national security strategy and the military for the next 20 years. How can the American military forces continue its position of world leader without maintaining or improving its preeminence in space-based information systems? This must include determining which of the many proposed ISR satellite systems would best provide the warfighter with dedicated support

How to better leverage current and proposed national systems must be investigated to better support the warfighter. Although this system would not be dedicated solely to warfighter support, an examination of how to better manage future systems so that both missions are supported with a single system is beneficial. The advantages are reduced cost and a better marriage of national and tactical goals.

A final area for additional research is to examine the possibility that as technology advances, revolutionary systems that may be proposed could reduce the importance of space based systems. An example of these systems would be micro-UAVs, improved manned flight systems and other technologies that enable ISR to be accomplished with significantly less expensive systems. These systems could provide the warfighter with dedicated support while relying on national space based systems for only specific portions of the ISR picture of the battlefield.

It is also important to note that, given the end of the cold war, the perception is that the threat has been extinguished. This may very well divert some of the momentum necessary to maintain our preeminence in space. Additionally, further cost restrictions will likely compel the DoD and the IC to further limit future spending, beyond the level currently anticipated.

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[1]U.S. Department of Defense. Office of the Undersecretary of Defense (Acquisition and Technology). Deputy Undersecretary of Defense (Space). "Department of Defense Space Program: Executive Overview for FY 1999-2004." Washington, D. C., Office of the Under Secretary of Defense (Acquisition and Technology) (OUSD(A&T)) Deputy Under Secretary of Defense (Space) (DUSD(S)) February 1998, 5. NTIS. ADA3278546XSP.

[2]Liam Sarsfield. *The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Science,* (Rand Corporation, Santa Monica, CA 1999), 21.

GLOSSARY

Asymmetric Warfare. The practice of using unconventional warfare against a technically superior adversary, technological prowess being strength, it's also a vulnerability. If an opponent, for example, controls or influences our means of producing, processing, manipulating, and understanding information, they can either control or influence the outcome of competitive endeavors.

Broad Area Search (imagery). Use of large-scale imagery to locate or find an area of interest or target, can be either mobile or fixed.

Bus. Everything on a satellite except the payload(s). The bus includes the structural frame, power, attitude control, thermal management systems, tracking, telemetry and control subsystems. The bus supports the payload, but the payload performs the mission of the satellite.

Constellation. A system of like satellites. Constellations are usually designed to provide increased coverage and redundancy for essential mission functions.

Effectiveness. The extent to which the goals of the system are attained, or the degree to which a system can be expected to achieve a specific set of mission requirements.

Fatsat. Lower cost satellites that are higher in weight.

Foot Print. The area on the ground along the ground track that the system can sense.

Future Imagery Architecture (FIA). The NRO sponsored program for researching and reviewing future imaging systems that will address the anticipated needs of the intelligence community

Geo-synchronous Orbit (GEO). A Satellite that has a period of one day and orbits the equator. To a ground-based observer, the satellite appears to remain in the same fixed location in the sky.

Ground Sampling Distance (GSD). The distance at which objects can be distinguished as being separate.

Ground Track. The path along the surface of the earth that traces the path of the satellite directly overhead.

Inclination. The angle of an orbit above the equator (0-180) measured from the point where the satellite crosses the equator to the northern hemisphere.

Information Dominance. Providing essential information to friendly forces, denying it to the enemy, and exploiting it to nullify or destroy the enemy's ability to control his forces, particularly through the use of and control of space.

Launch on Demand (LOD). The launch of a satellite into orbit in response to an unscheduled event or developing situation. Includes all events from time of launch call until on orbit provision of first useful service.

Launch on Schedule. Launch of a satellite at a predetermined time based on a projected requirement.

Low Earth Orbit (LEO). A satellite rapidly orbiting the Earth at a low altitude (approximately 200 – 1200 km) is said to be LEO. Satellite imagery comes almost exclusively from satellites in LEO orbits.

Multispectral. A means of subdividing the light spectrum into smaller bandwidths. Adding or subtracting these subdivisions can be useful in terrain or target analysis.

Payload. The portion of a satellite that performs the satellite's primary mission. A payload must be supported by a bus. There can be multiple payloads on a bus, thus giving a satellite a multipurpose role.

Period The time that it takes a satellite to make one complete revolution through its orbit. The period can be as low as 90 minutes for LEO orbits or up to 24 hours for a typical GEO orbit.

Rapid Re-visit. The ability to quickly (with in minutes) re-image a target. Normally this is done because of something of concern imaged on the first image, and normally is transitory in nature, for example a column of armored vehicles moving into offensive positions along a border.

Reconnaissance. "A mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or potential enemy."[1] The primary difference between the two terms is the target of the focus being enemy or not and the regularity of the focus.

Revisit. The ability of a sensor to return to similar position or same area.

Satellite. An object that is in orbit around another more dense object. For this thesis satellite will refer to primarily those objects that are man made and unmanned in orbit around the earth.

Small Satellite. Also known as Lightsat, and Cheapsat. Those satellites with a dry mass (weight of the satellite with out fuel) of less than approximately 500 kg.

Space Reconnaissance. Observation of the earth's surface from space using means of photo-optical, electro-optical, microwave, and multispectral imaging.

Space system. Will generally refer to all of the elements required to build, launch, fly (orbital platform), sensors, and the support infrastructure necessary on the ground to control and exploit the sensors.

Spatial Resolution. The smallest distance between two objects at which the objects appear to be separate and distinct.

Surge/Augment. Deploy additional satellites to supplement baseline capabilities during crisis.

Surveillance. "The systematic observation of aerospace, surface or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means."[2] It is "systematic" that is the difference for surveillance, it requires periodic or aperiodic observations of the target.

Tactical commander and warfighter. Will be used synonymously and generally used to refer to the CINC, JTF or below military commander in the theater, branch of service is not relevant.

Tactical satellite. Will refer to those satellites whose primary purpose is to provide direct support either real-time or near real-time, to the commanders in the field, either the CINC or the Joint Task Force commander. Tactical satellites may have dual national and tactical missions, however the emphasis will be on timely support to the war fighters without stove pipes. This would ensure priority dedicated direct support to the war fighter.

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[1]Joint Pub 1-02, Department of Defense Dictionary of Military and Associated Terms, 1 December 1989, 304.

[2]Joint Pub 1-02, Department of Defense Dictionary of Military and Associated Terms, 1 December 1989, 355-56.

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