RESPONSIVE SPACE SITUATION AWARENESS IN 2020

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Abstract

The U.S. strategy to assure freedom of access in space hinges on Space Situation Awareness (SSA): the ability to find and track space objects and determine their capability and intent. As a result, AFSPC is investing much to overhaul the aging sensors, network the sensors to enable data sharing and dissemination timeliness, and improve the tactics, techniques, and procedures required to integrate space surveillance into the command and control operations at the Joint Space Operations Center. Regardless, AFSPC is projecting a shortfall in deep space characterization and SSA responsiveness at the end of the mid-term planning cycle in 2020.

The goal of this research paper is to recommend a few strategy refinements and a key technology investment necessary to erase these shortfalls. The recommended strategy refinements include: seeking out more contributing sensors, establishing a layered network to free up dedicated sensors to monitor high interest objects and respond to events, using all means to erase the "lost" object list, and switching some SSA missions from persistent to routine for the sake of reducing cost and complexity. Though the added sensors and planned net centricity greatly improve coverage and shared situation awareness, the complexity of the network in 2020 and timeliness required to respond to tactical events suggest the need for shared division of labor between humans and machines. Humans must transform from looking at the network as a data provider and instead look at the network as a teammate capable of sharing in the decision-making. This paper recommends investment in artificial cognition technology and outlines the training program required to transform the network from the new kid on the block to the seasoned grey beard capable of sharing cognition in some instances and taking over cognition and directing responsive operations when complexity and timelines necessitate it.

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Chapter 1: Introduction

The U.S. military, intelligence, civil, and commercial sectors are heavily reliant on space. In fact, space systems have transformed the military's ability to fight and win wars by delivering precision navigation for surgical attack, secure communication linking command and control (C2) nodes and enabling blue force tracking, missile warning, weather services, and intelligence, surveillance and reconnaissance (ISR). The civil and commercial markets have benefited from GPS-enabled navigation, wireless communication, satellite television and radio, and commercial ISR ventures such as Google Maps. The Industrial Technology Research Institute predicts that GPS business revenues alone will grow to $21.5 billion in 2008.[1] According to the U.S. National Space Policy, the U.S. "national security is critically dependent on space capabilities, and this dependence will grow."[2] Many, including our enemies, view this critical dependence on space as a critical vulnerability. To ensure freedom of action in space, General Chilton (commander, AFSPC) and Major General Shelton (commander, 14th AF, and STRATCOM's JF-CC Space) have made space situation awareness (SSA) their number one priority.[3] After all, defense and response are not enabled without a network of sensors to detect, track, and disseminate a shared situation awareness. The goal of this paper is to show that despite much investment in the near and mid-term, a critical shortfall of SSA in 2020 will continue to be responsiveness unless the Air Force invests now in artificial cognition technology for autonomous operations.

1.1 Space Situation Awareness Background

The definition of SSA has evolved to mean much more than space surveillance given the array of spacecraft and threats projected in future operations. In the past, the space surveillance network (SSN) primarily conducted routine space catalog maintenance to support collision avoidance. The mission of the 1st Space Control Squadron required "detecting, identifying, and tracking more than 8,500 objects in space, some as small as a few centimeters in diameter."[4] A less publicized fact is that there are 11,001 known objects, leaving 2,625 objects not cataloged, including 38 satellites lost in near earth orbits and 131 satellites lost in deep space orbits.[5] Additionally, the proliferation of small satellites is stressing the sensitivity and resolution of the existing sensors. "Since 1991, about 10 nations have launched 373 small satellites into orbit, each weighing less than 1000 lbs."[6] Matters get worse with time as the number of small satellites orbited per launch increases with inventions such as the ESPA ring and miniaturization efforts ongoing at universities such as Surrey reduce the size of spacecraft for niche missions to the nano-satellite class (<10 kg, 1m^3). [7] Further, the threat of various ground and orbital attack scenarios continues to increase, including anti-satellites (ASATs), high altitude nuclear bursts, ground-based lasers, and satellites with secondary intent.[8] To keep up with these trends, General Chilton believes SSA requires much more than surveillance, it requires the capability to "identify what's up there, understand its mission and, ultimately, determine its intent."[9]

The following scenario, highlighted recently in much of the media coverage of the Chinese ASAT tests,[10] shows the huge challenges faced by SSA. If an ASAT launches today without warning against an intelligence asset, a Defense Satellite Program (DSP) spacecraft detects the launch, provides missile warning, and Missile Defense Agency (MDA) assets track it. This is nearly autonomous and controlled primarily within a single C2 node (the Joint National Intelligence Center, JNIC).[11] The breakdown comes in the lack of connectivity between the various ground stations and C2 nodes of the USAF, MDA, and the intelligence community (IC). In all likelihood, the ASAT destroys the intelligence asset long gone before the ground station receives an alert email or phone call. According to General Chilton, "the key element is time. It takes us six months to figure out the capability of a [newly launched space platform]. Our vision is, we'll know in one rev [orbit]."[12] Further, the amount of coordination required and the short timelines for these events demonstrate the need to collaborate to create a single space picture and create a common C2 network to synergize the array of space assets for the greater defense of all. According to the Counterspace Mission Area Plan:

> SSA encompasses traditional space surveillance (satellite/debris positional data, maneuvers, changes in space order of battle [SOB], etc.), more detailed reconnaissance of specific space assets (mission identification, capabilities, vulnerabilities, etc.) and analysis of the space environment and its effects (solar storms, meteor showers, etc.). It also includes the use of traditional intelligence sources to provide insight into adversary space operations and the fusion of all data and information into actionable knowledge that can be used by the warfighter or decision maker… [It] involves the collection, processing, fusion and assessment of data and information from many different sources and disseminates information to decision makers and various users.[13]

SSA consists of four sub-mission areas: surveillance and reconnaissance (S&R), environmental monitoring (EM), intelligence, and C2; each with their own significant hurdles in the near term. Key challenges in S&R include finding 100 percent of the catalogue (at least the satellites) and providing the persistence, accuracy, and responsiveness required to characterize high interest spacecraft and tactical events. Providing persistent EM coverage and integrating with S&R and intelligence data for anomaly resolution will be even harder in the near and mid term as the number of dedicated sensors decreases.[14] Intelligence refers to the use of traditional intelligence sources to provide insight into satellite characteristics, capabilities, users and networks, ground operations, and intent as well as any information pertaining to ground or space based threats. Providing timely and actionable intelligence and integrating across multiple intelligence sources and the rest of the SSA sensors (e.g. S&R, EM) continues to be a significant hurdle. Finally, C2 contains perhaps the greatest challenge of collecting and fusing the information, creating a single integrated space picture, and disseminating the information in time to enable a defense or appropriate response.

Table 2.1 (on page 5) displays a consolidated list of the SSA shortfalls described above and Figure 1.1 below displays the vision of SSA – clearly much more than catalog maintenance.

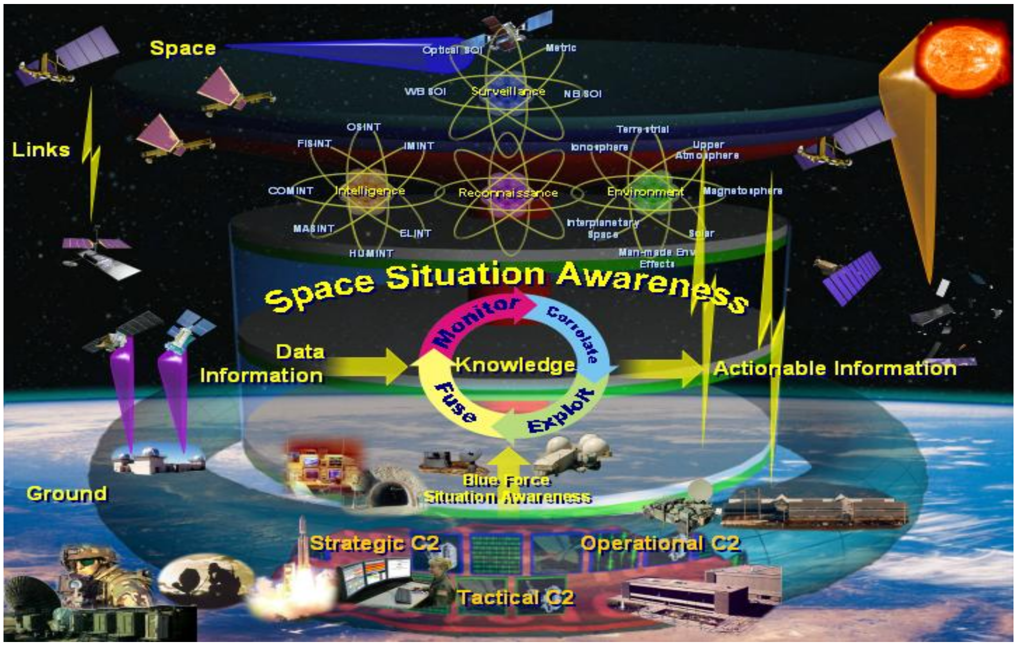


Figure 1.1 Space Situation Awareness Operational View

1.2 Overview of Remaining Chapters

The goal of this research paper is to highlight the single greatest capability shortfall that will remain unchecked by AFRL, AFSPC, and DARPA technology investments at the end of the mid-term planning window: responsiveness. To accomplish this, Chapter 2 highlights the current SSA capability shortfalls and lists the planned material, non-material, and strategy solutions that can erase all of the shortfalls except responsiveness by 2020. Next, Chapter 3 unveils the primary reason that responsiveness will continue to plague the SSA network in 2020: the current net-centric warfare insistence on human cognition and man-in-the-loop. To transform the responsiveness of the SSA network, Chapter 4 describes the technology investments required in the field of artificial cognitive (or autonomous) networks to enable responsive SSA. Finally, Chapter 5 summarizes the key strategy recommendations and lists the next steps for artificial technology and space situation awareness beyond 2020.

Chapter 2: Near/Mid-Term SSA Solutions

This chapter forecasts the SSA shortfalls at the end of AFSPC's near and mid term planning horizon, recommends various material and strategy solutions, and predicts one critical shortfall remaining in 2020: responsiveness.

2.1 SSA Challenges

Table 2.1 is a consolidated list of the current and projected SSA challenges according to various AFSPC documents. Near earth (NE) refers to low-earth orbits (LEO), and deep space (DS) refers to mid-earth orbits (MEO) or geosynchronous orbits (GEO).

Sub-mission area	Shortfall
S&R	Persistent/Responsive Surveillance: NE/DS timely find, fix, track adversary and non-aligned tactical space events
S&R	Persistent/Responsive Reconnaissance: NE/DS timely characterization of adversary and non-aligned tactical space events - space object identification (SOI), signals, imagery
S&R	Small Sat S&R: NE/DS high capacity, wide area search for small objects and ability to characterize their sizes and distributions
EM	Fusion of EM sensor data for predictive space weather
Intel	Timely, actionable intelligence for predictive battlespace awareness
C2	Timely fusion and analysis of related S&R, EM, and intelligence data yielding a single integrated SSA picture
C2	Timely dissemination to entire space community (e.g. IC, MDA, NASA, Commercial, Allies) to enable response

Table 2.1 FY08 AFSPC Space Situation Awareness Shortfalls.[15]

2.2 SSA Near/Mid Term Planned Solutions

To eliminate the surveillance shortfalls, the SSN must improve the coverage, search rate, sensitivity, persistence, and accuracy to ensure it can find and track space objects with enough accuracy and persistence to detect maneuvers and events. The SSN has three classes of sensors: dedicated, collateral, and contributing. Dedicated refers to STRATCOM sensors with the primary mission of SSA, collateral are STRATCOM sensors with a primary mission other than SSA, and contributing are non-STRATCOM sensors that perform SSA tasks by agreement. In the next ten years, the U.S. will replace all dedicated sensors with much more capable sensors. Space-Based Space Surveillance (SBSS) improves NE/DS find, fix, track coverage, timeliness and accuracy at LEO and GEO with a four-satellite constellation beginning in 2012. The Space Fence and two X-band sites improve LEO find, fix, track coverage and accuracy in 2014 and 2018, respectively. DARPA's Space Surveillance telescope (SST) replaces GEODDS and improves DS search in 2015. To increase coverage and persistence the SSN will build an additional SST in Australia and GEODSS Regional Augmentation Telescopes (GReATs) in tandem to the SSTs and far enough away to reduce the likelihood of weather obscuration of both sensors.[16] In addition to the dedicated sensor upgrades, various MDA collateral sensors come on line in the near term, such as the Space Tracking and Surveillance System (STSS) and Sea-Based X-Band, and several technology programs within DARPA and AFRL will upgrade Haystack and Maui Space Surveillance System (MSSS) to perform NE and DS surveillance (e.g HUSIR,[17] Raven,[18] PanSTARRS).[19] The cost of these sensor upgrades limit the number of sensors AFSPC can purchase and as a result, the network will continue to have difficulty finding small objects at GEO and fall short of the required responsiveness due in large part to a shortfall in persistent coverage enabled by more sensors.

With the surveillance architecture in place, the next step is to characterize each object via reconnaissance and intelligence sources to identify space objects and determine capability and intent. The dedicated X-Band and S-band sensors improve NE characterization coverage and sensitivity, while various MDA collateral sensors will continue to support NE missions as well. While SST is a significant improvement over GEODDS in the area of search, limited resolution will limit its characterization effectiveness at DS. In fact, AFSPC is forecasting a GEO imaging shortfall with no current planned solutions.[20] DARPA is also investing much to improve the NE and DS capability of contributing sensors, such as Haystack and Starfire Optical Range (SOR), to image and characterize spacecraft returns, via the Deepview and Longview programs, respectively.[21] In addition, AFSPC is requesting support from the intelligence community for spacecraft characterization.[22] However, past analysis suggests that while AFSPC can rely on the IC for "most intelligence to supplement current AFSPC capability … better partnering to acquire its own electronic support assets" is required.[23] The bottom line remains that sensor upgrades and intelligence support will overcome much of the NE characterization shortfalls, but coverage, imagery, and timeliness shortfalls will persist in DS.[24]

The EM community has many challenges but appears to be on the path to integrating environmental data into the single space picture. The current plan is to improve sensors such as CEASE to distribute sensors on future space craft, improve the data fusion algorithms and space weather models to support real time predictive EM, and integrate the data with other SSA data at the Joint Space Operations Center (JSpOC). The question facing the EM community is whether to launch dedicated satellites, such as NPOESS, or distribute sensors as secondary payloads on other systems. This is more of a funding and integration issue and less of a technology issue.

The goal of SSA intelligence is to analyze satellite or threat characteristics, capabilities, users and networks, intent and current disposition and provide timely and actionable intelligence. In the near term, the Space Intelligence Preparation of the Battlespace (SIPB) plans to "integrate DoD and National Intelligence Community space intelligence data bases for producing and sharing standard SIPB products."[25] Next, the Space Tasking, Communication, Processing, Exploitation, and Dissemination (TCPED) program plans to create object folders (red, grey, and blue), automate the data queries to fill the folders, and create the links to get the completed templates to the JSpOC for integration into the SISP. This program will prove out data mining, data fusion of multi-INT sources, and improve the timeliness of intelligence support to SSA requests by 2012. However, the process is still serial in the sense of the SSA community making requests to a second network – the IC network. These programs do not take advantage of recent multi-level security advances to integrate intelligence sensors and data into the SSA network or SISP by creating the direct links required to quickly cross-correlate intelligence data with other S&R data.[26] Events requiring responsive intelligence include maneuvers, collisions, and attack of space assets from the ground or space. A critical shortfall will continue to be the seamless integration of the intelligence network with the rest of the space network and timely or responsive intelligence (including cueing of collection assets) to support tactical space events.

The joint space C2 node, the JSpOC, is making great strides to creating an integrated SSA picture. Many of the functions outlined in this paper may occur at the SPADOC but to reduce complexity, the paper will focus attention of SSA C2 at the JSpOC. Currently, the JSpOC is creating links to the SPADOC, ground sites and C2 nodes (STRATCOM, MDA, IC), developing the tactics, techniques, and procedures (TTPs) to respond to events, and prove out the process of collecting, fusing and disseminating data to the space community and combatant commanders. The foundation of the JSpOC's C2 strategy is net centricity – the creation of a common networked repository for shared situation awareness to enable well-informed decisions. While the TPED improves connectivity and provides an operating picture for the JSpOC, AFRL is integrating TTPs via various decision support tools.[27] Next, the Extended Space Surveillance Architecture (ESSA) program is demonstrating the utility of "integrating multiple sensors/ platforms (e.g. SSN, missile defense, intelligence, etc.) in a net-centric environment to allow multiple mission areas to discover and use data."[28] Each sensor records the output data (e.g. metric data, SOI data, imagery) to a sidecar and publishes it to a network shared by all the sensors, C2 nodes and the JSpOC. Figure 2.1 displays a schematic of the resulting SSA network. While developing the links, TTPs, decision support tools, and net-centricity are necessary first steps, much work is required to link and sidecar collateral, contributing, EM, and even intelligence sensors for integration into the single picture, automate the data mining and data fusion for timely routine support, and enable responsive operations.

Appendix A summarizes the planned SSN roadmap and displays the resulting sensor locations in 2020. Table 2.2 summarizes the remaining SSA technology shortfalls in 2020.

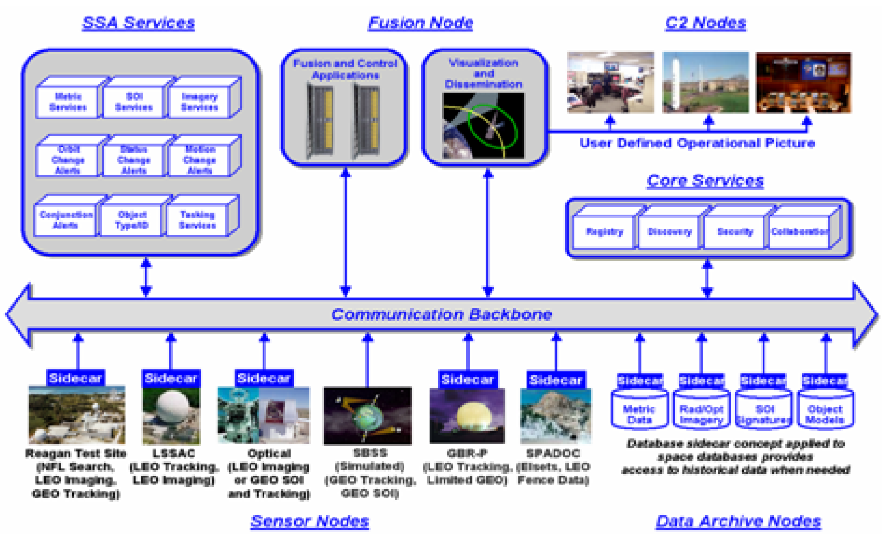


Figure 2.1. ESSA ACTD SSA Sidecars Schematic.[29]

2007 Shortfalls	Planned Programs & Aligned Technology	2020 Planned Tech Shortfalls
Persistent/Responsive Surveillance	DR: SBSS, SST, GReAT, Raven, PanStaRRS NB: S-Band Fence, X-Band	Responsive Ops
Persistent/Responsive Characterization	NB: Coll/Contr Sensors (STSS, MSSS), HUSIR DR: DeepView, LongView, SST, SOR	Image GEO Responsive Ops
Small Sat S&R	NB: S-Band Fence, X-Band DR: SST, SBSS	Find & Image GEO Responsive Ops
EM sensor fusion for predictive space weather	SEEFS, CEASE	Non Tech Issue: Need More Sensors
Timely, actionable intel	SIPS, TCPED Data Mining, Data Fusion	Non Tech Issue: Seamless Integration
Timely Fusion and analysis for SISP	TPED, ESSA, SSA Testbed	Responsive Ops
Joint interoperability and timely dissemination	SISP	Non Tech Issue: Connectivity of C2 nodes

Table 2.2. Planned Shortfalls in 2020.[30]

2.3 Near/Mid Term Strategy & Unplanned Technology Solutions

In addition to the planned SSA programs, AFSPC can further reduce the SSA shortfalls by 2020 by refining the SSA strategy to take advantage of mission partners and unaligned technology developed for other mission areas. The current SSA strategy is to provide timeliness via persistent S&R coverage of space objects with highly capable dedicated sensors. The cost of these sensors limits the number of sensors the U.S. can afford to a number less than what is required to provide the persistent coverage and responsiveness. Five recommended refinements to the SSA strategy are: find everything, leverage more sensors for a layered SSA approach, replace "persistent" with "routine" when possible, create two operational modes (routine and autonomous), and network all supporting sensors and C2 nodes.

SSA is meaningless if the SSN is not tracking everything on orbit – at least the satellites. In 1998, the launch of Space-Based Visible (SBV) reduced the "number of lost objects in GEO orbit by over a factor of two."[31] This shows that while the SSN is great at catalog maintenance, it is deficient in finding lost and small objects. The challenge is getting the initial vector. To do this, the U.S. should offer incentives to the amateur, academic, commercial, and allied communities to find lost spacecraft and newly orbited objects from foreign launches. One option is for AFSPC to offer cash awards as the asteroid community proposed in an act of Congress to leverage amateur astronomers to find asteroids for $3000 per object found.[32] A second option rewards contributors with reciprocal access to the unclassified SSA data or two line element sets either via direct connectivity or via a website similar to the AFSPC implemented Space Track site that is currently restricting access to registered users.[33] Alternatively, lost assets can be found by routine sweeps of the GEO belt via residual operations of DARPA or AFRL platforms (e.g. XSS-11) or by drifting satellites, nearing end of life, of limited surveillance capability (DoD or leased commercial assets). The goal is to reduce and possibly eliminate the "lost" catalog.

Next, AFSPC must increase the number of collateral and contributing sensors and adopt a layered SSA approach. In 2003, collateral sensors (mostly MDA radars), performed 70.6 percent of the NE SSA search and characterization.[34] This proves that it is possible to offload much of the routine catalog maintenance to collateral sensors. However, the long-term strategy focuses entirely on dedicated sensors, as shown in Figure 2.1, which contains zero additional planned contributing or collateral sensors than what exists by current agreement in 2007. The SSN must analyze all MDA, intelligence, civil/academic, research, commercial sites, orbiting assets, and even test assets for potential utility as AFSPC once did for SBV – a test asset that currently contributes 23.9 percent of the DS metric track missions.[35] In the past, AFSPC has denied the request of some sensors to support the network because the sensor did not satisfy the most stressing characterization or search requirements. Examples include STSS, Sea-Based X-Band, and NFIRE.[36] The goal of these sensors should not be to replace the dedicated sensors, but rather to plug gaps in coverage and offload many of the routine catalog functions, such as tracking large bright objects. Use these sensors to perform most of the unclassified or collateral missions to free up the dedicated sensors to perform S&R on high interest objects and be available to respond to events. In the future, all sensors that provide niche surveillance, SOI, or reconnaissance data must be "sidecarred" and added to the network.

Incentives to join and contribute to the network vary for each mission partner. For MDA and the IC, networking the sensors not only enables SSA to leverage them, it enables them to leverage the SSA for the cross-cueing missions likely to be required in the future between the various mission areas. The ASAT example in Chapter 1 is a perfect example of the synergy required between the three networks to enable a timely defense. Next, the civil, commercial, and allied sensor owners should know that "if you contribute you gain access to the SSA network's data." The SSN should seek agreements with universities and allies around the world, especially Australia, Africa, and South America where coverage is limited. Appendix B lists the array of highly capable large aperture telescopes under development around the world. Alternatively, the SSN could lease sensors for niche missions as recently proposed by SMC as a space version of the civil reserve air fleet (Space CRAF).[37] Such ideas are not only limited to ground sensors. The SSN should look to improve DS S&R coverage by seeking out contributing space sensors and adding payloads (e.g. web-cameras, small telescopes, CEASE, etc.) to planned space systems as SMDC recently did to Intelsat.[38] Again, to be effective, each sensor must link to the SSA network via sidecar, be available for SSA tasking, and publish real-time data to the net.

Soliciting SSA contributions from others is such a high payoff area that AFSPC should establish an office in TENCAP. This office should perform the missions above to search for contributing sensors, platforms to leverage with future SSA payloads, or systems with residual operations capability. Start with a budget of $10M/year and assess the program annually.[39]

The next strategy upgrade entails accepting that not everything needs to be persistent or timely and not everyone is a threat. Persistent surveillance is essential to enable timely event detection and anomaly resolution. However, the SSN must obtain exquisite characterization via reconnaissance and intelligence collection to determine capability and intent for objects of high interest or suspicion before an event takes place. Like air attack and cruise missile defense, space attack timelines leave little time to gain further information or intelligence about a potential threat during the attack. Thus, sweeps to obtain exquisite characterization for high interest objects, like the sweeps needed to find lost GEO objects, can become routine or preplanned missions. Finally, to plug the high interest characterization and GEO imagery shortfalls AFSPC should discard the "Cadillac" mindset and avoid building the ultra-capable systems with lifetimes of 5 or more years at a cost of approximately $500M each, such as the previous ODSI program.[40] Instead, AFSPC should utilize AFRL's miniaturization and bus technologies, take advantage of AFRL's XSS-11 and ANGELS micro-sat programs, and launch smaller, less capable systems in GEO drift orbits.[41] After all, the entire XSS-11 program cost was "$82M, including launch, operations, the spacecraft itself, and all the ground control hardware."[42] Appendix C shows the myriad of upcoming Atlas V launches with available weight margin.[43] Traditionally these rideshares have been used primarily by the Space Test Program of SMC Det 12 to launch R&D satellites, but can just as easily be set aside for routine SSA search and characterize missions.

The next refinement to the SSA strategy entails creating two operating modes: routine and autonomous. Routine mode primarily consists of the routine catalog maintenance, space weather monitoring, high interest object reconnaissance, intelligence collection, and most importantly change or event detection. Contributing and collateral sensors conduct as much of the routine mode as possible. Upon detecting an event, the JSpOC operations switch to autonomous operations and computers search for pertinent historical data, cue dedicated sensors to collect on the event, fuse the data, and analyze with decision support tools to characterize the event and make recommendations to the operator. Not only is this level of artificial intelligence currently unachievable, it violates the man-in-the-loop precept of military command and control.

All contributors to SSA must integrate into a single network. First, the SSN must utilize recent developments in the way of multilevel security and create a seamless integration of intelligence data into the SSA database for a single SSA picture. Second, the SSN must define the intelligence products of interest to characterize space systems and determine intent (e.g. communication wavelengths, network links and nodes, threat-specific spectral bands, etc.) with enough detail to simplify the required intelligence collection and data mining. Of course, much analysis must still go on within the IC, but automating as much of the data mining as possible frees up the analysts to make sense of the data or fill in items that require humans, such as analyzing imagery. Finally, the JSpOC should collect the intelligence products, integrate them into a single folder for a given asset (like AFRL's Satellite Information Database)[44] and combine with S&R sidecars and EM data to create a single folder with status for each space asset. As stated earlier, start with the assets of interest and populate those folders first. The goal of the second tier (the dedicated sensors) of the SSA network is to work with the EM and intelligence community to populate these folders while the first tier of SSA sensors performed the routine persistent surveillance for the sake of event detection.

2.4 Remaining Shortfalls in 2020

The above discussion summarized various planned and recommended solutions to provide persistent surveillance, integrate data from multiple communities via net centricity, populate space object folders, and create a layered SSA defense to free up dedicated assets to monitor high interest objects and respond to tactical events. The overall goal is to bring as many sensors and as much data as possible onto a network accessible to the operators and decision makers to enable data mining and fusion, analysis, decision support, and timely information dissemination. While the sensors enable coverage and persistence and the net-centricity enables data sharing and dissemination, the network C2 is still the chief limiter to enabling responsive operations. On the current path, SSA will fail to be responsive in 2020 due to insistence on having a man in the loop and a critical technology shortfall in the area of artificial cognition.

Chapter 3: Transforming SSA C2 to be Responsive

The capability to detect, monitor, and respond to tactical events such as the ASAT scenario outlined in Chapter 1 requires a SSA network that does much more than link distributed sensors to share data for a common situation awareness. It requires a level of automation that violates the current net-centric warfare (NCW) doctrine and JSpOC strategy of operations. This chapter outlines a strategy to overcome these final obstacles to responsiveness.

3.1 Net Centric Warfare Limitations

The goal of NCW is to achieve an asymmetric information advantage, via data sharing, which enables synchronization of efforts on the battlefield by ensuring the entire force is operating from a common operational picture.[45] There are three domains of NCW: physical, informational, and cognitive. The physical domain consists of the systems to be linked and the communication network sharing the data, the information domain is "where the information is created, manipulated, and shared," and the cognitive domain "is in the minds of the participants [and] the place where perceptions, awareness, [and] understanding … reside and where, as a result of sensemaking, decisions are made."[46] In the SSA arena, the physical domain consists of the contributing SSA sensors (S&R, EM, intelligence, contributing and collateral), their ground stations, links to the network, and the physical network itself, the information domain includes the sidecars, fusion algorithms, and analysis tools, and the cognitive domain resides within the minds of the JSpOC operators. The success of the network hinges on its ability to ensure information superiority and is a function of the completeness of the data, the accessibility to that data, and the timeliness of data dissemination for shared awareness. Further, current NCW theory assumes that "decision superiority results from superior information filtered through a warfighter's experience, knowledge, training, and judgment."[47] This is debatable.

Careful analysis of military decision-making theory shows that the current NCW insistence on human cognitive is its chief limitation. Though multiple sources agree, "the next technology game-changer in military operations … will be in the area of cognition,"[48,49] they focus primarily on decision support software to aid the human decision maker.[50] Due to the impact of military decisions, NCW theory assumes that "only humans command," primarily for the sake of accountability. Even the proponents of such theory concede, "For the foreseeable future, the ultimate decision maker will remain human, despite our slowness and fallibility."[51] As a result, the primary goal of NCW is shared situation awareness of the human decision makers and leaves operators asking, "What can the network do for me?" There are two shortfalls of this line of reasoning: time of command and complexity of command.

To demonstrate these shortfalls, one can trace the ASAT scenario through the OODA loop (Observe, Orient, Decide, and Act), subdivided into specific tasks and shown in Figure 3.1.

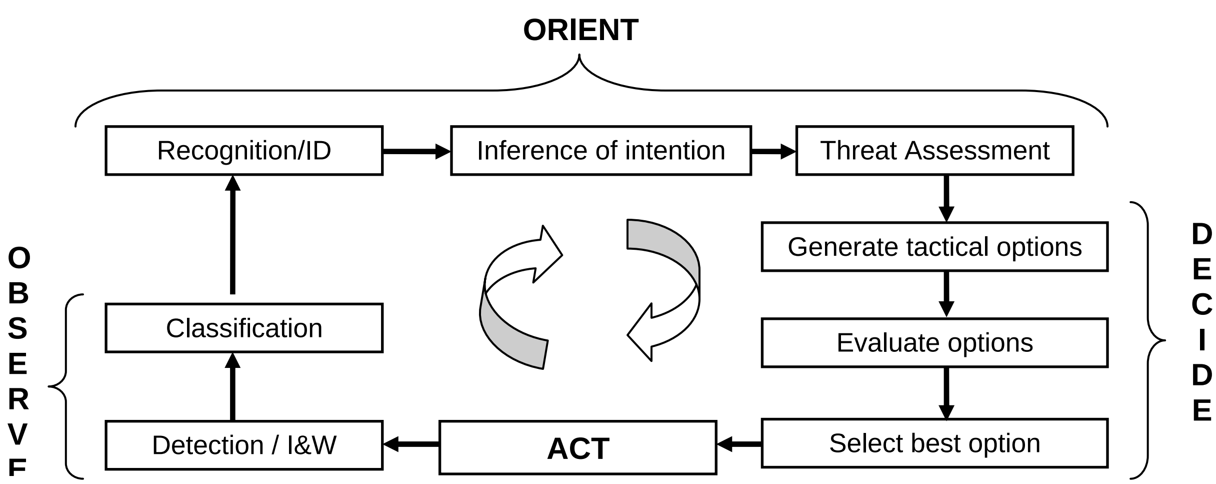


Figure 3.1. Elaborated OODA loop.[52]

The observe phase includes ISR assets detecting early indications and warning that a launch is imminent, DSP detecting the event, confirming its location, tracking the missile (handing off to SSN assets if it clears NE) and classifying the event as an ASAT. The orient phase includes fusing intelligence data (ideally archived already in the SID database) to identify the class of missile, inferring the intention and possible target(s) of the attack, and cross-referencing the susceptibility and vulnerability of blue target spacecraft. The decide phase occurs primarily within the JSpOC and entails generating options, evaluating, and selecting the best course of action. Finally, the JSpOC publishes the situation awareness and recommended action to the network and cues dedicated assets to track and characterize the event to enable countermeasures and record the attack to justify a response later.

While the timeframe associated with most of the threats, from detection to impact, ranges from seconds to minutes, any single step in the process can take a human over an hour (AT BEST). The ASAT scenario demonstrates the level of integration required of the JSpOC and MDA and IC nodes. For this discussion, assume these communities achieve the required level of synergy before 2020 and integrate their C2 structures or perhaps make the JFCC-Space the supported commander during space attacks. How much time will it take to determine the IC, MDA, and SSN assets in range to track and monitor the event, task these sensors, and receive the data to enable a response or defense? Every step that requires a human decision maker or even worse requires "coordination" with a chain of command or other organization will lead to mission failure. SSA would not be the first mission area to conclude that time-critical scenarios require automation. Cruise missile defense faces a five-minute timeline and experts believe "the limiting factor will be human decision times" only overcome with "automated decision-making aids, machine-to-machine links, automatic target identification, [and] cueing to tell me where to focus my search."[53] After all, there is not enough time to sift through data, develop courses of action, rack and stack them, and make a decision in time to respond.

Though some experts use complexity of the decision to determine ability to automate, it might be better to look at the complexity of the network. Given the vast amount of information associated with the event at hand - the various supporting assets, the historical data, the array of options, and the complexity of the given situation (orbits, velocities, sensor capabilities, etc.) – the JSpOC must determine the optimal division of labor between the machines and man. There are three classes of military decisions: simple, contingent, and complex.[54] Simple decisions are those that are obvious upon completion of the observation and identification steps of Figure 3.1. Contingent decisions require a bit more data on the intention and threat assessment, but the response is obvious upon completion of the threat assessment step. Finally, complex decisions are difficult to model, hard to predict, require much information to understand, and likely have many potential courses of action to respond. According to current theory, only simple decisions and contingent decisions are automatable. Some scenarios are so straightforward (e.g. ASAT and high altitude nuclear detonation) that the SSA decision is simple and requires cueing of assets to determine threat location to enable a response. This is clearly automatable.

On the other hand, complex scenarios require more information to assess the threat. Examples include a single event upset, a subsystem failure, interference, a laser attack on system without optical sensors, or a satellite drifting off course. According to theory, these situations are so complex that they require analysis from “grey beards” familiar with the space systems. This may suffice for after action reports, but will not meet the timeliness requirement. Further, many events require gathering more information by cueing available S&R, EM, and IC sensors, fusing the information from multiple sensors and possible multiple platforms, and comparing with historical data, to resolve anomaly from attack. While many reserve this highest level of complexity for the human decision maker, the sheer volume of information and level of fusion required make it impossible for anyone but a computer to accomplish. Thus, one could argue that simple decisions “can” be automated and complex decisions “must” be automated.

Assuming commanders agree with the timeliness and complexity arguments above, there is one remaining argument against automation: it is too hard. Common arguments against automation are that humans cannot teach computers creativity, reasoning, course of action generation, consideration of external factors and indirect consequences.[55] One could argue that we cannot always teach humans these skills and, as a result, the consistency of their decisions varies widely across different operators in identical situations. Regardless, recent advances in artificial intelligence, computer learning, and computer reasoning are the best hopes of driving the SSA network to provide the responsiveness to tactical events. As a result, the operators must "ask not what the network can do for you; ask what you can do for the network."

3.2 Responsive Net-Centricity in 2020

Job one for the SSA network is to ensure success in the physical domain. The JSpOC is the primary space C2 node and its personnel must integrate SSA data into the SISP. AFSPC must establish agreements with all collateral and contributing sensors to enable tasking. Next, the various dedicated, contributing and collateral sensors (SSN, MDA, IC, civil, commercial, etc.) must be sidecarred and linked to the network. In parallel, the ground sites and critical C2 nodes (e.g. STRATCOM, JNIC and NROC) must connect to the network. The network tasks the sensors, the sensors publish the data to the network via sidecars, and the network distributes to all across a multi-level security enabled architecture.

The next step is to create the informational domain. Net centricity ensures all nodes have equal access to the data. This domain consists of various data storage, data mining, and multi-level data fusion tasks required to perform change detection, cross-correlate events, populate object folders, and archive historical data. The network must use various decision support algorithms to present the data in the most palatable manner to avoid information overload with the operator. In addition, a data repository must be established off the primary network to archive historical data and experiment with new fusion and decision support tools.

Finally, the cognitive domain is a function of the two distinct operating modes: routine and autonomous. Routine mode consists of every day operations to maintain the catalog and ensure everything is where it should be. The collateral/contributing tier should conduct routine catalog maintenance and compare metric data to historical data for change detection. The EM sensors should provide data on the real time status of weather events for the sake or anomaly resolution. At the same time, the dedicated and IC sensors should be collecting data to track and characterize the high interest objects. The operators in the JSpOC retain cognition of the network, prioritize the tasks, develop the space tasking order (STO) for collection, and solicit various decision support algorithms to analyze the situation and respond to routine events.

When the network detects an event or anomaly it automatically takes over cognition and switches to autonomous mode. Contributing/Collateral sensors made available for tasking should continue maintaining the catalog. After all, if this first event is a feint, we do not want to lose timeliness to detect other events. Meanwhile, the network autonomously performs the multi-level fusion of recent sensor data, performs historical data comparisons, cues dedicated and IC sensors to obtain more information, and iterates until it converges on its most related description of the event or anomaly. While this iterative process is occurring, streaming status information on the pertinent object folders and relevant data passes to the JSpOC, relevant ground stations, and C2 nodes. The goal is to autonomously obtain and fuse the data required to understand the situation in time to enable a defense or response. The autonomous mode will obtain the required SSA data and the operator will retain the ability to override the network operations or augment these operations until the event or anomaly is resolved.

Chapter 4: Transforming SSA Artificial Cognition

Many technology areas must progress in parallel to create the level of artificial cognition required to achieve responsive SSA by 2020. This chapter lists the specific SSA cognitive goals, describes the technology contributions of others with similar cognitive goals, highlights the technology focus areas requiring more attention, and introduces a plan to mature these technologies to achieve the level of artificial cognition required for responsive operations.

4.1 Artificial Cognition Capabilities Required

Tracing the net-centric operations outlined in section 3.2 through the OODA loop of Figure 3.1 for two of the harder to detect threats reveals the specific capabilities required of the routine and autonomous operating modes. Consider the case of out of band communication jamming or an out of band laser attack. In the absence of dedicated in band threat warning receivers, the network must collect sensor and spacecraft telemetry data, fuse the data of multiple spacecraft along with EM and IC data, compare with historical data, detect the change (on one or more satellites), and resolve whether it was a spacecraft anomaly, weather event or an attack. Confirmation of attack triggers the autonomous mode. The network must rescan the data, compare with memory from past attacks to diagnose the attack type, and fuse the data from multiple sources to predict attack location. The network retrieves threat data while either cueing assets to collect more data or requesting information from the IC to monitor the event and determine intent (e.g. deny, degrade, destroy, or even accident). At every instant an abbreviated portion of the analyzed data, resulting pertinent information, status of network operations, and recommendations are streaming in to the operator in the JSpOC.

Thus, the computer has multiple requirements across the routine and autonomous modes. The goal of the computer during routine operations is support the operator, detect events, and train for autonomous operations. During routine operations, the computer mines data to populate object folders, archives sensor and spacecraft data, fuses and analyzes data from disparate sources (multiple spacecraft, EM, IC, MDA, etc.), compares with historical data, and uses various decision support tools and machine-human interface algorithms to refine and present the data. The computer must demonstrate reasoning to determine what data to scan and what to look for, memory and pattern recognition to search for event indicators, and logic to infer or confirm if an attack took place. Autonomous operations require all this, on a much shorter time scale, and with the added requirement of reasoning to cue dedicated assets or request data from the IC to classify the event, pattern recognition to identify the attacker, and logic to infer intention. In short, both modes require a high degree of artificial intelligence, with a potentially infinite pool of data, and desire resolution and justification within minutes.

4.2 Mission Partners Supporting Artificial Cognition

Several communities have similar capability requirements and are helping drive the artificial cognition technology. According to the Chapter 3, networks of high complexity, requiring the integration of many disparate inputs to enable decisions in extremely short timescales necessitate automation. Missions that have acknowledged the need for a cognitive network capable of a degree of autonomous operations are cruise missile defense,[56] responsive logistics,[57] Defensive Counterspace (DCS),[58] the ISR community,[59] and defensive network operations.[60] The ISR community is contributing multi-level security enabled networks, data mining, and object folders. The jamming attack listed above is a classic DCS example that has led to the development of neural networks to diagnose attack based on satellite telemetry via the Satellite-as-a-Sensor program.[61] The current program analyzes historical data and is strictly Bayesian in the sense of analyzing all satellite parameters (without prediction of the most pertinent parameters). However, according to the network operations community, it is possible to combine the Bayesian analysis with "expert" systems analysis (limiting search parameters to those known to be pertinent) to significantly reduce the false alarm rate.[62] In addition, focused logistics is driving much development in the fields of automated reasoning and decision-making.

But the number one mission area to leverage for network operations and artificial cognition is cruise missile defense. In fact, the ESSA sidecar and net centric approach came from the MDA Hercules program concept.[63] In addition, MDA spent $273M from 2003-2006 to connect the network, create the C2 architecture (C2BMC) headquartered at the JNIC, sidecar and integrate the sensors via the Cooperative Engagement Capability (CEC).[64] Specifically, MDA past investments developed the sidecar concept, open network architectures, data sharing and mining, multi-level fusion, machine-to-man interfaces, data analysis algorithms, and various decision support tools. In addition, current proposals are calling for "autonomous thinking systems."[65] While MDA is paving the way, not much investment has been specifically devoted to developing the artificial cognition of tomorrow's networks.

Specific investments in the area of artificial intelligence (AI) have been primarily focused on basic research. DARPA's Information Processing Technology Office (IPTO) has devoted nearly fifty years of funding to AI since its establishment in 1962 creating healthy AI and cognitive science programs at MIT, University of Michigan, Rensselaer, Carnegie Melon, and Stanford.[66] Two current DARPA IPTO programs, REAL and IL, provide basic research in the areas of automated learning and reasoning.[67] The current projects in academia entail creating and testing decision making architectures, often via war gaming, and appear to lack direct application in the near term.[68] Much AI investment continues in the area of modeling the human brain and nervous system for medical applications, but appears to be more relevant to multi-level fusion than artificial cognition.[69] Finally, AFRL investments in this area focus on decision support tools (e.g. WebTAS)[70] and man-machine interfaces (Master Caution Panel).[71]

The discussion above shows that while there is much going on in the area of AI and cognition, the investments are not focused. Thus, a coherent strategy outlining specific milestones for SSA artificial cognition is required to enable responsive operations in 2020.

4.3 SSA Cognition Strategy

The strategy discussion below assumes the strategy and technology improvements recommended in Chapter 2 are in place. Specifically, assume the IC, MDA, and SSA networks are integrated, all sensors contain sidecars and publish to the network, and all sensors are automatable and taskable. In short the physical domain is enabled.

The first phase of development entails preparing for routine operations and is human-driven. In this phase, the humans retain full cognition, improve their understanding of the mission area (through education, experience, and exercises), and direct the scope and goals of the computer-based data mining, fusing, and analysis. Humans use computers to perform time-intensive and numerically intensive analysis and humans utilize decision support software and human-machine interface developments to make sense of the computer analysis. In addition, the humans demonstrate the ability to share and mine data in a multilevel security environment, the ability to automate individual sensors, and the ability to cue multiple assets on a given event. In the mean time, the operators study the mission area, analyze the threats, develop TTPs, and study methods to detect attacks. The network performs change detection by looking for signals and events predicted by the human. In short, the human commands the network to provide shared situation awareness. By transitioning much of the technology implemented in C2BMC, this is technically achievable today and already under development at the JSpOC and SPADOC.[72]

The goal of the second phase is to train the computer to improve its cognitive abilities. At this point, the humans are the knowledgeable grey beards armed with rules of thumb, on-the-job experience, and a good understanding of the various moving parts. On the other hand, the computer is the new, but ingenious, kid on the block. The goal of the humans in this phase is to teach the machines the mission area to enable artificial cognition and autonomous operations.

First, a data archive and analysis node is required to store historical data, enable higher-level data analysis and fusion, and serve as a training node to train the computer and test software and algorithms before integrating into the operational network. MDA currently uses the X-LAB adjacent to the JNIC to prove out decision support and fusion algorithms and sidecar upgrades.[73] Given its enormous processing power and its proximity to a contributing sensor node (MSSS), the Maui High Performance Computing Center (MHPCC) is an optimal location for the data archive/training node. After all, the MHPCC already performs data analysis, analyzes orbits for SSA architecture assessments via the SSNAM tool, and conducts basic research with teams from the University of Hawaii. The node must employ a core team of SSA experts to establish a simulated SPADOC, integrate existing algorithms, and train the MHPCC to perform data mining, data fusion, and data correlation, and employ decision support algorithms to simulate the SPADOC operations. The multi-level data fusion algorithms should employ a mixture of Bayesian and “expert” logic. In other words, the experts must help the computer by estimating the pertinent parameters to search for to detect and characterize events. This will greatly reduce processing time in the short term and get the ball rolling.[74]

Next, the MSSS must bring the technology development to the data node by brining the basic research to the MHPCC. The goal is to establish foundational AI research programs at MHPCC to entice university, AFRL, and DARPA programs to push forward in AI while working to solve SSA automation and cognition problems. To do this, AFSPC should look to share funding with AFRL to establish two full time positions and fill the positions with AI scientists who in turn have a small research budget (approximately $500k/yr for supplies and travel). Next, the scientists need to establish the core SSA AI vision (near and far term), begin foundational AI research related to improving the multi-level fusion, learning, memory, reasoning, and decision making of the MHPCC. In addition, the scientists must solicit university professors, National Research Council (NRC) fellows, post-doctoral students, and summer researchers from the various artificial cognition schools to collaborate on SSA AI programs and possibly travel to MSSS to perform hands on research. Ideally, the core scientists or the various collaborators would craft specific basic research programs to sell to the National Science Foundation, DARPA, and AFRL to increase the flow of dollars into the SSA AI mission area.

With the data node and basic researchers in place, the humans must teach the machines to learn and reason. The goal of the cores SSA team is to provide the SSA expertise, knowledge of missions, capabilities, and TTPs to provide the scenarios to test the computer and compare the computer findings with the human or knows solutions. Historical data and events are used to provide practical experience for the computer. By using past events the basic researchers can develop the reasoning, logic and decision making algorithms. These algorithms help the network autonomously mine, fuse and correlate, refine searches, reason, recognize situations, and ultimately develop cognition of the interrelation of the various sensors, nodes, and data within the network. The network must learn the parameters and processes enabling timely convergence on a solution and archive its experiences into memory for pattern recognition. Simulated demonstrations with historic SPADOC data can be used to test the timeliness and soundness of the network's reasoning and decision-making before transitioning software to the SPADOC.

The third and final phase involves releasing cognition to the network. Cognition must transition to the network for all areas that it has demonstrated an ability to accomplish more effectively than the grey beards. In the end, it will be a team effort and the goal is not to retire the human grey beard but to share cognition between the humans and computers to optimize responsiveness. As the cognitive tools are developed, tested, refined, and ultimately proven, they should be integrated with the decision support, data mining, and data fusion tools already in the JSpOC to hand over cognition as the computer comes up to speed on specific tasks.

Autonomous mode and the precise cognitive relationship between human and network will take years to iron out and will likely change with each upgrade to the network. The best methods to test the autonomous mode are to use the various R&D and operational tests being planned annually (e.g. XSS-11, Orbital Express, NFIRE, etc.) to serve as the Red Team to practice these operations. In each exercise, the grey beards and network should conduct operations together to work out the division of labor and learn each other's strengths and weaknesses. The team must practice the handoff from routine operations to autonomous operations just as pilots practice handing over command of the aircraft (e.g. "my plane", "your plane"). Results of the exercise drive development of SPADOC TTPs and network algorithms. The goal is to give the network/human team enough practice to identify procedural shortfalls, and optimize the division of labor to maximize efficiency and timeliness. With each exercise, the humans should automate whatever the network demonstrates an ability to consistently, accurately, and quickly accomplish. To confirm the responsiveness of the network, the array of simulated attack scenarios should be red-teamed against the network to confirm the timeliness of the detect, characterize, ID, and infer intention phases of the SSA network.

Chapter 5: Next Steps

Space Situation Awareness is AFSPC's number one technology focus area in the near term. Despite this, various AFSPC, NSSO, and AFRL documents forecast capability shortfalls in 2020. This paper recommended several refinements to the SSA strategy to reduce the number of shortfalls to one: responsiveness. This chapter will summarize the key recommendations of the paper and outline future steps for artificial cognition and net centric operations.

5.1 Key Recommendations

AFSPC has few dollars remaining after the planned investments to overhaul the dedicated sensors, but projects a critical shortfall in the area of SSA responsiveness in 2020. Rather than solving all the shortfalls (e.g. DS S&R of small objects, finding the lost catalog, and persistent DS S&R) with costly technology solutions, this paper recommended various strategy refinements to leverage the low hanging fruit. Examples include rewarding civil, commercial, or allies for finding lost spacecraft, launching less-capable satellites routinely on rideshares to characterize DS high interest objects, and drifting satellites nearing end of life through the GEO belt to reduce the "lost" catalog. On the other hand, to enable responsiveness, we need more sensors, we need dedicated assets to focus their attention on high interest objects, and we need to ensure we are not one-deep in coverage in high interest areas limiting our ability to respond to multiple events. As a result, the natural recommendation is to increase the number of sensors, create a layered SSA approach, and bring all contributing space systems and sensors onto a single network (including IC and MDA assets) to enable data sharing and timely information dissemination.

With this foundation in place, the paper focused on the need to reduce man in the loop and invest in artificial cognition to automate much of the SSA functions to overcome the complexity and timelines required in 2020. Though the strategy followed the template used by

MDA in creating a data node to develop decision support tool, two things distinguish MDA from SSA. First, MDA has not fully embraced the need for artificial cognition yet and SSA does not have the amount of funding that MDA has devoted to C2BMC. The strategy of creating an AI center at a network node and populating it with AI scientists is a cost effective way of vectoring AFRL, DARPA, and universities brainpower to accelerate the artificial cognition capability.

5.2 Next Steps

This paper showed the struggle between humans and machines. Various mission areas are adopting net centric approaches and are currently building architectures to link to the GIG and share data. As a result, operators will be inundated with an unprecedented amount of data. With the exponential increase in complexity of the battlefield and the shrinking timelines for attack (e.g. cruise missiles, ASATs, network viruses), many mission areas will wrestle with the idea of automation. Though the current NCW visions suggest that decision support tools can keep humans in the loop, at some point the complexity will be too great and the timelines too short. To prepare for the complex, fast-paced future, each mission area must determine the optimal division of labor between the network and the warfighter.

Second, this paper showed that integrating the various space participants even for SSA is a coordination and C2 nightmare. We can no longer view the JFCC-Space as a supporting commander. We need a plan to integrate all of space into a single chain of command in the event of an attack so that all space participants know who is in charge and who are the supported and supporting commanders. Without this C2 structure, the simple tasks of cueing assets can degrade into coordination battles that will eliminate the responsiveness enabled by artificial cognition.

Finally, this paper focused primarily on the artificial cognition required to solve the most obvious shortfall – timely attack detection and reporting. Obvious next steps include increasing connectivity to other relevant networks, to include allies, and seeking out additional data sources that may be of utility to increase the amount of data accessible by the network. However, while this paper focused on the things we know we need the computer to do (e.g. data mine, data fuse, etc.), it did not discuss on the possible searches that the computer may initiate to seek higher levels of correlation and predictability within the network and perhaps correlations with other networks when humans are not looking.

Humans must learn to trust the network to perform autonomously. Otherwise, human cognition timelines will continue to limit network operations and the U.S. will remain vulnerable to a space pearl harbor. Artificial cognition is the technology of the future.

Appendix A: Counterspace SSA Roadmap and Geographic Location

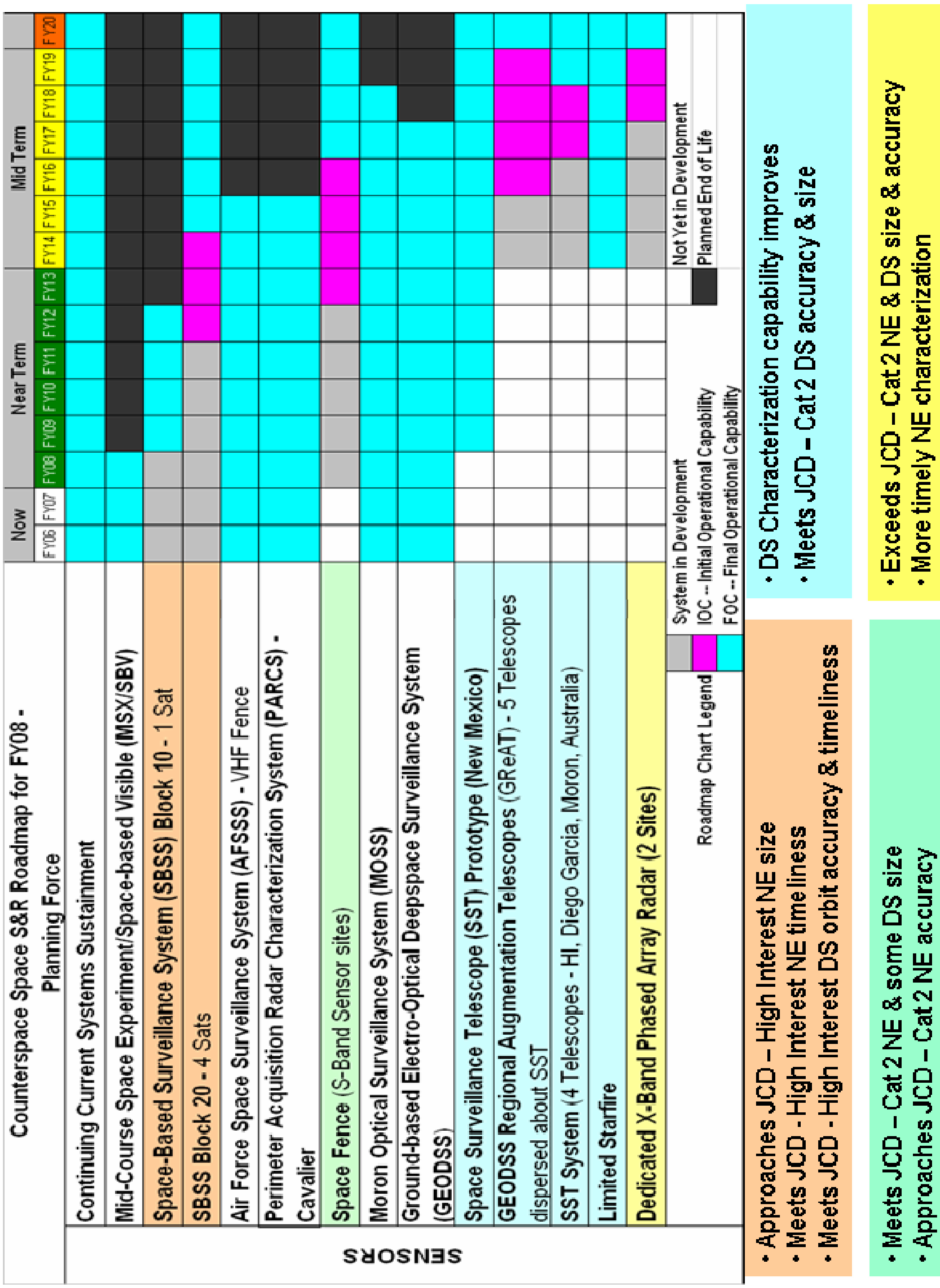


Figure A.1. AFSPC Counterspace Mission Area Plan SSN Roadmap. [75]

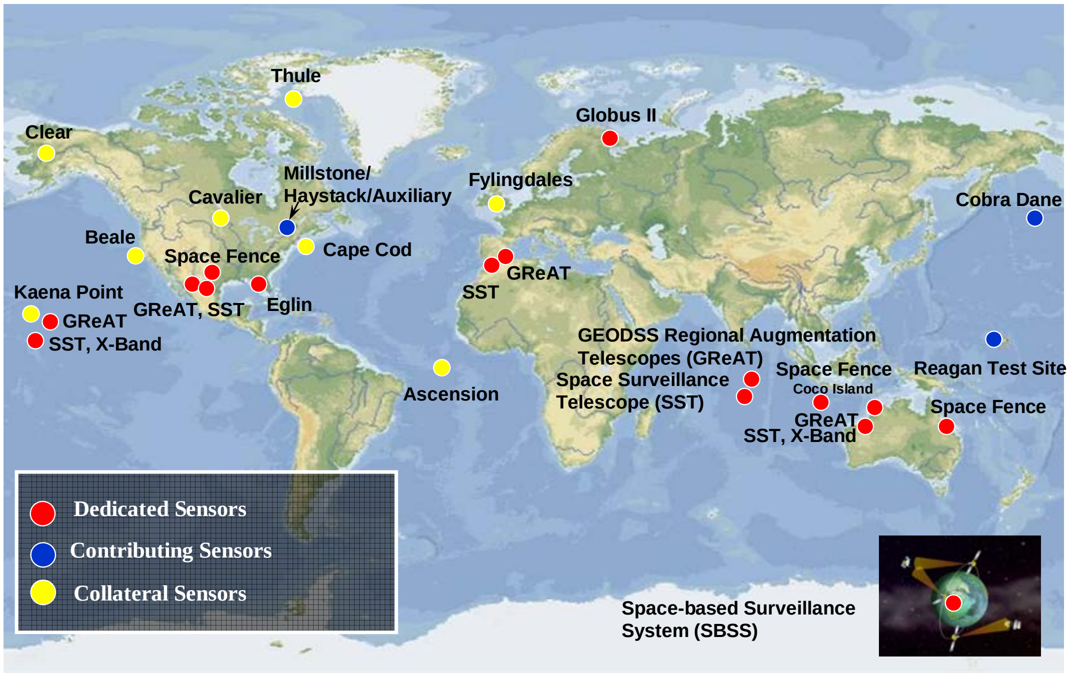


Figure A.2. Planned SSN Sensors : 2020.[76]

Appendix B : Large Optical Telescopes

From: http://astro.nineplanets.org/bigeyes.html#vlt[77]

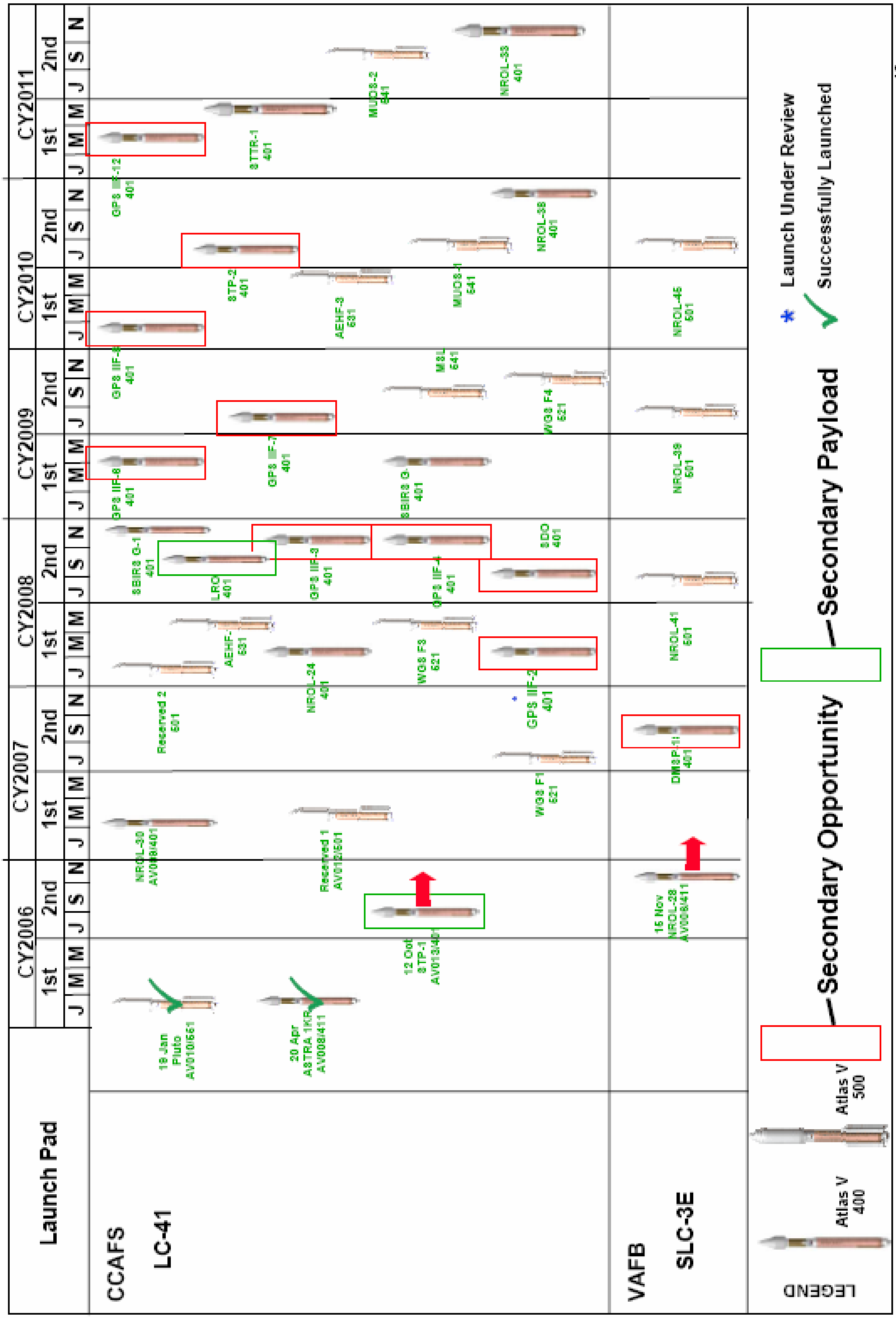
Aperture (meters)	Name	Location
10.0	Keck	Mauna Kea, Hawaii
	Keck II	
~10	SALT	South African Astronomical Observatory
9.2	Hobby-Eberly	Mt. Fowlkes, Texas
8.4	Large Binocular Telescope	Mt. Graham, Arizona
8.3	Subaru	Mauna Kea, Hawaii
8.2	Antu	Cerro Paranal, Chile
	Kueyen	
	Melipal	
	Yepun	
8.1	Gillett	Mauna Kea, Hawaii
	Gemini South	Cerro Pachon, Chile
6.5	MMT	Mt. Hopkins, Arizona
	Walter Baade	La Serena, Chile
	Landon Clay	
6.0	Bolshoi Teleskop Azimutalnyi	Nizhny Arkhyz, Russia
	LZT	British Columbia, Canada

Aperture (meters)	Name	Location
5.0	Hale	Palomar Mountain, California
4.2	William Herschel	La Palma, Canary Islands, Spain
	SOAR	Cerro Pachon, Chile
4.0	Victor Blanco	Cerro Tololo, Chile
3.9	Anglo-Australian	Coonabarabran, NSW, Australia
3.8	Mayall	Kitt Peak, Arizona
	UKIRT	Mauna Kea, Hawaii
3.7	AEOS	Maui, Hawaii
3.6	"360"	Cerro La Silla, Chile
	Canada-France-Hawaii	Mauna Kea, Hawaii
	Telescopio Nazionale Galileo	La Palma, Canary Islands, Spain
3.5	MPI-CAHA	Calar Alto, Spain
	New Technology	Cerro La Silla, Chile
	ARC	Apache Point, New Mexico
	WIYN	Kitt Peak, Arizona
	Starfire	Kirtland AFB, New Mexico

Under Construction

Aperture	Name	Location
21.4 (7x8.4)	Giant Magellan Telescope	Chile?
16.4 (4x8.2)	Very Large Telescope	Cerro Paranal, Chile
14.6 (2x10)	Keck Interferometer	Mauna Kea, Hawaii
10.4	Gran Telescopio Canarias	La Palma, Canary Islands, Spain
8	LSST	Cerro Pachon, Chile
4.2	LAMOST	Xinglong Station, China
	DCT	Happy Jack, Arizona
4	Vista	Cerro Paranal, Chile

Appendix C : Atlas V Secondary Payload Availability[78]



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