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# Evaluating Options for Civil Space Situational Awareness (SSA)

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# Evaluating Options for Civil Space Situational Awareness (SSA)

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# Executive Summary

## Key Findings Relevant to the Federal Aviation Administration, Office of Commercial Space Transportation

- Space situational awareness (SSA) and space traffic management (STM) are distinct concepts with different technical requirements and policy implications, and should be treated separately, especially when it comes to determining the extent to which they are governmental functions.
- The core civil SSA tasks—updating the high-accuracy catalog and performing conjunction assessment screenings for all operational satellites—require a relatively small number of personnel, compared to the other missions performed by the Department of Defense (DOD) Joint Space Operations Center (JSpOC). Currently, this work is done in JSpOC by about twenty people from DOD and five from NASA.
- No public data exist to prove the validity/accuracy of the existing conjunction assessment warnings provided by DOD to commercial and civil users, but some stakeholders have performed analyses not publicly available that have raised questions about rates of false positives and false negatives.
- A review of current commercial SSA providers indicates that private sector non-governmental entities are already providing SSA data, software, and services to private and governmental customers, and are on a trajectory to match, and perhaps even surpass, government capabilities for providing conjunction assessments in the near future. However, as noted above, there are no detailed public data to enable an analysis of the relative validity/accuracy of government and commercial conjunction assessments.
- The review indicates that the expected price of a civil SSA system to provide conjunction assessment and other safety-related products for civil, commercial, and international satellite operators could be in tens of millions of dollars annually. There has also been an increase in the number of private sector providers in recent years, making SSA a potentially competitive market that may drive prices down for the services provision aspects of an SSA architecture.
- The growth in diversity of U.S. private sector space activities, including the emergence of new activities such as satellite servicing and asteroid mining, leads many experts to believe that the existing governmental oversight mechanisms may be insufficient for the United States to fulfill its obligations under the 1967 Outer Space Treaty, specifically the Article VI requirements related to authorization and continuing supervision.

## Background and Goals

In recent years, space has become increasingly congested. The congestion is driven by an increase in the number of active satellites and human-made orbital space debris; an expansion of activities in space, as is currently being proposed by many commercial and international entities, is expected to further exacerbate the problem. Space situational awareness (SSA)—knowing where space objects are, communicating the information to stakeholders, and developing regimes for ensuring safety of space flight—is more crucial now than it has been in the past.

The U.S. Department of Defense (DOD) currently provides SSA services to various degrees of precision to the global space community. However, changes are being sought to the system. Through the Commercial Space Launch Act of 2015, Congress has proposed that "an improved framework may be necessary for space traffic management of United States Government assets and United States private sector assets in outer space and orbital debris mitigation." This demand for better service for international and commercial users comes at a time when DOD is under pressure to better prepare for and respond to growing space-based threats to national security. Concerned about the possibility of overextending across conflicting missions in a fiscally constrained environment, some DOD officials have publicly noted a desire to move non-national security-related SSA services out of its purview.

In recognition of the need to both improve SSA services provided to private-sector entities and enable DOD to focus on its core mission, the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) asked the IDA Science and Technology Policy Institute (STPI) to identify and evaluate potential approaches for providing SSA services for civil and commercial operations in space. In addressing its charge, STPI conducted a review of foundational reports and the current literature, interviews with key stakeholders and experts, and a market survey of private sector entities that could in principle support civil SSA service provision.

## Providing Civil Space Situational Awareness Services

Provision of SSA services is the technical act of tracking objects in Earth orbit as a means for understanding the space environment (near-Earth objects, space weather, and radio-frequency interference, among other things), possible hazards on the ground or in the air space due to on-orbit events (such as reentries and collisions), and specific activities related to national security (such as object characterization and identification of hostile threats in space). The concept of SSA is often conflated with that of space traffic management (STM), but they are, in fact, distinct concepts. STM relates to the oversight, coordination, regulation, and promotion of space activities, which is different from, though by necessity utilizes, SSA information. While the two activities are linked, it is important to analyze the activities, best practices, and policy implications related to provision of SSA and STM services separately.

SSA is typically achieved using ground- and space-based sensors to detect the location of objects; computer software and algorithms to process the data into potential close approaches, or conjunctions; and, finally, provision of higher level analyses and products to owner/operators of satellites and other spacecraft. Figure ES-1 provides a conceptual diagram of a generic SSA system. The red boxes and arrows refer to data inputs (including location of satellites). The blue boxes and arrows represent the analytic engine that creates and manages the space object database, analyzes data to create visualizations and reports of the analytic products, and maintains an archive of historical objects. Boxes and arrows in green represent the messages provided to owners and operators of space objects, and additional sensor tasking if needed.

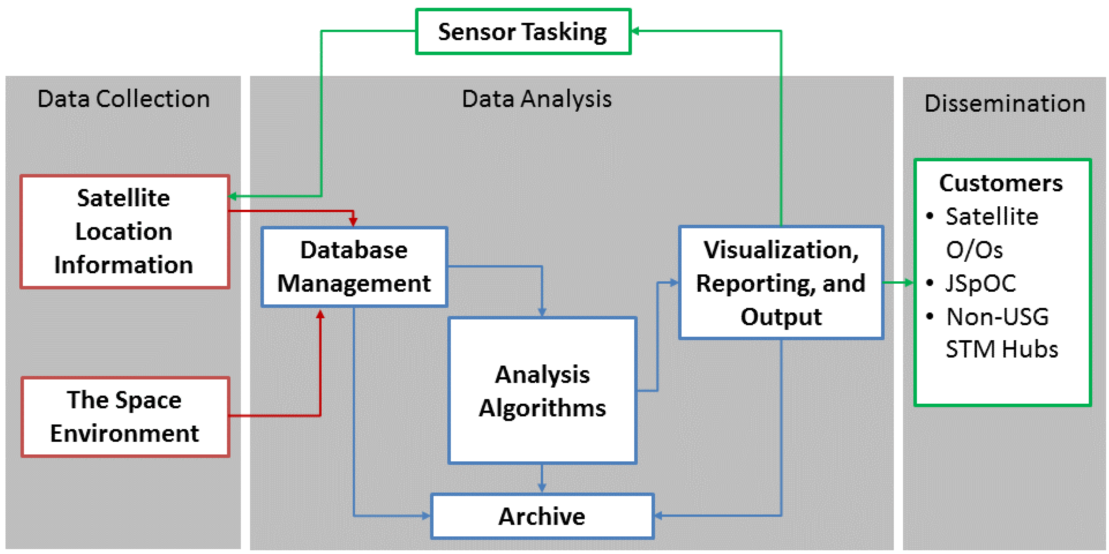



**Figure ES-1. Elements of a Conceptual SSA System**

SSA data and services to support safety of space flight are currently provided primarily by the U.S. Government and complemented by private sector owner/operators and the international community. The Joint Space Operations Center (JSpOC) of DOD's United States Strategic Command (USSTRATCOM) protects U.S. space assets and the warfighter mission by monitoring potential threats to space assets, and providing SSA services to the DOD and other U.S. Government agencies, with specific roles taken by organizations that host valuable space assets, such as NASA, National Oceanic and Atmospheric Administration (NOAA), and the National Reconnaissance Office (NRO). JSpOC also provides SSA data and information to domestic, international, and commercial satellite owner/operators on a voluntary basis.[1] The newly created Joint Interagency Combined Space Operations Center (JICSpOC) facilitates data fusion among DOD, the intelligence community, and interagency, allied, and commercial entities to boost JSpOC's ability to detect, characterize, and attribute irresponsible or threatening space activity in a timely manner. The U.S. Government spends about $1 billion annually for operation, maintenance, and upgrades of its SSA capabilities, with nearly all of the funding coming from DOD.

In recent years, partly because of the technological foundations laid by DOD SSA systems, the private sector has emerged as increasingly qualified to provide SSA data, software, and services. As part of a market survey, STPI identified more than two dozen entities that are currently providing or claim to be capable of providing some subset of SSA data, software, or services. Three of these entities are currently providing complete SSA solutions, from data collection and processing to delivery. At least seven can provide or plan to provide catalog management or analysis software, as well as risk assessment software.

Building on lessons learned from models outside the sector (e.g., GPS) and other sources, as well as a market survey of vendors that can provide data, software, and systems, STPI identified four *approaches* to the provision of civil SSA services in the United States: (1) maintaining status quo, or continued provision by DOD; (2) provision by a civil government entity such as FAA/AST; (3) industry self-provision; and (4) provision by an international organization. Within the second approach, assuming the provision of SSA by FAA/AST, STPI identified four options:

- *Option 1: FAA/AST service capability embedded within DOD/JSpOC.* In this option, FAA/AST has access at JSpOC to JSpOC hardware, software, procedures, and data. FAA's principal role would be to reduce DOD's burden by analyzing civil and commercial conjunction analyses and communicating with commercial, civil, and international operators.
- *Option 2: Independent FAA/AST service capability, using DOD software and systems.* FAA/AST would develop SSA products and services, either using its own staff or a vendor embedded on-site, using DOD-provided, FAA-procured hardware, software, procedures, and data. This option counts on access to the DOD catalog supplemented with commercial data to produce a high-quality database.
- *Option 3: Independent FAA/AST service capability, using commercial software and systems.* FAA/AST would develop SSA products and services, either in-house (using its own staff or embedding vendor on-site) or at NGE facility *using*

[1] At the time of publication, the DOD was in the process of transferring core SSA functions from the JSpOC to the 18th Space Control Squadron under Air Force Space Command. However, this shift appears to be mainly organizational in nature, and at the time of publication does not appear to have any major impact on the findings of this report.

*primarily non-DOD NGE software*. In this option, FAA/AST can use the DOD catalog or observation level data, if provided, or commercial data alone if DOD data are not available.

*Option 4: FAA/AST certifies non-governmental entities (NGEs) to provide service capability*. FAA/AST would certify one or more NGEs to provide launch, on-orbit, and reentry conjunction analyses as a service. This option implies the use of DOD data that are available publicly, and commercial software and data.

In all, there are at least seven different ways in which SSA services can be provided, differentiated by the level of service, the data sets being used, and the location where activities occur (see Figure ES-2 and Table ES-1). The options differ in vendor engagement and vendor-reported prices, ranging from $2 to $60 million, as Figure ES-3 shows. In addition to different costs to the government, each approach and option has strengths and challenges (Tables ES-2 and ES-3) that need to be evaluated in concert with its price; a low-cost option may appear desirable in the near-term but have adverse consequences in the farther-term.

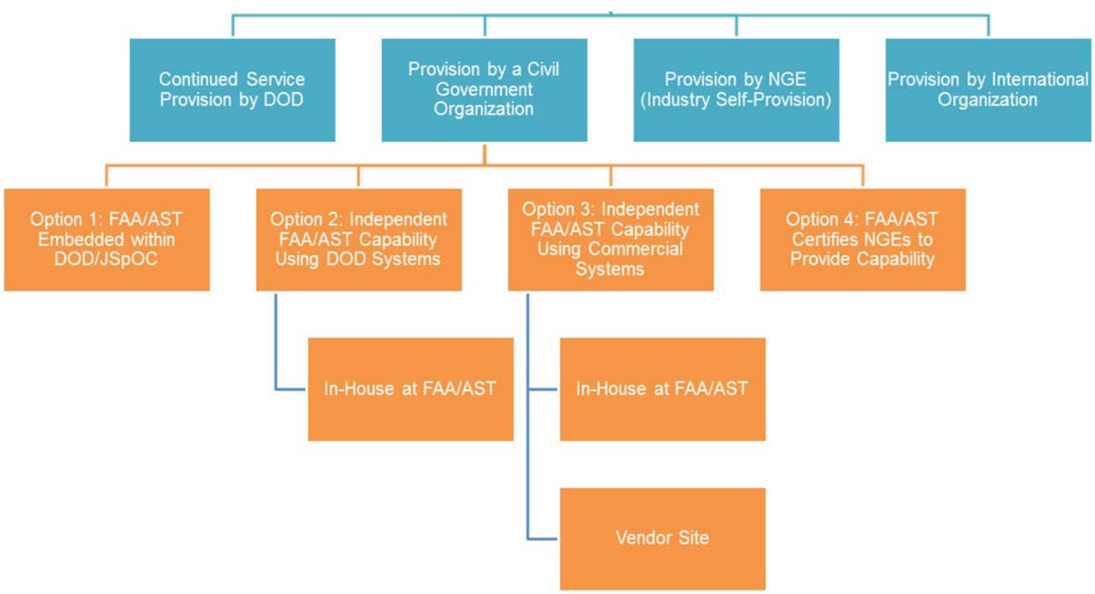



**Figure ES-2. Full Suite of Approaches (Blue Boxes) and Options (Orange Boxes) to Provide Civil SSA Services**

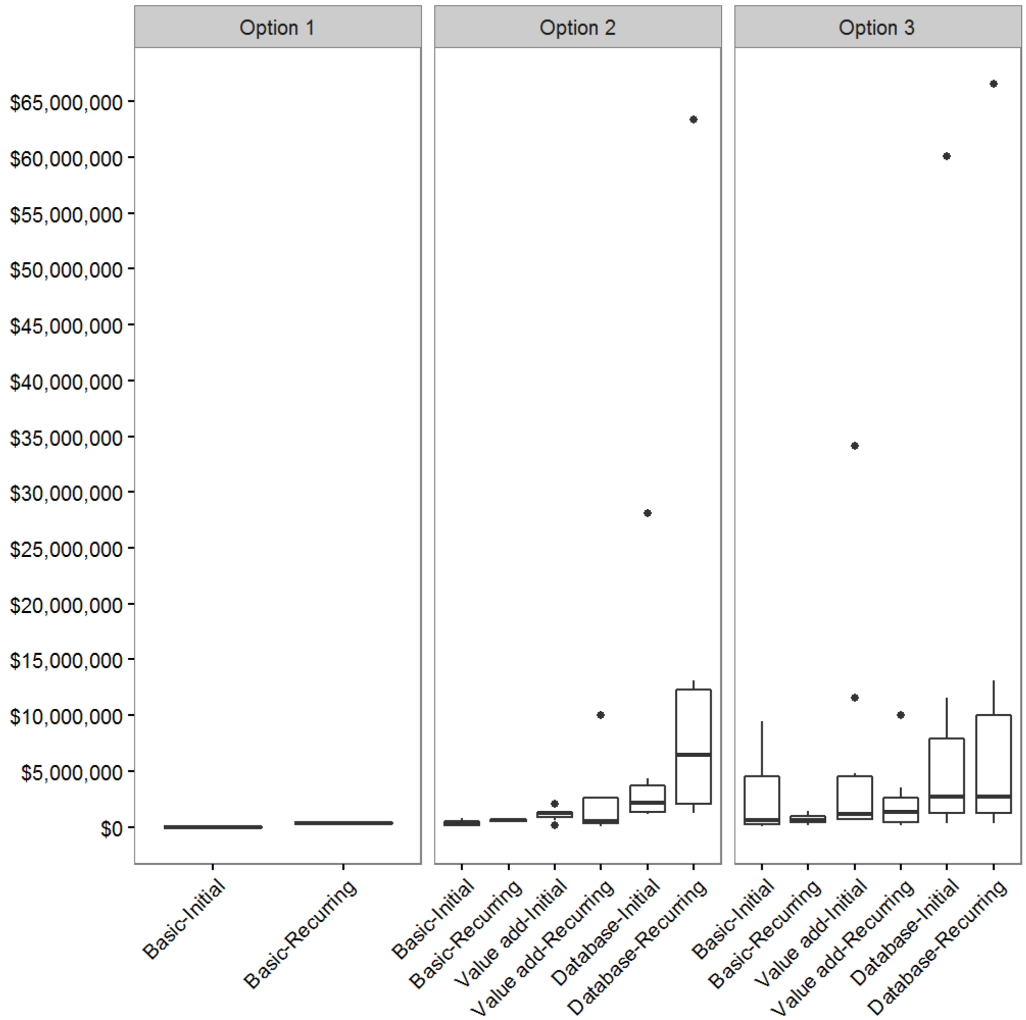
**Table ES-1. Summary of *Options***

| | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Description** | FAA/AST capability embedded within DOD/JSpOC | Independent FAA/AST capability using DOD software | Independent FAA/AST capability using commercial software | FAA/AST certifies NGEs to provide capability |
| **Sensors used** | DOD | DOD, commercial | Commercial, DOD | Commercial |
| **Analyst** | DOD, FAA/AST | FAA/AST | FAA/AST, NGE | NGE |
| **Interface with owner/operators (non-national security)** | FAA/AST | FAA/AST | FAA/AST | NGE |
| **Timeframe of availability** | 2018 or later* | 2018 or later* | Immediate | Immediate |
| **Primary data source** | DOD Catalog | DOD catalog and commercial | DOD observations or catalog and commercial | Commercial |
| **Software** | DOD JMS \ | DOD JMS | Commercial | Commercial |
| **Resulting database** | None | FAA/AST Compiled Database | FAA/AST Integrated Database | NGE Database |
| **Location** | JSpOC | FAA/AST** | FAA/AST** or NGE | NGE |

*Sources*: Compiled database supplements DOD HAC and includes maneuver and other data from commercial sources. Integrated database fuses data from DOD observations and commercial data.

* Assumes JMS would be available by 2018.

** Contractors can be embedded on-site as with current JSpOC operations.




*Note*: The price for Option 4 is not provided visually due to uncertainty in data collected (the prices provided by NGEs ranged from $10,000 to $500,000 per event, while annual prices ranged from $100,000 to $1 million per satellite annually). The terms *Initial* and *Recurring* refer to set-up and recurring annual prices, respectively. *Basic* refers to provision of SSA services at the same level as JSpOC. *Value add* refers to improvements related to risk analyses, improved user interface, and better product presentation. *Database* refers to creation of an independent database.

**Figure ES-3. Vendor-Reported Estimated Prices of Each Option**

**Table ES-2. Strengths and Challenges of *Approaches* to Providing Civil SSA Services**

| Approach | Strengths | Challenges |
|---|---|---|
| 1. Continued Provision by DOD (Status Quo) | • Continuity in provision of services<br>• No additional latency or increased friction in system<br>• Minimizes some level of duplication that will necessarily occur if a civil agency were to provide SSA services in addition to DOD<br>• Allows the national security community to continue to exert control over SSA data to protect sensitive activities and satellites | • Inflexibility of DOD to respond rapidly to civil and commercial users' growing needs or advances especially in software technology<br>• DOD systems (JMS) delayed and not ready for full implementation<br>• Continued gap between SSA data collection agency and future regulation/oversight agencies<br>• Reduced focus on industry needs as compared with DOD mission needs<br>• Future increases in potentially hostile or threatening activities may cause de-prioritization of civil and commercial operator needs<br>• More difficult to extend to an international SSA regime |
| 2. Provision by Civil Government Agency | • Greater flexibility to respond to industry needs and collaborate internationally (e.g., add non-U.S. sensors or extend to an international regime)<br>• Greater flexibility to incorporate non-DOD data and leverage commercial advances in software<br>• Ability to mandate the use of SSA services through licensing<br>• Easier pathway to civil STM and international coordination<br>• Provides redundancy to a critical national security and public safety relevant system | • Additional costs into tens of millions of dollars annually<br>• Creates some duplication of activities<br>• Learning curve for a civil agency to develop operational expertise<br>• Need to address concerns over possible confusion stemming from multiple satellite catalogs<br>• Potentially lower ability to mask national security activities in space, particularly if using non-DOD data sources |
| 3. Industry Self-Provision | • Supports a more industry-driven community of practice<br>• Low cost for the Federal Government<br>• Provides redundancy to a critical national security and public safety relevant system | • Enforcement would be difficult<br>• Industry may be unwilling to bear the cost, particularly for new and smaller satellite operators<br>• Concerns over masking national security activities in space, particularly if using non-DOD data sources |
| 4. Provision by International Organization | • End-state an SSA system needs to be in given that it is an inherently international activity<br>• Could provide the most accurate data and services, if it included access to data from multiple countries<br>• Would create a level playing field for all countries and satellite operators, regardless of national capability<br>• Could help support the development of international standards for space traffic management<br>• Provides redundancy | • Lack of trust in international institutions<br>• High transaction costs to negotiate and implement<br>• Would need to overcome significant challenges stemming from sensitive national security activities in space<br>• Unclear which international body would have the competence, credibility, and resources to perform the service<br>• Issues of sovereignty to be negotiated and decided |

**Table ES-3. Strengths and Challenges of *Options* (within Approach 2) for FAA/AST Providing Civil SSA Services**

| Option | Strengths | Challenges |
|---|---|---|
| 1. FAA/AST Embedded within DOD/JSpOC | • Expected to somewhat reduce JSpOC's workload not related to national security mission<br>• Preferred by stakeholders who would like to: minimize near-term cost, reinforce the role of USSTRATCOM as primary hub for SSA, remove possible confusion of a competing FAA/AST database, and reinforce political backing for improvements to JSpOC's core hardware and software | • Capabilities subject to the limitations of JSpOC's software and data<br>• Flexibility and innovation limited to improvements in JMS<br>• Continue to have significant restrictions on ability to share data with commercial and international customers<br>• FAA has little value added compared to DOD's current service provision |
| 2. Independent FAA/AST Capability Using DOD Software and Systems | • Only slightly changes the status quo<br>• FAA/AST has more insight into the DOD SSA process<br>• May better prepare FAA/AST for a future role in STM | • FAA/AST would face significant hurdles to make modifications to any processes or software that DOD has<br>• Unclear how difficult it will be for FAA/AST to add value-added software services and a database on top of the DOD architecture<br>• Dependence on DOD data (by not being able to augment with commercial data) could be detrimental if FAA/AST loses data stream<br>• Potential challenges in linking JMS data on SIPR to FAA/AST capabilities on DOT networks |
| 3. Independent FAA/AST Capability Using Commercial Software and Systems | • FAA/AST has significantly greater control and flexibility to align service with civil and commercial requirements<br>• Changes to the system based on NGE software will likely be lower priced than changes to DOD software (long term prices will likely be lower than Option 2)<br>• If properly designed, could promote greater flexibility and rapid development of software than utilizing DOD software and data<br>• Likely the best option to prepare FAA/AST for a future role in STM | • Increased upfront costs over previous two options<br>• Using a different database than the DOD catalog could lead to conflict across agencies<br>• If systems are customized (i.e., do not remain commercial), would deter quick/agile improvements<br>• Liability concerns when using NGE software |
| 4. FAA/AST Certifies non-Governmental Entities (NGE) to provide services | • Supports commercial SSA industry while still protecting civil space assets through governmental oversight<br>• Low cost burden for government<br>• Greatest flexibility for service improvements | • Not appropriate if SSA services are deemed to be governmental functions<br>• May not meet the requirements for government oversight under international obligations<br>• Unclear who would bear the cost of services: government or users<br>• Liability concerns<br>• May cause issues with current international partners<br>• Owner/operators may choose the least restrictive or expensive vendors, which could be counterproductive to safety in space |

There are several important caveats to the analysis: (1) it is unclear how DOD's spending would change, if at all, upon the adoption of one of these options; (2) while STPI attempted to ensure that prices are comparable across vendors, it is possible that vendor services are not comparable to each other or to JSpOC; (3) vendor pricing was self-reported and not independently validated; and (4) for options 2, 3, and 4 where the price was based on vendor services, personnel estimates included only the vendors' own staff, not any additional FAA/AST staff that might be required.

## Space Traffic Management

At present, there is no overarching national or international STM regime that seamlessly incorporates launch, reentry, and on-orbit activities. Current U.S. STM efforts focus on pre-launch governmental licensing by FAA, Federal Communications Commission (FCC), and NOAA, but there are no clear authorities for the U.S. Government to license any new and emerging on-orbit activities being proposed by U.S. private entities. This has led to questions as to whether private U.S. space entities are being provided continuing supervision as per the United States' international treaty obligations, in particular Article VI of the 1967 Outer Space Treaty. According to many experts, as the number and diversity of activities that fall outside existing oversight responsibilities increase, clearer U.S. Government on-orbit authority could augment space safety, and better allow the United States to meet its international obligations. Given the strong links between SSA and STM, and the need for a civil SSA regime to be extensible to STM, STPI briefly reviewed a range of future potential STM regimes and surveyed possible models from other sectors.

As with SSA, STM can be accomplished at various levels by industry, governments, or international bodies. STPI identified four potential ways, which are not mutually exclusive, in which STM services can be developed in the United States. The first is to augment current space licensing authorities to include on-orbit activities. A second is to support industry best practices and standards, and let industry set the rules. A third is to have government-set regulations for preventing collisions, with penalties for violation. The fourth is an active space traffic control regime where the government or another entity has the authority to instruct satellite operators when and how to move to avoid collisions, similar to an air traffic control regime currently. An assessment of STM options is outside the scope of this report.

## Policy Issues for Civil SSA

In addition to examining the costs of each SSA option presented, STPI identified a range of policy-related challenges that would need to be resolved before a decision is made regarding which option to pursue:

- Are SSA and STM governmental functions, and if so, does that mean that they need to be performed *within* government, as opposed to being *overseen by* the government? This is an important issue that may determine the role of the private sector in SSA and STM.

- To what extent is provision of civil SSA a “public good” in an economic sense, and what is the implication of this with respect to who pays for civil SSA services—the government or the end users? This issue becomes especially relevant in the certification option in which not all owner/operators may be willing or able to pay, and may select lower quality vendor services depending on their risk tolerance.
- How should the challenges related to sharing of sensitive national security or proprietary information on satellite location be addressed? This issue has been addressed in other domains, which may be applicable to developing a solution for the space domain.
- How can stakeholder buy-in from all relevant constituencies—the national security community, civil space agencies, satellite owner/operators, the emerging commercial sector, and Congress—be gained to any path forward?
- How do existing agreements, policies, and regulations limit or impact civil SSA, and which ones would need to be augmented if there a change to the system? How should international commitments such as those related to the Outer Space Treaty, and the United States’ desire to be seen as a global leader in the SSA domain, be addressed?
- What is the role of government in promoting innovation and creating new industries, especially in the context of developing IT products and services related to SSA?

The options and policy issues identified in this report are complex, and there are likely additional options, issues, and concerns that were not addressed. A decision on the best course of action is similarly complex, as it will require balancing many competing interests and ideologies. Ultimately, the decision about the shape of the future civil SSA regime should be made based on what is best for the United States’ long-term strategic interests, and not just the near- and short-term economic costs.

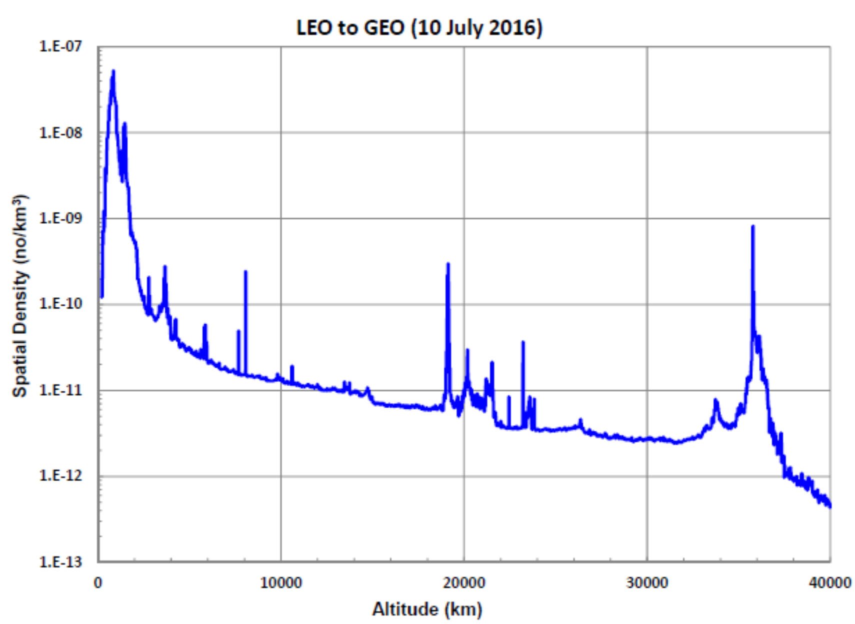
# Contents

# 1. Introduction

## A. Challenge of Growing Congestion in Space

Whereas 50 years ago, the United States and the Soviet Union were the major players in space, now over 80 countries have one or more space-based interests (Lal et al. 2015). Nearly 1,400 active satellites are in Earth orbit—approximately twice as many as there were only 12 years ago (Jah 2016; Johnson 2004). This increase is due in part to the ever-expanding role space systems play in a variety of terrestrial applications, from GPS to meteorology to telecommunications, but also to the recent proliferation of spacefaring nations and commercial activities in space.

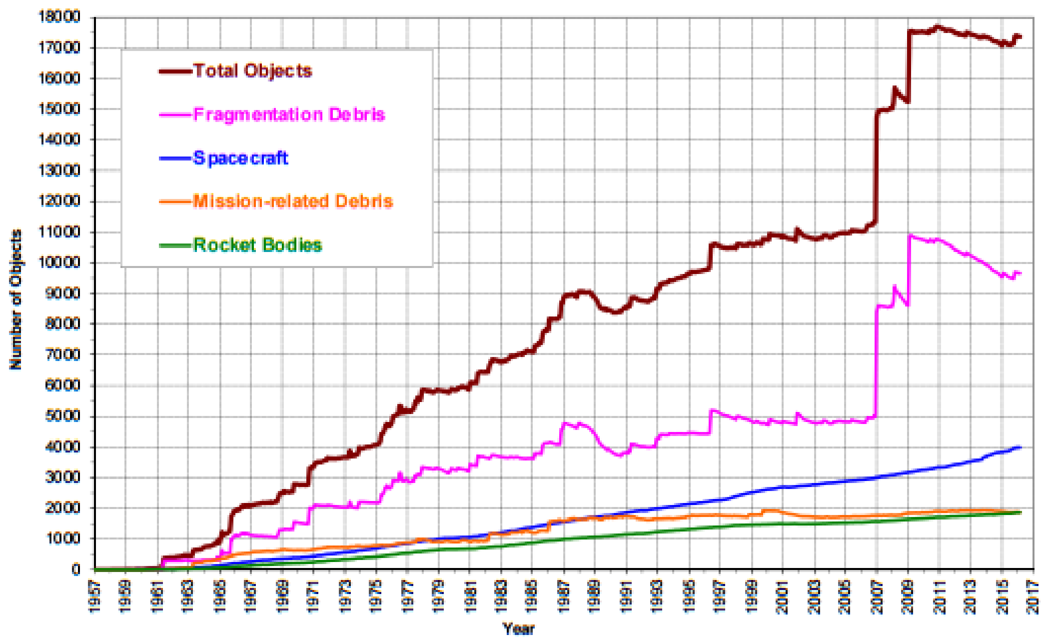
Although the size of an individual satellite is small compared to the scale of space, on-orbit crowding in the most populous orbits is a serious concern. Active satellites are concentrated in a few specific orbits that are well suited to certain applications (Figure 1). For example, low Earth orbit (LEO) between 700 and 900 kilometers is well suited to remote sensing, weather, and certain types of communications. Navigation satellites are clustered in medium Earth orbit around 20,000 kilometers altitude, and broadcast communications satellites are clustered in geosynchronous orbit (GEO) near 36,000 kilometers altitude.




*Source*: Liou (2016).

**Figure 1. Spatial Density of Currently Tracked Human-Generated Objects in Earth Orbit**

However, it is not just the growing number of working satellites that is a challenge; the problem of orbital debris is also becoming critical. Hundreds of thousands of nonfunctional objects are on orbit in addition to the active satellites (Figure 2) (Union of Concerned Scientists 2016). These objects range from large discarded rocket bodies the size of tractor-trailers to small paint chips a few millimeters in size.[2] Determining sources of space debris and tracking them is enormously difficult, especially when it comes to smaller objects. As with active satellites, the number of inactive objects and debris has been growing at an increasing rate over the last fifty years. Known collision events like the Iridium-Cosmos collision in 2009 and the Chinese antisatellite test in 2007 have also caused dramatic spikes in the number of smaller objects. In fact, according to David (2013), the debris created by both of these events accounts for over one third of the total objects cataloged in LEO.




*Source*: NASA Orbital Debris Program Office (2016, 14).

*Note*: "Spacecraft" includes both active and inactive satellites. The sharp jumps in the number of tracked fragmentation debris in 2007 and 2009 correspond to the Chinese antisatellite test and the Iridium-Cosmos collision, respectively. The occasional dips correlate to periods of high solar activity, which increases natural decay of space objects into the atmosphere.

**Figure 2. Monthly Numbers of Objects in Earth Orbit by Object Type**

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2 Approximately 23,000 of the objects currently in Earth orbit that are tracked by the DOD Joint Space Operations Center (JSpOC) are larger than 10 cm in diameter. An estimated 500,000 objects larger than 1 cm in diameter are not currently tracked but could potentially be in the future, and over 100 million objects smaller than 1 mm in diameter are not likely trackable (Jah 2016 and NASA Orbital Debris Program Office website, "Orbital Debris Management," http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html).

The population of existing satellites and space debris has created two main challenges for safe space operations. The first challenge is in detecting and tracking objects in Earth orbit, and being able to predict their future trajectories. The second is using the information about future trajectories to detect and prevent future collisions between space objects, which could damage or destroy functional satellites and generate additional orbital debris Meeting these challenges poses operational costs on satellite operators. In 2014, JSpOC issued a daily average of 23 “emergency reportable” close approach warnings, where close approach is when an active satellite and another space object are predicted to be closer than 1 kilometer apart. As a result of those warnings, satellite operators conducted more than 120 maneuvers to try and minimize the chances of a potential on-orbit collision.[3] Additionally, there are growing concerns that the increase in space launches and reentries, particularly those over populated areas, could further impact air traffic.

These challenges will increase in difficulty and cost in the future. An estimated 3,800 planned launches of new satellites are scheduled between 2016 and 2020, which, if realized, would almost quadruple the population of active satellites.[4] Many of the projected new satellites are small satellites, which will be launched into large constellations, or even smaller CubeSats, which are difficult to track and identify. Recent studies have attempted to assess the impact of the projected launch rates. One study (Virgili et al. 2016) estimates that just one of these large constellations of small satellites could increase the number of conjunctions (i.e., close approaches between objects) by a factor of 70 compared to today. Anything less than 100% compliance with proper post-mission disposal guidelines would create significant increases in the density of objects in LEO (Figure 3). Another study (Lewis et al. 2016) estimates that the new population of CubeSats alone will generate millions of conjunction warnings each year. Failing to improve the accuracy and reliability of current conjunction analysis techniques will result in a massive increase in false positives as the number of space objects, caused by both human placement and naturally occurring conjunctions, increase over time. This will not only drive up operational costs for many satellite operators, but increase workloads for the analysts at JSpOC currently performing these services (Figure 4).

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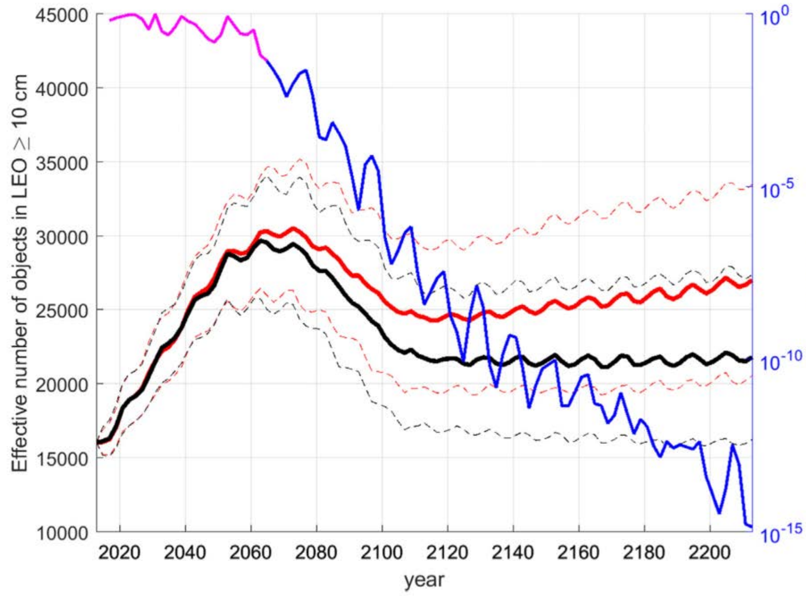
[3] Given current data and analytical techniques, it is impossible to know how many of the predicted conjunctions may have actually resulted in a collision, if the mitigation steps had not been taken.

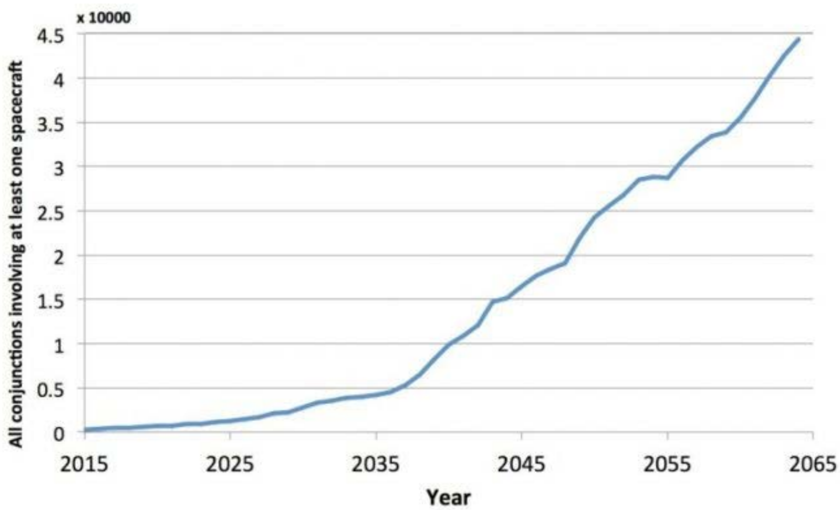
[4] Spaceflight Insider website, “Impact of New Satellite Launch Trends on Orbital Debris,” http://www.spaceflightinsider.com/missions/earth-science/impact-new-satellite-launch-trends-orbital-debris/.




*Source*: Virgili et al. (2016).

*Note*: The figure includes objects in a large constellation that disposes to eccentric orbit with 25-year lifetime with 100% success (black lines) versus a constellation that disposes to eccentric orbit with 25-year lifetime with 90% success (red lines). The thick lines are means of the MC runs and the dashed lines are the standard deviation around the means with a 95% confidence interval.

**Figure 3. Comparison of Spatial Density of Objects in LEO**




*Source:* Karacalıoğlu (2016).

**Figure 4. Predicted Number of Conjunctions Involving at Least One Spacecraft**

## B. Rationale for Conducting this Research

The United States Strategic Command (USSTRATCOM) within the Department of Defense (DOD) is currently the lead agency for all U.S. SSA activities.[5] USSTRATCOM's space control mission includes "surveillance of space, protection of U.S. and friendly space systems, prevention of an adversary's ability to use space systems and services for purposes hostile to U.S. national security interests, and direct support to battle management, command, control, communications, and intelligence."[6] The space control mission is conducted by USSTRATCOM's Joint Functional Component Command for Space, primarily through the Joint Space Operations Center (JSpOC) (Office of the Director, Operational Test and Evaluation 2013). Part of JSpOC's original tasking was to provide warning of close approaches between important U.S. Government satellites and other space objects, but these warnings were expanded in 2010 to encompass all operational satellites, including those commercial and foreign (Ferster 2012). Approximately, 90% of conjunction messages that JSpOC provides are not related to DOD's mission (Earle 2015).

The first reason to reconsider this approach is the increased desire by the U.S. military to reduce its role in providing all SSA services. Over the last two years, USSTRATCOM has signaled an interest in shifting operational responsibility for some SSA activities to another agency or department. One reason is the growing concern over threats to U.S. national security space capabilities, and greater need on the part of JSpOC to focus on these threats. A second reason is the increase in commercial space activities, and the potential for greatly increased numbers of commercial satellites on orbit to take away focus from JSpOC's primary national security focus. High-level USSTRATCOM officials have publicly noted a desire to move all civil SSA services from JSpOC's purview. (Weisgerber 2016). In 2015, for example, Lt. Gen. James M. Kowalski, deputy commander of USSTRATCOM, stated, "We spend a lot of time doing catalog and tracking and collision avoidance kind of things…. If you think about who does that in the airspace, it's probably not military, it's a civilian agency…such as the Federal Aviation Administration…. We need to revisit how we've allocated military personnel to what may not be really a military mission" (Freedberg 2015).

More recently, General John E. Hyten, Commander of the U.S Air Force Space Command, noted, "I would prefer that I take the airmen today that are doing basically collision avoidance and orbital analysis across the board for everybody else, and if somebody else could do that and I could focus those airmen on other missions, I'd be much

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[5] The distinction between the terms *space situational awareness* (SSA) and *space traffic management* (STM) is discussed in Chapter 2.

[6] See U.S. Strategic Command website, "USSTRATCOM Space Control and Space Surveillance," https://www.stratcom.mil/factsheets/11/Space_Control_and_Space_Surveillance/.

happier…. We shouldn't be doing flight safety for everybody in the world, we should be focused on missions for the Department of Defense" (Seligman 2016).

A second reason to reexamine the current system for providing SSA is to better support government oversight of private sector space activities. The *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, also known as the Outer Space Treaty, establishes much of the international legal framework for principles of outer space activities. Article VI of the treaty makes States that are parties to the treaty responsible for providing "authorization and continuing supervision" of their non-governmental activities in space. Historically, this obligation has been met by pre-launch licensing of private sector activities in space, focusing on remote sensing and communication. However, the existing licensing and oversight responsibilities have not kept pace with the expansion and evolution of the private sector towards new activities such as on-orbit satellite servicing and active debris removal. None of these activities currently has an explicit licensing regime, thereby creating questions as to how the United States can continue to comply with the authorization and continuing supervision requirements of the Outer Space Treaty. The Office of Science and Technology Policy (OSTP) in the Executive Office of the President (EOP) understands this issue and called for FAA to gain this authority through FAA's Payload Review Process (Holdren 2016). A significant part of meeting the oversight obligations is providing civil regulatory and licensing agencies with SSA information.

The challenges the U.S. military has faced in upgrading its capabilities to meet the changing environment are a third reason for reevaluating the current SSA system (Government Accountability Office 2015). Since the early 2000s, a series of procurement programs encompassing several hundred million dollars of spending have attempted to upgrade the hardware and software systems that form the core of JSpOC's ability to provide SSA services, but have met with limited success (Weeden 2012). The most recent iteration of these efforts, known as the JSpOC Mission System (JMS), has continued to struggle, with the recent announcement that Increment 2 of JMS has been delayed 19 months until at least 2018 (Gruss 2016c). Increment 2 will provide critical upgrades to JSpOC's ability to process larger amounts of data from a more diverse set of sources, manage a larger catalog of space objects, and provide more sophisticated analytical services. Until Increment 2 is delivered, JSpOC will continue using existing legacy computer systems that cannot satisfactorily meet current and future SSA needs.

The fourth reason for reexamining the current regime is that the private sector has demonstrated a significant increase in capabilities for providing SSA data and services over the last few years. Multiple private sector entities have demonstrated the ability to provide many of the same or similar civil SSA capabilities as JSpOC, including collecting observations on large numbers of space objects, processing the observations into a database, and providing conjunction warnings and other products to users. For example, the Space Data Association (SDA) runs an automated system designed to reduce the risks of on-orbit collisions and radio frequency interference to provide complementary capabilities to JSpOC.[7] The SDA was created by leading satellite communication companies, and uses data from participating satellite owner/operators to augment and enhance the conjunction warnings provided by JSpOC. The SDA has successfully dealt with sensitive satellite ephemeris data (described in Chapter 3) from members, and is a key example for exploring potential provision of SSA services outside the Federal Government. Other private sector entities, such as the Commercial Space Operations Center (ComSpOC) created by Analytical Graphics, Inc. (AGI), are designed to be alternatives to JSpOC. ComSpOC currently maintains a database (referred to as the "SpaceBook") of space objects that is developed entirely from non-DOD data sources, and AGI recently announced that it plans to match the number of space objects in JSpOC's public catalog by the end of 2016 (Henry 2016).

The continued development and maturation of private sector SSA capabilities raises important questions about the role of the government in providing SSA data and services. The 2010 National Space Policy has not provided clear direction on this issue (EOP 2010). On one hand, it specifically prohibits the U.S. Government from partaking in activities that preclude, discourage, or compete with U.S. commercial space activities, unless required by national security or public safety. On the other hand, the policy directs DOD, in consultation with other agencies, to foster the development of space collision warning measures by collaborating with industry and foreign nations to maintain and improve space object databases, pursue common international data standards and data integrity measures, and provide services and disseminate orbital tracking information to commercial and international entities, including prediction of space object conjunctions.

There are also multiple considerations regarding the role of the government in providing SSA services (e.g., there is debate over which part of the government should take a leadership role). Some of the experts interviewed for this project argued that SSA should remain under the purview of national security due to the large number of sensitive national security assets in space and the need to control access to SSA data to protect their locations and activities. Other experts interviewed proposed that the activity should shift to a civil agency such as FAA/AST; these experts believe civilian involvement in an SSA regime would better promote public safety, satisfy U.S. obligations under OST Article VI, and facilitate movement towards an international STM regime. They argued that as the proportion of private sector and commercial activity in space increases, placing excessive priority on national security interests above all else could stifle or hamper economic development and innovation. Still others argued that the task should be handed to non-

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[7] From Space Data Association website, "SDA Overview," http://www.space-data.org/sda/about/sda-overview/.

governmental entities, as has been done in sectors such as air traffic control in countries such as Canada. The debate is still open as to whether SSA is an inherently governmental activity, especially when the private sector can, and is, providing data and analytic SSA services already. We revisit this debate in Chapter 9 of this report.

## C. Goals and Overall Approach

The Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) asked the IDA Science and Technology Policy Institute (STPI) to identify and evaluate potential approaches for providing space situation awareness (SSA) services for civil and commercial operations in space. In addressing its charge, a team of STPI researchers reviewed foundational reports and the current literature, interviewed key stakeholders and experts, and conducted a market survey of private sector companies that could, in principle, support civil SSA service provision.

As part of this task, we developed seven in-depth memoranda on specific topics of interest. This report summarizes all prior deliverables into a single overarching report. It delineates potential approaches for future provision of civil SSA services to support the safety and efficiency of space activities, and discusses potential directions for civil space traffic management (STM). The STM discussion is less detailed than the SSA discussion because the precise nature of how an STM regime might be implemented is less clear, and the issue is still in its infancy. While SSA has both civil and national security elements, this report focuses only on a civil SSA regime for civil, commercial, and international spacecraft.

In an assessment of options for SSA, we discuss the policy implications as well as the cost,[8] where feasible to determine. Our goal is not to make a recommendation as to the best option; it is to lay out the range of options in an as unbiased a manner as possible, and present the strengths and challenges of each.

Working with subject matter experts as consultants to the team, we used a multi-method approach, which included a review of the key foundational reports in the community as well as current literature and one-on-one and roundtable discussions with key stakeholders, experts, owner/operators of satellites, and launch and transportation service providers. We also conducted a market survey of known private sector companies that could in principle support SSA service or data provision.

## D. Organization of the Report

This report is organized as follows: Chapter 2 clarifies the definitions of and differences between the commonly conflated concepts of interest, SSA and STM. Chapter

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[8] We use the terms *cost* and *price* interchangeably in this report, with the implicit understanding that dollar figures provided by the vendors represent the price they wish to charge.

3 describes the current provision of civil SSA. Chapter 4 presents examples, models, and lessons learned from other sectors. Chapter 5 summarizes the market survey. Chapters 6 and 7 leverage the models from Chapter 4 and the market survey from Chapter 5 to present a range of approaches and options for provision of civil SSA services, including pricing information where available, and policy implications of each. Chapter 8 describes how STM services are currently provided and presents possible models for, and approaches to creating an STM regime for the future. Chapter 9 summarizes broader policy issues.

Appendix A lists foundational documents in the community. Appendix B lists the key stakeholders and experts interviewed. Appendix C reproduces the questionnaires administered to non-governmental entities (NGEs) that could potentially use or provide SSA software, systems, and services.

# 2. Differentiating between Space Situational Awareness and Space Traffic Management

As discussed in Chapter 1, over the past decade, there has been growing attention paid to the rising number of human-generated space objects and their interactions in orbit around Earth. The terms *space situational awareness* (SSA) and *space traffic management* (STM) have been loosely and interchangeably used in the literature (International Academia of Astronautics 2006; Ailor 2006; D'Uva 2014). At the time of this writing, neither has a precise definition in any legally binding international document, and in many contexts, the two are spoken of as if they were one, so the difference between them has been conflated (Kaiser 2014). For the purpose of this report, SSA involves learning about the space environment, while STM focuses on making decisions based on that information. In this chapter, we describe the distinction and discuss why it is important to consider them separately.

## A. Space Situational Awareness

Although humans have been observing the stars and planets for millennia, it was not until the Soviet Union's launch of the first artificial (human-generated) satellite, Sputnik, on October 4, 1957, that humans started to focus significant attention on tracking objects in orbit around the Earth. For the next few decades, space surveillance was an important part of the Cold War conflict between the United States and Soviet Union. In particular, the Air Force needed a way to prevent false alarms as satellites came within view of missile-warning radars, while the U.S. Navy needed a way to alert deployed units of possible reconnaissance by satellites overhead. During this time, the militaries of both countries built large networks of ground-based tracking facilities that collected data on human-generated objects in Earth orbit. Consisting primarily of large tracking radars and optical telescopes, these facilities had dual purposes, such as ballistic missile warning and tracking. The primary focus of space surveillance at this time was on determining the precise orbit of human-generated objects around the Earth.

Over the course of the Cold War, space surveillance capabilities became more sophisticated. New techniques were developed to help characterize space objects with the goal of determining their function and whether or not they posed a threat to either other space objects or people and facilities on the surface of the Earth. The armed forces and national security departments of various countries began to share some space-surveillance data with civil space agencies, whose scientists used the data along with other resources to develop models of the population of space objects and in particular space debris.

By the 2000s, concerns over the growing population of space objects had increased significantly, and with it, the importance of space surveillance as a tool for measuring the increase in space debris and the potential threat it poses to operational satellites. The term *space surveillance* was replaced by *space situational awareness*, or SSA, to indicate the new focus on not just tracking space objects but generating information about the entire space environment, including space weather and radio frequency interference (RFI).

SSA is the result of a variety of technical activities, typically achieved using sensors to detect the location of objects, computer software and algorithms to process the data into potential close approaches (conjunctions), and communication tools to communicate to stakeholders the positions and movements of objects. SSA services typically include the following activities:

1. Tracking and Characterizing Space Objects: Monitoring space objects with ground- and space-based sensors; identifying the observation(s) with an established list of known objects; updating the list of space objects as needed; determining the size and shape of space objects.
2. Launch and Early Orbit Collision Avoidance (COLA): Comparing the planned launch trajectory above 150 kilometers from time of launch through the first several hours post-launch (currently, 3 hours, with a commonly stated goal of 48 hours) against all other orbital space objects to determine potential on-orbit conjunctions.
3. On-Orbit Conjunction Assessment (CA): Comparing the orbital trajectory of all active satellites against all other orbital space objects to determine potential on-orbit conjunctions that meet a pre-determined close-approach threshold distance.
4. On-Orbit Collision Risk Assessment and Maneuver Planning: Determining the probability of collision resulting from a close approach between an active satellite and another space object, and assessing options for maneuvers to minimize or eliminate the probability of collision.
5. End-of-Life (EOL) Verification: Monitoring an active satellite’s end-of-life procedures and verifying compliance with a pre-determined orbital debris mitigation plan specified in the operator’s license.
6. Controlled De-Orbit COLA: Comparing operator-generated planned de-orbit trajectories against all other orbital space objects and air traffic flight corridors.
7. Reentry Risk Analysis: Predicting the atmospheric decay of space objects, estimating the potential threat they may pose to aircraft in flight or people and

installations on the surface of the Earth, and providing appropriate notifications and warnings.

8. Archive and Analysis: Capture and long-term storage of events for historical analysis and archival purposes.
9. Space Weather Warnings: Monitoring solar activity, and providing notification of a space weather event that poses potential risk to spacecraft or the Earth.
10. Radio Frequency Interference Notifications: Assisting satellite operators in detecting and resolving radio frequency interference impact on satellite command and control or payloads.
11. National Security Activities: Characterizing adversary space object capabilities and intentions, and detecting and addressing hostile threats to satellites

This is a fairly comprehensive list of SSA services. In the rest of this report, we focus on only those services that are likely to be provided by a civil agency (those that relate to safe and efficient operation of space flight activities). We assume that SSA activities related specifically to national security will remain with national security agencies. Figure 5 highlights the overlap between civil and military SSA. It is important to note that this report focuses on civil SSA.


Source: Weeden (2014).

*Notes*: Civil SSA data includes those data that are essential to providing safety of space flight services. National Security SSA data build upon the civil SSA data and include data essential to characterizing actions and behavior in space, and assessing potential threats.

**Figure 5. Division of Labor between Civil and National Security SSA Data**

## B. Space Traffic Management

*Space traffic management* (STM) is a newer term. Although *traffic* was first applied to space activities in the 1980s, perhaps as a counterpart of air traffic, the concept of STM has been gaining discernible traction in the literature only since the beginning of the 21st century (Schrogl 2008, 272). Its definition has generally only been discussed vaguely, and the term is often used interchangeably with SSA. The first comprehensive approach to shaping an STM system was used for a 2006 International Academy of Astronautics study. Since then, the term has steadily been gaining traction in conferences and articles. In that study, the term was defined as follows: "Space traffic management means the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency damage" (International Academy of Astronautics 2006). However, this definition conflates the two unique activities of SSA and STM because it combines the regulatory (STM) and technical (SSA) activities.

This report separates the technical aspects related to SSA, and defines STM as actions related to the oversight, coordination, regulation, and promotion of space activities (including preservation of the space environment) at several distinct phases of the mission—launch, operations in space, and return from space. A full STM regime would use the SSA services discussed in the previous section, and add mechanisms—technical, regulatory, or other—for oversight and possibly active control (European Space Policy Institute 2007).

*In short, and for the purpose of this report, SSA relates primarily to learning about the space environment, including location of space objects, while STM focuses primarily on making decisions based on that information to improve safety of space operations.* The two concepts are clearly interrelated, and the latter cannot be done without good knowledge of the former. SSA is feasible without STM, as has been the case the last many years with JSpOC providing SSA services with little formal STM, but STM requires strong capabilities in SSA. In the rest of the report, we use SSA when we mean the technical tasks related to knowing where objects are, and we use STM when we mean activities related to oversight, coordination, regulation, and promotion of space activities.

# 3. Current SSA Regime

Before we can propose civil SSA options for the future, we must first understand how SSA services are currently provided. This chapter summarizes the current SSA regime. There are three parts to service provision: data on the location and movement of space objects, software and computer algorithms that process streams of data to compute how objects may interact, and higher-level analyses for owner/operators of satellites and other spacecraft.

## A. SSA Data

SSA data span multiple types: metric data on an object's orbital trajectory, characterization data on the object itself, and descriptive information about when it was launched and who owns or operates it. Table 1 defines each of the data types.

**Table 1. SSA Data Types**

| Data Type | Definition |
|---|---|
| Metric | Information about an object's orbital trajectory |
| Characterization | Information about a space object such as size, tumbling, composition, emissions, and capabilities |
| Descriptive Information | Information about a space object such as owner/operator (O/O), launch date, launching State, and mission |

Metric data itself comes in levels ranging from the actual collections at a sensor to analytical products. Lower levels of metric data (raw sensor data being the lowest, and ephemeris or predicted position of an object, the highest, as defined in Table 2) can be aggregated to higher levels, but the reverse is not generally feasible without some loss of fidelity or useful information. Having access to lower levels of metric data allows an SSA provider greater freedom in fusing data from multiple sources, greater understanding of the data accuracy and precision, and greater flexibility in creating analytical products and services.

**Table 2. SSA Metric Data Levels**

| Level | Description |
|---|---|
| 1–Raw sensor data | Focal plane images, radar returns |
| 2–Observation | Location of a space object at a point in time relative to a sensor |
| 3–Element Set | Set of variables (function) describing an object's orbital trajectory |
| 4–Ephemeris | Predicted position of an object generated by propagating an element set over a period of time |
| 5–Analysis Product | Information that is the result of an analysis based on element sets or observations (such as de-orbit prediction time) |

One important characteristic of SSA metric data is timeliness, which can be defined in multiple ways. One definition is how long it takes for the process of tasking a sensor to track an object, that sensor's collection of observations on the object, and receipt of the data by the SSA service provider to be completed. Another definition is how long it takes a space object to pass within collection range of a given sensor network. Yet another is how often an SSA service provider updates the element sets (elsets) or state vectors[9] for space objects. Data providers with computational limitations may be able to update objects only a few times per day, while others may be able to update every object as soon as new tracking data are available.

A second important characteristic of SSA metric data is the size of the data in terms of digital information (bytes). Raw sensor data can be gigabytes in size, particularly if it comes from a large phased array radar or an optical sensor with a large charge-coupled device (CCD). When reduced down to a set of observations, the data becomes lines of text, and when reduced down even further to an element set, it is expressed by just a few variables. However, when an element set is propagated over a period of time, the resulting ephemeris files can be hundreds of megabytes or even gigabytes in size, depending on the time period used and the number of time steps.

In general, a lower level of data, such as observations, is preferable to enable better data fusion from multiple sources, better understanding of the data accuracy and precision, and flexibility in creating analytical products and services.

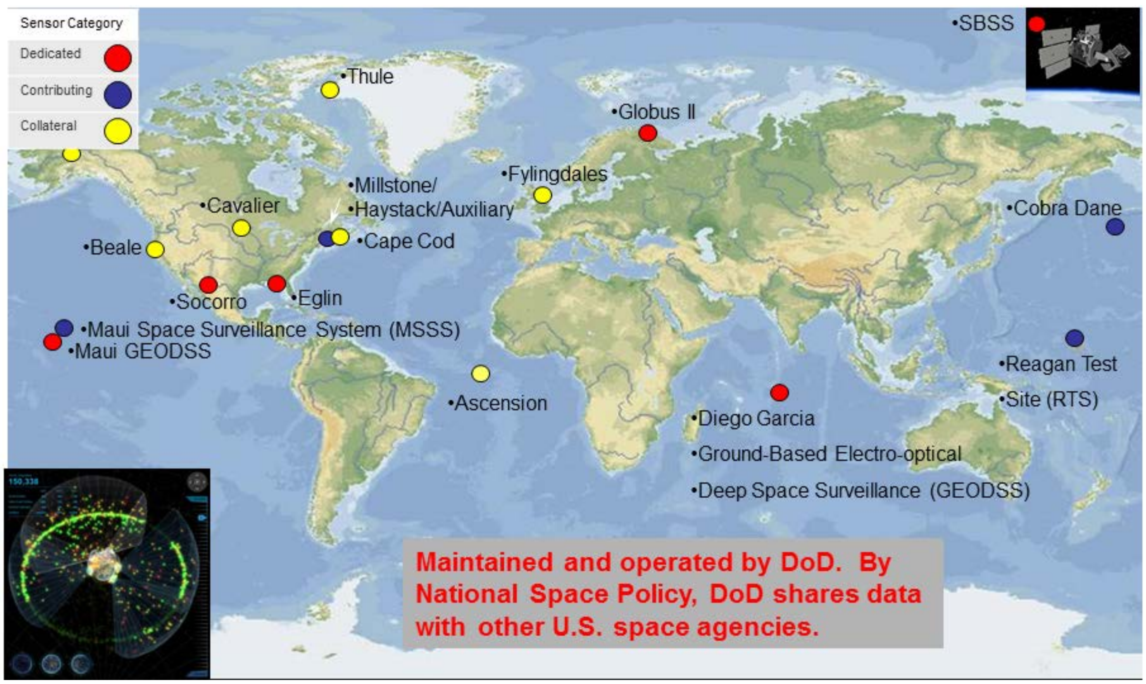
In the United States, metric SSA data generally comes from three main sources: the Space Surveillance Network operated by the DOD, non-DOD tracking networks, and satellite owner/operators themselves. No data provider within or outside the government currently has access to all critical data that could be used to support SSA services. Data sets and providers tend to have either tracking data on non-cooperative space objects, such

9 Element sets and state vectors contain parameters describing an object's orbital trajectory. Element sets are usually expressed in terms of Keplerian elements (semi-major axis, eccentricity, inclination, right ascension, and argument of perigee), while state vectors are expressed in Cartesian coordinates of position and velocity (x, y, x, xdot, ydot, and zdot), usually relative to the center of the Earth.

as space debris, or owner/operator data on active satellites. Combining tracking data and owner/operator data from various sources results in more accurate and actionable SSA services.

### 1. Space Surveillance Network (SSN) Data

JSpOC uses data collected by the SSN, a global network of ground and space-based telescopes and radars, to maintain a catalog of the predicted trajectories of human-generated objects in Earth orbit (Figures 6 and 7). It uses observation-level data to develop a catalog of space objects, which is then used to provide SSA information in the form of Conjunction Summary Messages (CSMs) to U.S. Government, commercial, and international entities.[10] The current major limitation of the SSN is that it cannot ingest non-SSN observations. The Non-traditional Data Pre-Processor (NDPP) software update will try to address this limitation, as discussed later in this chapter.

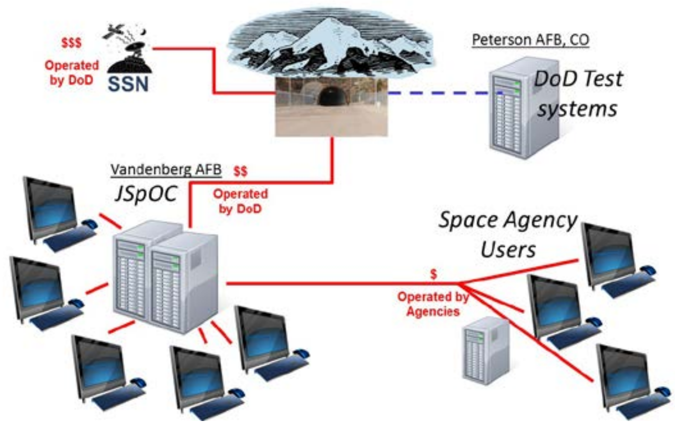



*Source*: Earle (2015).

*Note*: This image does not include the space-based GEO Imager or future planned sensors.

**Figure 6. JSpOC's Space Surveillance Network Sensor Locations**

[10] A Conjunction Summary Message is a fixed ASCII-formatted message that contains information about a conjunction between a high-interest space object and another resident space object (Space-Track.org website, "Conjunction Summary Message Guide," https://www.space-track.org/documents/CSM_Guide.pdf).




*Source*: Earle (2015).

**Figure 7. DOD System Overview**

JSpOC provides the data received from its network of sensors and through data sharing agreements at the following levels:

- Space surveillance network (SSN) observations: Observations refer to historical locations of space objects in orbit, relative to a sensor, provided to JSpOC, and used to create and update element sets for space objects.
- The high-accuracy catalog (HAC) is a compilation of special perturbation element sets[11] that are stored in state vector format with associated covariance.[12] The element sets are generated from SSN observations and used as the basis for current JSpOC analyses. Merging the HAC with other data sets is much more difficult than when using SSN observations.
- Special perturbation ephemerides are predicted future positions of space objects created by running the HAC state vectors and covariance through a special perturbation propagator.
- The public two-line element (TLE) catalog is a compilation of general perturbation element sets that are stored in TLE set format without covariance. TLEs used to be generated independently from the HAC using a general perturbation process, but are currently being generated from the HAC. TLEs are used for SSN queuing, and they are provided publicly on Space-Track.org. Because they do not have covariance, TLE data are nearly useless for further

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[11] Perturbations are the forces acting on an object in orbit other than gravitational attraction of a single other massive body. In the context of Earth-orbiting space objects, important perturbations include atmospheric drag, the gravitational pressure of the Sun and Moon, and the oblateness of the Earth. Special perturbation methods use numerical integration of the differential equations of motion.

[12] *Covariance* can be thought of as uncertainty in a state vector, which is an essential part of realistic propagation and prediction.

processing or integration with other data. However, TLEs are the most widely known and used SSA product, and they are still used as a basis for understanding SSA.

### 2. Non-SSN Data

SSA data can be collected at all levels of granularity from a variety of facilities around the world. DOD itself estimates that more than 350 potential SSA sensors are outside of the SSN (Government Accountability Office 2015). Commercial sources of SSA data include companies such as ExoAnalytic Solutions, Rincon, and SRI International. These companies provide radar, optical, and radio frequency tracking with sensors located around the world. Some scientific organizations have sold time on their telescopes or radars to companies interested in collecting data. The sensors being used are smaller, more diverse, and less trusted (by the DOD) than SSN sensors. The benefit of using a wide variety of sensors is the low cost, the diversity and global distribution, and the rate of innovation in new types and technologies. Some in the owner/operator community fear that these sensors cannot be trusted since their data are not verified at the same level DOD sensors' data are; others have used statistical strategies to detect and weed out inaccuracies.[13]

Internationally, China, Russia, Canada, South Korea, and some European nations (Germany and Norway) have SSA sensors (Weeden, Cefola, and Sankaran. 2010). A multitude of sensors is available around the world for SSA tracking, but many of them are not used to their fullest potential.

JSpOC currently ingests little non-SSN data, due to computer system limitations and security concerns. Sharing data across nations is an area with potential for future expansion.

### 3. Private Sector Owner/Operator Data

Satellite owner/operators usually, but not always, have highly accurate data about the trajectories of their active satellites.[14] Satellite owner/operators can use internal GPS, ground-based satellite laser ranging, or telemetry signal analysis to derive trajectory. Owner/operator data are important for accurate SSA because owner/operators can provide information about ongoing maneuvers instead of relying on sensor tasking to pick up the maneuver, which also increases the validity of future predictions that need to take planned maneuvers into account.

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[13] The Defense Advanced Research Projects Agency's Orbital Outlook program examined the viability of an open, competitive market for ingesting a wide range of data from non-traditional sources, including detecting inaccurate or misleading data (Blake et al. 2014).

[14] Satellite owner-operator data on the trajectory of their own satellites can be biased (from an accuracy standpoint), particularly if the data is derived from a single source.

## B. SSA Services

### 1. Government SSA Services

DOD, including U.S. Strategic Command (USSTRATCOM) and National Reconnaissance Office (NRO), NASA, the FAA Office of Commercial Space Transportation (AST) and the National Oceanic and Atmospheric Administration (NOAA) are the Federal organizations currently involved in the provision of civil SSA services. The details of the role and operations of NRO in SSA are beyond the scope of this project. FAA/AST is discussed in detail in subsequent chapters of this report. Here we discuss the SSA services provided by DOD (specifically USSTRATCOM), NASA, and NOAA.

#### a. Department of Defense, U.S. Strategic Command

JSpOC has primary responsibility for providing SSA services for all DOD space assets. Title 10 U.S.C. § 2274 authorizes JSpOC to also provide SSA data and information to domestic, international, and commercial satellite owner/operators on a voluntary basis, to the extent that it is consistent with the national security interests of the United States. JSpOC also maintains classified and unclassified versions of SSA data sets and shares some information in accordance with SSA sharing agreements with both foreign governments and commercial operators. JSpOC provides deorbit, reentry, and disposal/end-of-life support as well.

A relatively low number of USSTRATCOM personnel directly support SSA services for safety of space flight. Although some 400 personnel are assigned to JSpOC, only approximately 20 active-duty military, government civilians, and contractors are directly involved with management of the satellite catalog and interactions with commercial and foreign satellite operators. These individuals are mainly located within the Combat Operations Division (Curtis E. Lemay Center 2012). The remainder of JSpOC personnel primarily focus on national security functions, such as providing command and control of military space capabilities and providing space effects to warfighters in theater.

It is worth noting that at the time of publication, authority over the catalog maintenance and sharing of conjunction assessments was in the process of shifting from JSpOC to the Air Force’s 18th Space Control Squadron (18 SPCS). The details of this transition are not clear, and this study did not attempt to investigate it in depth, but interviewees suggested that the change was mainly in organization and chain of command and not operational. However, any discussion of issues pertaining to DOD provision of civil SSA services will still apply regardless of the named authority within DOD.

### 1) Data Sharing Agreements

The SSA information and STM services currently provided to commercial satellite operators by the U.S. military are the result of several decades of evolution. In 1958, NASA's Orbital Information Group (OIG) began sharing SSA data collected by the North American Aerospace Defense Command (NORAD). In 2004, the U.S. Congress modified Title 10 of the U.S. Code to give the DOD authority to carry out a "a pilot program to determine the feasibility and desirability of providing to non-United States Government entities space surveillance." This became the Commercial and Foreign Entities (CFE) Pilot Program. The Secretary of Defense delegated the authority to run the program to Air Force Space Command (AFSPC), which took over from NASA OIG and created Space-Track.org as the primary mechanism. In 2009, the delegated authority shifted to USSTRATCOM with the creation of the Joint Force Component Commander for Space. The CFE Pilot Program was renamed the SSA Sharing Program, and USSTRATCOM was designated the lead entity for negotiating SSA sharing agreements with commercial and foreign entities (Chow 2011). In 2010, the program's pilot phase was completed.

The services and data offered by USSTRATCOM under the SSA Sharing Program are broken into three levels. The first level of service is providing close approach notifications to all satellite operators, and occurs without the need for any formal agreement. The second level is the Space-Track.org website, which consists of publicly available two-line element (TLE) sets and selected other information. Any individual or organization can sign up for a Space-Track.org account to access the public information, but must sign an agreement with USSTRATCOM in doing so. The third level is advanced services supporting safe space flight operations during launch, on-orbit, and decay or reentry operations, and is available to commercial and governmental satellite and launch operators. These operators must sign an SSA sharing agreement to access the third level of services.

Currently, nearly all domestic commercial satellite operators and many international partners rely on the SSA information and STM services provided by USSTRATCOM to protect their satellites from collisions with other space objects. These relationships have been built slowly over a number of years, as both USSTRATCOM and the satellite operators developed an understanding of the risk of on-orbit collisions and the value of sharing data.

Since the creation of the SSA Sharing Program in 2009, USSTRATCOM has worked hard to market its value to satellite operators.[15] Through a combination of public articles, attendance at conferences, and provision of the first level of close-approach warnings, USSTRATCOM has gradually convinced a growing number of satellite operators that on-

[15] For example, JSpOC held discussions with domestic and foreign owner/operators in February 2015.

orbit collisions are a potential threat and their service can be of value. As of February 2016, USSTRATCOM has signed SSA sharing agreements with over 50 commercial entities (U.S. Strategic Command Public Affairs 2016).

The current SSA information services provided by JSpOC are not ideal for commercial satellite operators; interviewees noted a series of limitations such as product timeliness and poor representation and visualization, lack of transparency on data accuracy, lack of actionable data, and limited assistance by JSpOC in reviewing conjunction warnings.

The existence of freely provided SSA services presents a barrier to entry for a potential replacement civil SSA service. The close-approach warnings provided by JSpOC have convinced many satellite operators that the service is useful, even though there are little to no data on the accuracy of the warnings. This is particularly true for smaller satellite operators, or those from emerging spacefaring states, who do not have a significant degree of expertise or experience and lack the resources to develop alternative sources of data. Finally, although some international operators are reluctant to work with USSTRATCOM for political reasons, there is a level of trust in, and international recognition for, the service.

As of June 2016, eleven foreign governments have signed SSA sharing agreements with USSTRATCOM: Germany, the United Kingdom, South Korea, France, Canada, Italy, Japan, Israel, Germany, Australia, and the United Arab Emirates (U.S. Strategic Command 2014, 2016). The United States has also signed agreements with two intergovernmental organizations, the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

#### 2) JSpOC Software History

To understand the limitations of DOD's current provision of SSA services, it is important to explain the current software environment within JSpOC.

JSpOC currently relies on two legacy systems to maintain its satellite catalog and provide SSA services. The Space Defense Operations Center (SPADOC, pronounced "spay-dock") began development in the early 1980s by the Ford Aerospace Corporation, with SPADOC version 4C being made operational in the 1990s. For many years, SPADOC was the system of record to provide SSA and many other space control functions. In 2000, analysts working within Cheyenne Mountain began development of a second system known as the Correlation, Analysis, and Verification of Ephemerides Network (CAVENet) to augment SPADOC 4C's limitations. Over time, many operational functions have gradually shifted over to CAVENet, and SPADOC 4C has been reduced to a largely vestigial role.

DOD has launched multiple acquisitions efforts to replace SPADOC and CAVENet with more modern systems, all of which have faced significant challenges. In 2000, the

Combatant Commanders' Integrated Command and Control System (CCIC2S, pronounced "kicks") was created to replace and upgrade many of the critical systems in Cheyenne Mountain across air, missile, and space warning missions, including SPADOC. CCIC2S air and missile portions ran over budget, and the space portion was never delivered. In the mid-2000s, three new acquisitions programs were created to replace SPADOC and CAVENet: the Space C2 program, the Integrated SSA (ISSA) Program, and the Rapid Attack Identification and Reporting System (RAIDRS) Block 20. In 2009, all three were merged into a new program called JSpOC Mission System (JMS), which was slated to be completed in 2018 and includes three increments:

- Increment 1 provides the initial system infrastructure and data display capabilities.
- Increment 2 is "being developed to deliver most of the required mission functionality, including replacement of legacy data processing and analysis capabilities to directly task sensors, ingest sensor data, produce and sustain a high-accuracy space catalog, increase orbit determination and prediction accuracy, and improve capacity to support conjunction assessment (predicting orbit intersection and potential collision), orbital safety, threat modeling, and operational decisions" (Office of the Director, Operational Test and Evaluation 2013).
- Increment 3 "is expected to provide a battle management system. That program would help the Air Force prepare for threats to its satellites and bolster the Defense Department's space-event monitoring, planning, tasking, execution and post-event assessments" (Gruss 2016b).

JSpOC is currently awaiting delivery of Increment 2, though a further delay was announced in April 2016, this one for 19 months, pushing the Phase 2 Delivery until 2018. JMS has faced many similar delays in the past, and stakeholders remain concerned about overrun budgets and delayed improvements. Between 2006 and 2010, an estimated $132 million was spent on the three predecessors to JMS. Since 2010, the U.S. Air Force has spent another $492 million on JMS, and plans to spend another $337 between 2017 and 2021 (Department of Defense 2016, 535).

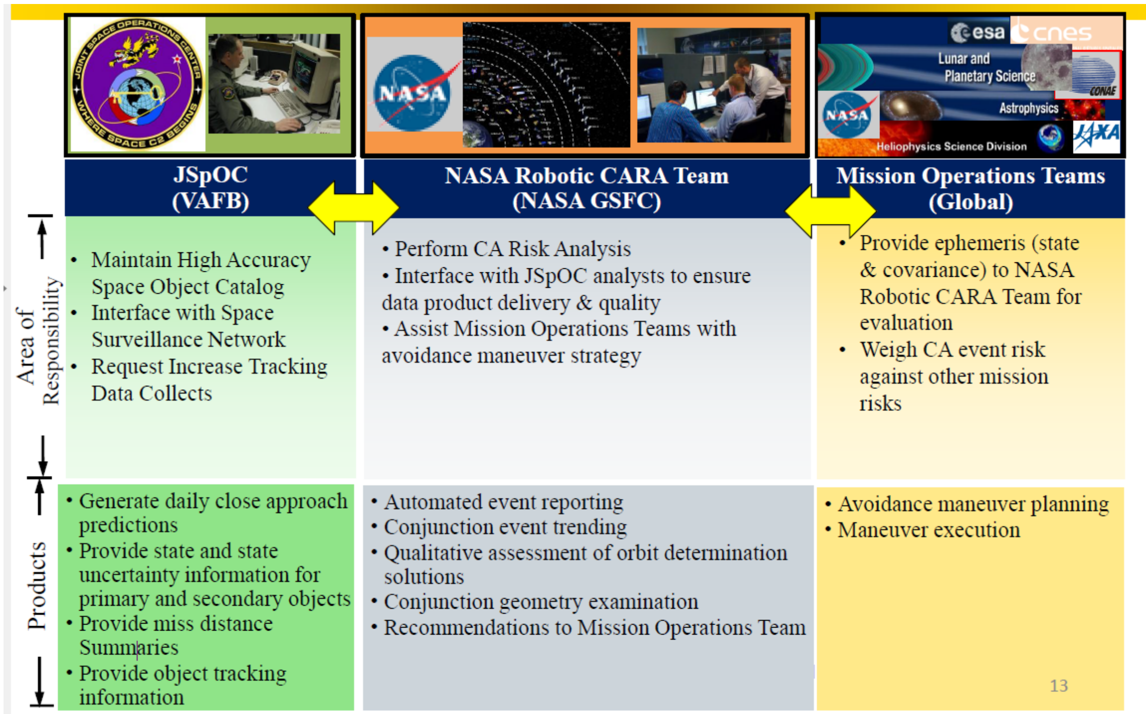
In April 2016, after the announcement of the latest JMS delay, Congress expressed a desire to withhold the Increment 3 funding of $18 million until DOD provided a clear plan for the funds (Gruss 2016b). Some fear that Increment 3 might overlap with the new Joint Interagency Combined Space Operations Center (JICSpOC) that was set up in conjunction with USSSTRATCOM, AFSPC, the NRO, and the rest of the space-centric intelligence community. JICSpOC's mission is to "create unity of effort and facilitate information sharing across the national security space enterprise…, and boost [JSpOC's] ability to detect, characterize, and attribute irresponsible or threatening space activity in a timely manner." This makes Increment 3's goal to better prepare the Air Force for threats against its satellites somewhat redundant (DOD Press Operations 2015). JICSpOC has also recently signed contracts with at least one commercial SSA provider, and has solicited requests for information for additional commercial services, calling into question its relationship with JSpOC and the viability of JMS (Ferster 2015).

As part of the JMS upgrade, the Air Force is also developing the Non-traditional Data Pre-Processor (NDPP). The purpose of the NDPP is to overcome the current communication limitations, allowing JMS to ingest and process a much wider range of data from sources such as commercial and foreign government satellite operators, research telescopes, and foreign government space surveillance systems, and convert them to a format acceptable by current mission systems. By ingesting and transforming a variety of data formats, NDPP will potentially allow non-SSN data to be validated, verified, and used operationally in JSpOC missions. Information is securely exchanged across security classification levels using the Defense Information Systems Agency's Cross Domain Enterprise Services (CDES), which allows the transfer of unclassified launch customer ephemeris files to a classified network containing the government's satellite catalog and analysis tools. The CDES permits the delivery of analytical results back to the launch customer at unclassified levels.

A key part of the NDPP is integrating Space-Track.org into the system. Space-Track.org is the main tool by which JSpOC currently communicates with and provides data to commercial and foreign entities. Installation of the NDPP will allow outside entities to upload data such as launch trajectories to Space-Track.org and have those data automatically ingested into JMS. This will eliminate some of the current inefficiencies in current processes that require manual input of data or delivery via CD.

**b. NASA**

NASA is both a provider and consumer of SSA data, and is heavily invested in and integrated into the current JSpOC system. NASA's Conjunction Assessment Risk Analysis (CARA) mission at Goddard Space Flight Center is responsible for the safety of NASA robotic missions along with selected robotic missions from other civil and commercial customers, and engages in conjunction assessment risk analyses for these missions. A visual representation of NASA CARA's mission is in Figure 8.




*Source*: Newman (2015).

**Figure 8. NASA CARA's Responsibilities**

NASA's Procedural Requirements for Limiting Orbital Debris requires NASA to use the USSTRATCOM high-accuracy catalog to conduct conjunction assessment analyses in NASA CARA for its maneuverable Earth-orbiting spacecraft with a perigee height of less than 2,000 kilometers in altitude or within 200 kilometers of GEO (NASA, Office of Safety and Mission Assurance 2009, Section 3.4). NASA reports its space events to JSpOC, including launches, maneuvers, and reentries. It also provides information on NASA operational missions to JSpOC for conjunction assessment purposes. NASA makes its project protection plans available to JSpOC to assist it in identifying vulnerabilities to NASA's robotic space systems. To serve the CARA mission, NASA Goddard funds a team of contractors who are embedded within JSpOC as CARA Orbital Safety Analysts (CARA OSAs). CARA OSAs provide dedicated and focused support, ensure mission safety and provide timeliness of required data streams to support NASA robotic space mission. Because CARA OSAs have access to appropriate CA systems and their time is paid by NASA, they can produce additional products for the benefit of NASA missions without taxing JSpOC resources. The CARA OSA's have the appropriate access and proficiencies to write scripts and tailor processes to quickly meet CARA mission needs and exigencies. NASA's agency requirements currently stipulate that all CARA-supported missions must use the CARA OSAs' capabilities.

Originally, the CARA OSAs were the primary individuals maintaining the high-accuracy catalog (HAC) and performing conjunction assessment (CA) screenings.

However, as it stands now, primary responsibility for maintaining the HAC and conducting the vast majority of CA screenings belongs to staff funded by the Air Force. The Air Force-funded individuals conduct CA screenings for approximately 1400 satellites, while the OSAs provide focused screenings and additional dedicated analyses for the CARA supported missions (about 65 satellites). This enables a favorable ratio of satellites to OSAs for the CARA mission and unique support above and beyond the standard JSpOC CA services. While the OSAs routinely update the HAC for CARA orbit regimes and related CA processes, they are not responsible for maintaining the HAC.

NASA has also invested significant resources in its own software and hardware that interface closely with the JSpOC systems, and is working on more effectively integrating space weather data into the JSpOC system. NASA also provides these services to the ESA satellites that are part of the global Earth observation constellation (referred to as the Afternoon Constellation or A-Train).

Both these investments give NASA a high degree of influence in the current system. As a result, NASA is unlikely to welcome a significant change to the status quo, unless it results in a better outcome for NASA (e.g., if NASA could save on funding OSAs after implementation of a new system).

#### c. National Oceanic and Atmospheric Administration (NOAA), Space Weather Prediction Center

NOAA is both a provider and consumer of SSA data and is heavily invested in and integrated into the current JSpOC system. As a provider, the NOAA Space Weather Prediction Center monitors and provides forecasts, alerts, watches, and warnings to a broad user community spanning the public and private sectors for space weather phenomena (e.g., solar flares and geomagnetic storms) that could have a negative impact on technological systems on the Earth’s surface or in orbit. This forecasting and warning service is important both for satellite launch and operations and for human space flight. A space weather event can disrupt or permanently damage satellites on orbit (Chu 2013). Understanding space weather phenomena and their potential impacts on these systems can help explain malfunctions and teach engineers how to build satellites that are more resilient. The Space Weather Prediction Center’s warnings are crucial for launch activities because a planned launch can be scrubbed due to an expected and unusually large space weather event. Human space flight also benefits from forecasts because humans can be evacuated from on-orbit stations if a large event that could potentially harm the astronauts is expected.

### 2. Private Sector Civil SSA Services

SSA capabilities in the private sector have increased significantly since DOD first began the SSA mission years ago. The private sector SSA industry was at one point almost entirely engaged in supporting the government; in recent years, however, these companies have expanded to support a growing demand by commercial satellite operators for SSA data and services to complement, and in some cases replace, those historically provided by the government.

Based on a market survey we conducted, companies today appear to be able to not only provide data and software as individual components, but also provide SSA services that are increasingly comparable to, or according to some companies interviewed, even superior to DOD's. Some companies have developed full commercial Resident Space Object (RSO)[16] databases using commercial, scientific, and international data. These databases are not yet on par with JSpOC's, but they are expected to be within a few years (Henry 2016).

Several companies currently provide data and services to augment JSpOC's free set of conjunction warnings. Many satellite operators view JSpOC's Conjunction Summary Messages as sufficient for their mission needs, but some commercial and governmental operators with more investment in space have seen the need to protect their assets by joining the Space Data Association (SDA) or purchasing services from SSA companies. One example is Boeing, which purchased ComSpOC services to monitor the launch and deployment of two commercial GEO satellites in 2015 (Ferster 2015).

In addition to individual for- and non-profit firms, private non-profit associations such as the SDA also serve the commercial space sector. SDA is a membership-based organization of satellite owner/operators that wanted more accurate and up-to-date collision avoidance data. JSpOC is currently unable to ingest data from owner/operators on the location of their satellites and planned maneuvers in an automated fashion, which can sometimes create errors in conjunction predictions. The analytical core of the SDA is the Space Data Center (SDC), run by Analytical Graphics, Inc. (AGI), and it provides the ability to ingest many different types of owner/operator positional data and maneuver plans. The SDC conducts in-depth analyses on collision warnings provided by JSpOC using DOD and owner/operator data. It also provides radio frequency interference mitigation tools, definitive contacts for collision avoidance, and radio frequency interference coordination to all 22 members of the SDA (Space Data Association 2013). In exchange for these services, all members pay fees.

The SDA was an important achievement for the commercial sector because: (1) the SDA has successfully protected sensitive owner/operator data; and (2) the SDA has ingested data of many different formats from various sources, a feat that JSpOC has unsuccessfully struggled to accomplish for years. However, the SDA does not possess an independent source of metric data (Level 1 as per Table 2) on space debris and non-member

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[16] An RSO is a natural or artificial object that orbits another body. For this report, RSO refers to objects orbiting Earth. It is typically used in the national security space world.

satellites, and it still relies on JSpOC as its primary source of data on non-member space objects. It has also had a variable relationship with JSpOC, with which it both cooperates and competes to various degrees.

# 4. Lessons from Other Domains

Several examples in other domains can provide insight into future models for civil SSA services. In principle, the approaches to data provision, dissemination, and access used in these other domains could be informative, whether as models or cautionary tales, for future decisions regarding civil SSA data and services.

We have chosen four examples to examine. The first example, the Minor Planet Center, is an international organization that ingests and checks data from a wide variety of sources on celestial objects in orbit around the Sun and then releases the data for processing internationally. The second, the U.S. Global Positioning System, is a DOD-provided capability that gives a wide range of civil, military, commercial, and international users access to free position and timing data, though their access to data differs. A third example, the International Committee on Global Navigation Satellite Systems, sets international standards for data accuracy and interoperability of satellite navigation systems in order to improve national data sets. The final example, the International Charter for Space and Major Disasters, is one where sensitive and potentially classified remote sensing data (as exist in SSA) are provided voluntarily to other countries to support humanitarian responses to natural disasters.

These four examples could inform a future civil SSA regime in two ways. First, they offer straightforward examples of how data sharing could work, given multiple players with different interests (civil, military, commercial, international, etc.), as well as different data sensitivities (e.g., the desire to protect classified information). Elements of these data-sharing systems could be implemented for an SSA system. They are not mutually exclusive and each could provide some insight into a potential future civil SSA system. Likewise, no single example is intended to be completely portable to an SSA system—only some of an example's features may be relevant. Second, they can offer general best practices and lessons for U.S. decision-makers when implementing a civil SSA regime—these lessons relate to organizational and developmental concerns, rather than the practicalities or specifics of a system. Table 3 is a summary of these lessons, and details are provided in the subsections that follow.

**Table 3. Summary of Lessons for SSA**

| Example | Aspect of the example relevant to SSA | Lesson |
|---|---|---|
| Minor Planet Center | Data sharing | • Feasible to have a decentralized, open data sharing system with minimal top-down planning; greater number of sources improves the quality of the information<br>• National security concerns and short required timescales in SSA make copying system difficult. |
| | Implementation | — |
| Global Positioning System | Data sharing | • Feasible to have a partially open data sharing system, where data/services available to military vs. all other users differs<br>• Feasible to have military entirely control data collection while having other user bases receive it free<br>• Providing data at no cost can deter growth of (potentially more innovative) alternatives<br>• Providing high-resolution data does not necessarily halt the development of competing systems when they pertain to national security. |
| | Implementation | • Government-funded data at no cost to user can be a source of innovation in use and driver of economic development, under certain circumstances<br>• Tension between the demand to open access to spur innovation and the desire to control access to minimize national security risks when system maintained by the military<br>• Interagency challenges over requirements, funding, and management of the capability given different user needs<br>• Difficulties of military maintaining control over access given growth of non-military users. |
| ICGS | Data sharing | • Feasible to see voluntary cooperation of national authorities to set international standards for interoperability of systems/capabilities—"better together than separate" |
| | Implementation | - |
| The Charter | Data sharing | • Provision on an "as needed" basis to any approved party. |
| | Implementation | • Removing limits on participation/access as system grew, in order to encourage participation and buy-in. |

## A. Minor Planet Center (MPC)

MPC operates under the auspices of the International Astronomical Union and is responsible for the designation of minor planets, comets, and natural satellites. MPC maintains a database of natural space objects' locations and orbits. Funding for MPC comes from a NASA grant, and it is housed at the Smithsonian Astrophysical Observatory at Harvard College. Observers around the world, from amateur astronomers to academic researchers at NSF-funded telescopes, collect and provide data voluntarily to others online through the forum on MPC's website. MPC is responsible for not only the collection of data, but also the analysis, quality control, and dissemination of the observations internationally.[17] Private citizens, researchers, and governments are all users of the MPC data and products released online.

### 1. Data-Sharing Model

The data-sharing model used by MPC is one of openness and international collaboration, and one where direct government control is largely absent. It is also an example of a system that can successfully function without the vast majority of the sensors being under the direct control of the coordinating entity.

A few key differences between MPC and SSA data limit the applicability of such an open system to SSA. First, MPC does not deal with sensitive items related to military or national security issues. Although its contributors may occasionally collect data on sensitive military satellites in orbit around the Earth, the data are not maintained in the MPC database, as they can be dismissed as irrelevant to the MPC's mission, which cannot be the case with SSA. Furthermore, the data MPC collects come almost entirely from non-military sources, which minimizes security concerns about sharing it. By contrast, SSA involves tracking of human-generated space objects, which will inevitably include objects sensitive from a national security perspective, and the vast majority of the current data comes from military data sources. Even for non-military objects, many commercial owner/operators do not want their ephemeris data shared out of concern over competitive advantage. As a result, it is unclear whether such an open data-sharing system as the MPC's could be applied to SSA, until concerns over sensitive data are outweighed by other potential benefits.

The second difference is the timeliness of the data requirements. For the vast majority of cases, the MPC has longer timelines of interest than SSA; most of the objects tracked by the MPC are cosmic in nature, and do not feature significant changes to their orbits over short periods of time. Thus, the MPC is under less pressure to have immediate access to a wide variety of tracking sources at any particular moment in time. By contrast, Earth-

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[17] International Astronomical Union website, "Minor Planet Center," http://www.minorplanetcenter.net/iau/mpc.html for more information.

orbiting objects tracked by SSA need several observations per day, creating more demand for timely data, which may not be able to be met by a network that is not directly tasked for SSA.

Differences aside, it is important to understand that MPC provides a potential model for how a wide variety of contributors can provide data, which can then be coordinated and managed by a central body while still being open for analysis. One model for a future SSA system could involve a central entity accepting data from a wide variety of sources, and providing a variety of data and services in return. However, this will likely only be possible if the national security concerns over handling the tracking of sensitive national security satellites can be resolved. This is a possibility, as some experts believe that it is increasingly futile for governments to keep their satellite locations classified when an increasing number of governments, commercial entities, and even individuals interested in looking for them can already determine their location. It is also possible to envision a system where satellite owner/operators have access to tracking data, but not necessarily the classifications of objects, thereby decreasing the risk of civilians or international users identifying the exact locations of U.S. military assets.

## B. Global Positioning System (GPS)

GPS is a constellation of 24–32 satellites in medium Earth orbit. Originally developed by DOD to meet military requirements for precision navigation and timing (PNT) needs, GPS reached Initial Operational Capability in December 1993 and Full Operational Capability (for military users) in 1995 (Pace et al. 1995). The total cost of deployment over two decades was over $10 billion, and was funded almost entirely by DOD (Pace 1996).

GPS was conceptualized and implemented for national security purposes, which is why it is funded almost entirely by the U.S. military. In its early years, however, it became clear that its potential applications were much farther ranging, and could include both civil and commercial functionality. By the time the system was fully operational, it had not only military but also civil, commercial, and international users (McNeff 2002).

The U.S. Government has allowed for civil use of GPS almost since the system's inception. In 1983, following the downing of Korean Airlines Flight 007 after it strayed over the Soviet Union's territory, President Reagan announced that GPS would be made available for international civil use as soon as it was operational, and the original system did indeed include a civil signal that was publicly accessible (Pace et al. 1995). In 1987, DOD assigned the Department of Transportation (DOT) the responsibility of establishing an office to respond to civil users' needs and work with DOD to implement GPS for civil use. In 1989, the U.S. Coast Guard became the lead agency for this effort, now known as the Navigation Center (Pace et al. 1995; Ripple 2005).[18] Then, at the 1991 International Civil Aviation Organization (ICAO) Air Navigation Conference, the FAA administrator announced that GPS would be available free of charge to the international community continuously for at least 10 years beginning in 1993. At the 1992 ICAO Assembly, this offer was extended to last indefinitely, with the United States promising to provide at least six years of warning prior to any termination of GPS services.

While GPS service is freely available, DOD has tried to control the accuracy of GPS signals available to non-military users. U.S. and allied military users receive the Precise Positioning Service (PPS) data, while all other users receive the Standard Positioning Service (SPS) data. Originally, a feature called Selective Availability (SA) was used to degrade the accuracy of the SPS signal to approximately 100 meters. The growing demand for a more accurate civil signal, including for its use in increasing the efficiency of air traffic management, prompted an interagency debate during the mid-1990s that resulted in the discontinuation of SA in May 2000.[19] In 2007, the next generation of GPS satellites were procured without this feature altogether (White House Office of the Press Secretary 2007).

In addition, the U.S. Government controls the export of some civilian GPS receivers to prevent their use in military applications, such as the guidance of aircraft or missiles.[20]

While GPS is a valuable resource for all its users (including the military, as intended), it has had a much greater commercial impact than was originally anticipated. Some experts are doubtful whether the government would have provided the service free to all users if the demand had been accurately predicted, given the scale of the initial investment. At the same time, by providing the service free to users, the government stimulated commercial GPS market growth more than would have occurred under the imposition of user fees. Executive Order 13642, "Making Open and Machine Readable the New Default for Government Data," dated May 9, 2013, cited GPS as an example of why U.S. Government data should be made openly available:

> Decades ago, the U.S. Government made both weather data and the Global Positioning System freely available. Since that time, American entrepreneurs and innovators have utilized these resources to create navigation systems, weather newscasts and warning systems, location-based applications, precision farming tools, and much more, improving Americans' lives in countless ways and leading to economic growth and job creation.

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[18] Navigation Center website, "U.S. Coast Guard Navigation Center." http://www.navcen.uscg.gov/.

[19] GPS.gov website, "GPS Accuracy," http://www.gps.gov/systems/gps/performance/accuracy/.

[20] Arms Control Association website, "Missile Technology Control Regime (MTCR)," http://www.armscontrol.org/documents/mtcr.

The U.S. practice of free provision of GPS data has also led Russia (GLONASS) and the European Union (Galileo) to adopt no-charge policies for their open global navigation satellite services. In any case, making the transition now to a fee-based system would be extremely difficult if not impossible (Pace 1996, 265). The other side of this is that it is unlikely that a serious commercial competitor to GPS would arise under the current system.

GPS is a unique system in both its development and rapid cross-sector adoption. However, there are aspects of both the data sharing system in addition to its implementation history that could be applied to the development of SSA services.

### 1. Data-Sharing Model

The data-sharing model used by GPS is a partially open one. Some of the GPS services—namely the SPS—are made available to all users. In addition, the U.S. military publishes an Interface Control Document (ICD) that provides details on how to process the GPS signal, and which specifies the level of accuracy the SPS will provide. The U.S. military retains control of the satellites and ground control segments, but has opened up the user segment to the private sector through the ICD. Any private sector innovation occurs only within the user/receiver segment of the capability. This is not strictly analogous to the current provision of SSA data through JSpOC. Although there, too, DOD controls the sensors, operates the database, and controls who can access sensor data, in SSA's case USSTRATCOM has not provided public details on the accuracy of its SSA products, let alone a guaranteed level of accuracy. This hinders the ability of civil and commercial users to innovate.

The civil/military user divide for the data is also relevant. One of the concerns with provision of SSA services is how sensitive data relevant to national security would be kept away from non-government users. This is not a concern for GPS, which is government owned and operated and has a specific office for handling civil users' needs and a clear bifurcation of services provided to the military vs. the civil sector. DOD also segments the military use of the system (PPS) from the civil/commercial use of the system (SPS), and has developed capabilities to enable it to deny adversary use of GPS or other Global Navigation Satellite System (GNSS) capabilities during a conflict. However, national security concerns for GPS and SSA are not completely analogous. When a GPS receiver accesses data to determine position, that receiver has no way of using the data to determine the locations of any other receivers, so the positions of U.S. military assets are not revealed. However, in SSA, a catalog of space objects or sensor observations on an object might include the locations of U.S. military assets. As a result, a bifurcation of services based on the same data effectively addresses the civil/military user divide for GPS, while for SSA the division may need to be in the data provided itself.

### 2. Implementation Lessons

GPS, like SSA within JSpOC, is owned and operated by DOD, but currently has a vast user base of non-military users. Over the life of the GPS program, DOD's attempts to control or limit access to the service have generated pushback from civil entities that had come to depend on the GPS data, and DOD has largely failed to control access (e.g., with the advent of third-party services to improve the accuracy of SPS, and with the protests against and eventual elimination of SA). Similarly, DOD has so far tried to centralize global SSA capabilities by making itself the almost sole provider of SSA data[21] and simultaneously making only the low accuracy TLEs available publicly on the Space-Track.org website. The growing civil and commercial demands for better data and services suggests DOD may face similar pushback on its attempts to control access to SSA as it did on GPS. This is evident already in the creation of SDA, and the growing interest worldwide in obtaining SSA-related products and services from the private sector (Hae-Dong 2015).

The National Space Policy of 2010 affirms that the United States must maintain its leadership in the service, provision, and use of global navigation satellite systems. The United States' provision of civilian access to GPS worldwide and free of direct user fees has furthered U.S. policy to maintain GNSS leadership. Some experts believe it is beneficial to the United States to have users worldwide rely upon GPS as opposed to the systems operated by Russia, China, and the European Union. The United States may similarly seek to maintain a global leadership role in the provision of SSA services.

The GPS example further offers a case study of what can happen after DOD lifts controls over the capability. With GPS, there was undeniable growth of commercial and civil applications, both immediately after it was announced that GPS would be free to non-military users and after it was announced that SA would be discontinued. Innovation is difficult to predict, but some experts expect that similar growth in civil and commercial applications of, and innovation in, SSA could result if high-fidelity SSA data were made freely available to all.

On the other hand, other experts view GPS as a case study that shows that military ownership and operation does not preclude innovation, as commercial uses for GPS still blossomed while DOD retained control. The key enablers for this was a clear designation that the user segment of GPS was open to innovation and the publication of the ICD, which enabled such innovation to occur.

Finally, the oversight of GPS has led to interagency disputes over the years over budget, management, and system requirements. While DOD retains control over the acquisition program for GPS, many other agencies and departments (notably DOT) have

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[21] As discussed elsewhere in this report, this is changing with the provision of SSA services by the private sector.

equities in establishing requirements and international users as well, which has led to disagreements over user needs and priorities. The current system of governance evolved slowly over two decades as a result of multiple interagency debates and policy decisions, and includes the GPS Executive Committee (ExCom) to provide interagency oversight and management of GPS. Similar issues might arise if provision of SSA for civil and commercial users becomes FAA/AST's responsibility, but still relies on DOD's capabilities and data (this possibility for future provision of SSA services is discussed in more detail in Chapters 6-7). Such a relationship might require the creation of a similar interagency body for SSA.

## C. International Committee on Global Navigation Satellite Systems (ICG)

The United Nations (UN) established ICG in 2005 to support voluntary cooperation on civil satellite position, navigation, and timing (PNT) services. The group membership includes core service providers like the United States (GPS), China (Compass/BeiDou Navigation Satellite System), and the European Union (Galileo), Russia (GLONASS), as well as many nations that use PNT services and applications even without having a constellation of their own; and those that provide augmentation services (United Nations Office for Outer Space Affairs 2016). ICG's goals include achieving compatibility and interoperability of worldwide PNT services and integrating PNT services into national infrastructure, particularly in developing nations (United Nations Office for Outer Space Affairs 2016). In addition to setting standards for interoperability of GNSS, the ICG also maintains a global network that monitors all of the GNSS services in near real-time, and provides warnings of service disruptions or anomalies.

### 1. Data-Sharing Model

The data-sharing model used by the ICG is one of voluntary cooperation of national authorities at the international level. While each of the primary PNT providers operates their own GNSS constellation, the ICG coordinates standards to ensure interoperability of the civil GNSS capabilities, as well as monitors them for potential errors and disruptions.

ICG is a valuable example because it is entirely built upon the concept of creating interoperable resources—something on which any SSA system will likely depend. The members understood that even though several participants already had fully functional PNT services for themselves, the data were "better together than separate"—having multiple PNT systems that can work together is better than having multiple PNT systems that all need a different receiver to use (United Nations Office for Outer Space Affairs 2016).

A similar model could be seen for the future of SSA, with several governments maintaining their own national SSA capabilities that are interoperable at some level, or involve some degree of data exchange. As is the case with GNSS, having multiple sources of SSA data could increase accuracy and help detect inaccuracies or deliberate tampering. In this model, SSA data can remain at the national level, but international standards would be in place to ensure the data are interoperable and as accurate as possible. Further, some independent, global monitoring of the data quality would be needed to ensure data meet these standards.

## D. International Charter for Space and Major Disasters

The International Charter for Space and Major Disasters (also known as "the Charter"), founded in 2000, is a collaboration among space agencies in which they share satellite-based Earth observation information to better support a disaster response effort. The current members include the European Union, China, Canada, the United States, India, Japan, and others.[22] Membership is voluntary and supported financially by each nation.

Any authorized user (currently, any national disaster management authority that has registered with the Charter's Executive Secretariat) is able to activate the Charter and obtain emergency response support for their own country or for a country with which they cooperate.[23] The Charter can only be activated for fast-onset disasters of natural or technological origin, and only within 10 days of the occurrence of the disaster (i.e., it cannot be activated for slow-onset events like droughts).

When an authorized user makes an activation request and the Charter accepts it, an on-call officer will analyze the request and scope and prepare an archive and acquisition plan using available satellite resources. A Project Manager will oversee the image acquisition and generate the relevant products and information to support the disaster response. Any Charter members can collaborate on the analysis and interpretation of the images if they wish. The products provided to the user are usually one or more maps of the affected area, which are free of charge and usually made public on the Charter's website.[24] Between 2000 and 2013, the Charter was activated 368 times ("International Charter Space and Major Disaster" 2013).

### 1. Data-Sharing Model

The data-sharing system here is one of provision on an as-needed basis to any approved outside party, using data from any or all participants. This model can be used for SSA if there is a conjunction warning with an international owner/operator or if a collision has occurred and debris analysis is required. In both cases, it would be in the best interests

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[22] United Nations, Office for Outer Space Affairs website, "International Charter for Space and Major Disaster," http://www.un-spider.org/space-application/emergency-mechanisms/international-charter-space-and-major-disasters.

[23] Ibid.

[24] Ibid.

of all space operators to use the existing SSA capability to mitigate the situation, even if the parties involved are not participants in the SSA system themselves.

### 2. Implementation Lessons

Similar to the origins of GPS, the Charter also broke down barriers to participation as it evolved. At first, only Charter member countries could activate the Charter and benefit from the data collected. Starting in 2012, however, a principle of “universal access” was adopted. Now, any country’s disaster response organization can register to use the Charter, and even if a country has no registered user, any registered user can still activate the Charter on the country’s behalf. Here, again, practices that place the fewest limits on participation or buy-in encourage the most civil participation and use of the system. This may seem like an obvious point, but it is important to consider in thinking about the future of SSA/STM. If one believes that space traffic is or will become a serious problem, the best system for managing it will be one that either incentivizes or requires participation from all space owner/operators. The Charter’s model is one of incentivizing its use by minimizing the cost and effort of gaining access to their information.

# 5. Market Analysis

## A. Methodology

STPI researchers conducted a market analysis of the users and non-governmental entity (NGE) providers (also called "vendors") of SSA products and services. We collected data from vendors via two survey questionnaires with the goal of exploring commercial capabilities. We sent an initial vender questionnaire in 2015. In 2016, we sent a second questionnaire to those vendors who had contributed useful information in the first round and to five additional vendors not contacted in the first round (Table 4). Both sets of questionnaires are available in Appendix C. We received responses from 12 of 14 vendors contacted, and 7 of 12 respondents provided complete cost data.[25]

We also held discussions with 17 current and potential future users of SSA software (Table 5) with the goal of determining SSA needs of commercial launch providers and satellite owner/operators. The questions posed to users are also available in Appendix C.

In reviewing the results of the market analysis, three caveats are worth noting. First, the scope of the task did not include verifying or validating company capabilities. One way to do so would be to organize a vendor capability demonstration that would show if and how companies' commercial off-the-shelf and government off-the-shelf software can meet the SSA system requirements for processing and fusing various types of data, creating analytical outputs, and how the software and their capabilities compare with current JSpOC products and services.[26]

Second, many of the companies that responded did not wish for their capabilities to be made public, and almost none of them were comfortable sharing pricing information. Company information presented in this section is generic enough that it would not be feasible for a reader to identify the individual companies or their capabilities.

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25 MIT Lincoln Laboratory and Aerospace are federally funded research and development centers (FFRDCs) that are both involved with SSA service provision and research. Because they did not respond with prices to the original survey, and because they are invested and have equities in the current system, we did not follow up with them in 2016.

26 We envision the vendor demonstration to be similar to a small exposition, perhaps as part of a request for information where multiple vendors are invited to demonstrate their particular software packages and solutions in a shared space using a common input data set. FAA/AST and other stakeholders would be able to visit the demonstration, see the capabilities of the various software packages, and compare and contrast various capabilities with the current government system and with each other.

**Table 4. Software/Service Providers Surveyed in 2015 and 2016**

| | 2015 | | 2016 | |
|---|---|---|---|---|
| | Contacted | Responded to Survey | Contacted | Responded to Survey |
| **a.i. Solutions** | Yes | Yes | Yes | Yes |
| Aerospace (FFRDC) | Yes | No | No | No |
| **Analytical Graphics, Inc.** | Yes | Yes | Yes | Yes |
| **Applied Analytics Solutions, Inc.** | No | N/A | Yes | Yes |
| Boeing Company | No | N/A | Yes | Yes* |
| CAESAR | Yes | Yes* | No | N/A |
| CS Systems | Yes | Yes* | No | N/A |
| Kratos | Yes | Yes* | No | N/A |
| **Lockheed Martin** | No | N/A | Yes | Yes |
| MIT Lincoln Laboratory (FFRDC) | Yes | No | No | N/A |
| North Star | No | N/A | Yes | Yes* |
| **Omitron** | Yes | Yes | Yes | Yes |
| **Schafer Corporation** | No | N/A | Yes | Yes |
| Space Data Association | Yes | Yes* | No | N/A |
| **Solers** | Yes | Yes | Yes | Yes |
| SpaceNav | Yes | No | No | N/A |
| TASC Engility | Yes | Yes | Yes | No |

* The response either did not provide cost data or did not inform the market analysis.

*Notes*: Companies in bold provided complete cost data. N/A means not applicable (i.e., the organization was not contacted, so did not have the option of responding).

**Table 5. Users Surveyed**

| Launch Operators | Satellite Operators | Other Users |
|---|---|---|
| Orbital Sciences | Avanti | Bigelow |
| Space X | Eutelsat | Boeing |
| Virgin Galactic | Inmarsat | Lockheed Martin |
| Blue Origin | Intelsat | Sierra Nevada |
| XCOR | SES | Vulcan Aerospace |
| | StarOne | California Polytechnic State University, San Luis Obispo |

Lastly, company capabilities are current only as of the writing of this report. These capabilities are evolving rapidly with new companies acquiring them almost continually.

Figure 9 lists the companies by the areas that they serve. The following sections provide additional detail as to their capabilities.

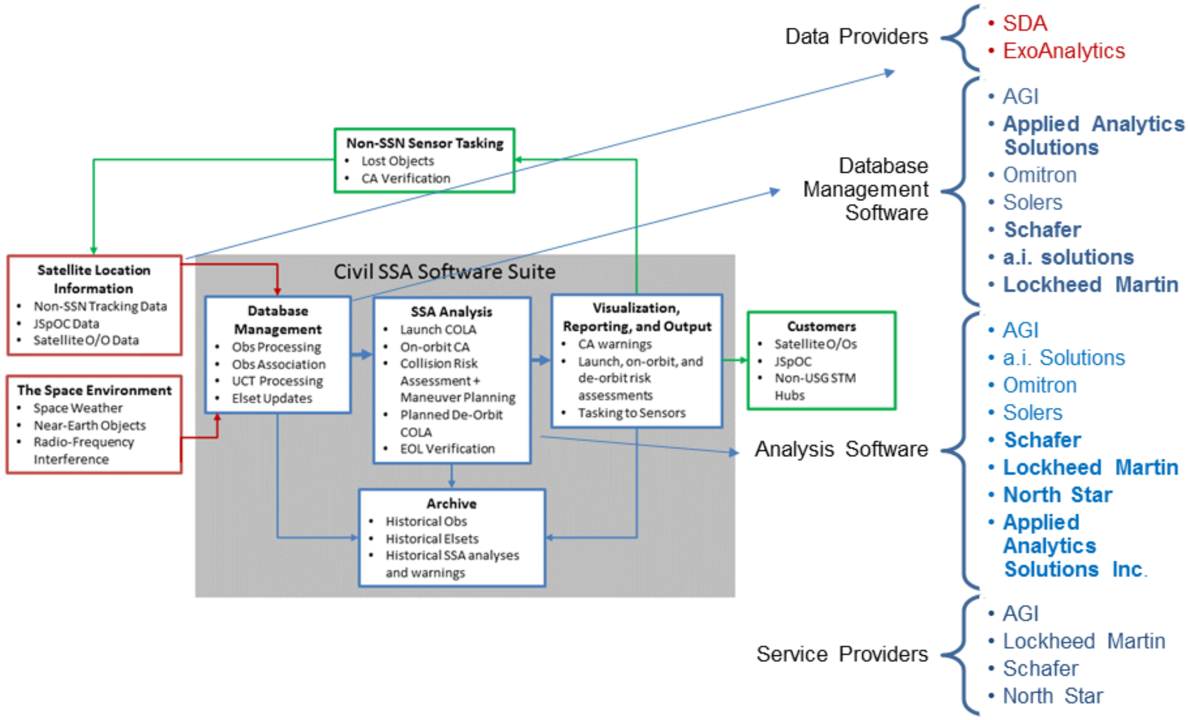



**Figure 9. List of Provider Companies**

## B. Overall Findings

### 1. Launch and Controlled De-Orbit Collision Avoidance (COLA) Services

All of the technical experts, vendors, and users surveyed indicated that pre-launch COLA and controlled de-orbit assessments were more technically challenging than on-orbit conjunction assessment (CA). The challenges stem largely from the increased number of variables and uncertainty involved in the dynamics of launch and reentry as compared to the dynamics of on-orbit operations.

Furthermore, commercially available software tools that we identified were designed for on-orbit CA, not for detailed launch or reentry analyses that involved transition through the atmosphere. The software tools could handle launch and de-orbit analyses for trajectories above 150 kilometers because those are similar to on-orbit CA. Analyses for trajectories below those altitudes would likely require specialized software. Current DOD systems do not handle trajectories below 150 kilometers, either.

Finally, data necessary to confirm and validate launch and reentry activities, specifically on-orbit infrared sensors, are not currently available outside the U.S. military, and are not expected to be available from non-military sources in the near future.

### 2. On-Orbit Conjunction Assessment (CA) Services

Existing on-orbit CA services provide basic warnings of potential close approaches, but they typically do not provide satellite operators with enough data to do more than a cursory validation of a specific warning, nor do not they provide the data necessary to detect false negatives or conduct independent assessments. Further, most users surveyed considered the existing services to be neither timely nor responsive enough to meet operational needs. Most satellite operators use more than one SSA service provider in order to get a more complete and robust solution to their needs.

### 3. Data Sets and Data Set Providers

Currently, no data provider within or outside the Federal Government has access to *all* critical data that could be used to support SSA services. Data sets and providers tend to have either tracking data on non-cooperative space objects or owner/operator data on active satellites. Combining tracking data and owner/operator data results in more accurate and actionable STM services.

## C. Overall Vendor Capabilities

All seven of the companies that responded fully to the 2016 market survey claim SSA capability in three areas: analysis software (including "value-add" software), database management software, and commercial SSA data. Most companies surveyed sell software directly; however, some companies are only willing to sell services that rely on their software. Some companies provide a fully commercial SSA solution from data integration to processing and reporting. These services are already being sold to commercial satellite owner/operators and a few government customers. Almost all companies have worked with DOD or NASA on conjunction warnings, risk analysis, or catalog management software. All seven companies have had direct experience with JSpOC software. Most of these seven have been supporting JMS. One company designed and implemented the Integrated Space Command and Control system and is maintaining it, and another maintains the Astrodynamics Support Workstation (ASW). Two companies have significant experience with the intelligence community.

## D. Analysis Software

All seven companies that responded fully to the 2016 market survey have developed software to process on-orbit conjunction analyses. Six companies claim to provide launch and reentry analysis in addition to on-orbit analyses, while one company can complete only launch and on-orbit analyses. On-orbit notifications are often automated when a threshold, set by the user, is met. For example, a user can define the parameter of a close approach, and if another object is expected to pass that distance, the owner/operator will be notified. Launch and reentry analyses are more difficult to accurately predict, and it is unclear if more than one of these companies have performed launch and reentry analyses commercially. Currently these are conducted for the U.S. Government by Aerospace, an FFRDC not included in this market analysis.

## E. Value-Added Capabilities

Beyond the analytical processing core of each company, many provide "value-added" improvements beyond what JSpOC provides today. Most of these services are included in the purchase of the basic analysis software, but they were priced separately for the purpose of this project. These software improvements include web-based user interfaces that allow users to log into the company's website to review conjunctions. Many of the companies surveyed also provide visualizations for conjunction warnings instead of the text-only warnings DOD provides. Users identified these value-added services as key deficiencies of JSpOC. The information provided in addition to the visualization varies by company but can include the conjunction window and time of closest approach; minimum range and maximum probability of collision; and details of both satellites' tracking history, orbital accuracy, neighborhood watch, matching orbit alerts, and more. Additionally, many companies provide risk analysis to increase the user's understanding of the risk associated with the close approach.

## F. Database Management Software

Three companies surveyed claimed to have database management software, while the other four proposed building a database management system as needed. All companies have had some level of experience either building or maintaining a database for clients, but the four that need to build the systems do not have commercially available options. These databases can ingest DOD SSN, commercial, scientific, and owner/operator data.

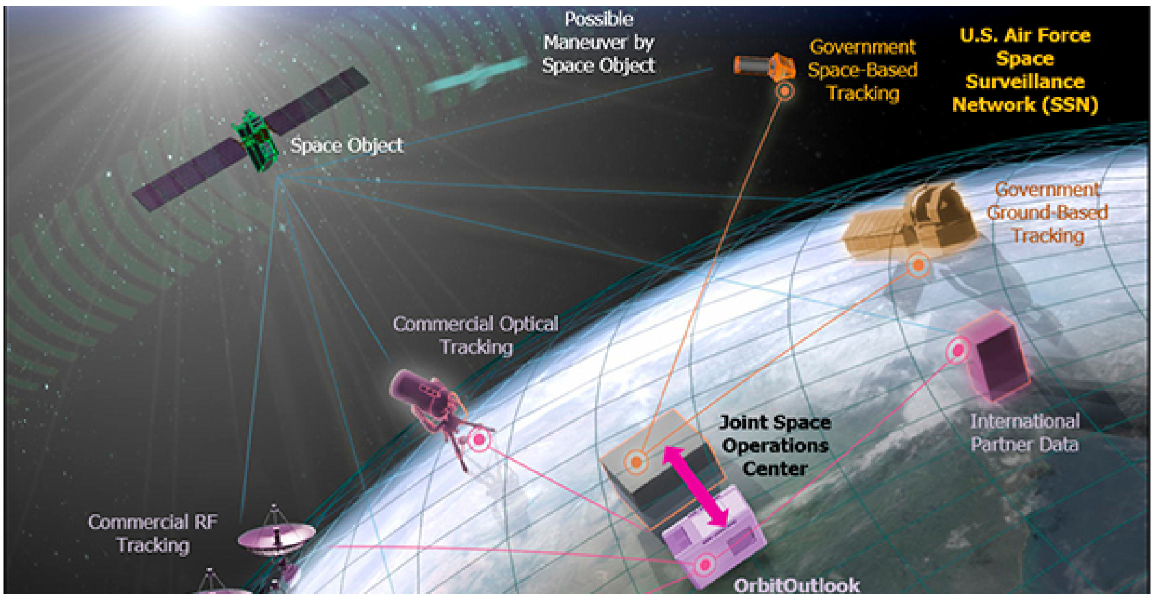
All companies provided prices for software, while only five companies provided prices for services. This is likely either because the company does not have mature enough capability to provide a service to FAA/AST or the company believes SSA is an inherently governmental function and contracting it out is inappropriate. Maturity of database management capabilities varies based on how the data have been used in the past. Three companies have used databases for government customers or owner/operators while only one company has used its database for purely commercial purposes.

## G. Commercial Data

We had discussions with representatives of two companies that provide commercial SSA data. In addition, many of the software providers shared information about data companies with whom they work. One software and services company, for example, has contracts with 18 observatories with over 70 sensors on four continents tracking objects. This company has an independent database of 1,500 resident space objects (RSOs).

Another company has a database with 9,000 RSOs. When combined with JSpOC's catalog, these databases account for over 15,500 RSOs. This company currently has the capability to view GEO using deep space C-band radar, passive radio frequency, worldwide optical telescopes, and L-band passed arrays, and will eventually have space-based optical sensors.

Other companies provide optical tracking systems for discovery, tracking, or identifying RSOs. They sell portable or fixed telescopes on gimbals that allow for 26-bit pointing resolution and accuracy on order of one micro-radian. Figure 10 shows how commercial sensors can supplement DOD sensors.




*Source*: DARPA (2016).

**Figure 10. Commercial Sensors Supplement DOD's SSN**

## H. Other Issues Identified in End-User Survey

### 1. Definitional Clarity

Definitions play a critical role in successful development of SSA services. Even small changes in the definitions of SSA services can lead to significant changes in the required data and architecture. For example, a launch COLA for a planned launch trajectory above 150 kilometers requires a different set of data and analytical tools than a planned launch trajectory to only 100 kilometers. The lack of clarity and standardization of definitions can also adversely affect SSA operations and communication between SSA service providers and satellite operators.

As a result, there is a need to develop clear and precise definitions of what specific services are necessary across the launch, on-orbit, and reentry portions of space activities. The definitions will determine what data and software tools are required to build the analytic products, which in turn determine the architecture that must be developed to provide SSA services to end users. While recent progress has been made in developing standard terminology for detecting and alerting on conjunctions across the space community (e.g., Consultative Committee for Space Data Systems (CCSDS) *Recommendation for Space Data System Standards: Conjunction Data Messages*—more work is needed.

### 2. End-User Capabilities

Some satellite operators, particularly new ones, still lack robust risk analysis and contingency planning processes to deal with conjunction warnings and developing avoidance maneuvers. Thus, SSA service providers need to offer more detailed collision risk analysis and avoidance maneuver planning services to support these operators. Doing so could also help develop norms and operator best practices, while also helping new actors get up to speed on safe space operations.

### 3. Other Requirements for Future Services

Feedback from vendors and users provided some clear requirements for future SSA services. Future services should be designed from the start to have the capacity to handle accelerating growth in the number of satellite operators, the total number of space objects, and the volume of tracking data necessary to deal with the increases in space activities. Development of future SSA services should explicitly define end-user needs, measures of effectiveness, and measures of performance, all of which should be incorporated in the system design process. Future SSA services should be accessible, transparent, and responsive to end-user needs as well as flexible and scalable to adapt to the changing nature of space activities.

### 4. Gaps in Current SSA Services

Overall, the most significant gap in current SSA services is the lack of a single data set or data provider within the government or in the private sector that has access to *all* the critical data that could support STM services. As a result, false positive and false negative rates are significant for existing conjunction warnings.[27] Additionally, the relative inflexibility of the organizations currently providing SSA services to adopt new data

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[27] Based on a study conducted by satellite operator Intelsat in 2012. Although the study has not been released publicly, the study conclusions were discussed publicly by then-Intelsat Vice President Richard DalBello at an event hosted by the Marshall Institute. Video of the event and DalBello's briefing slides can be found at http://marshall.org/events/space-situational-awareness/.

sources and new algorithms makes it difficult to adapt to changes in the space environment and be responsive to end user needs.

As the market survey revealed, many data sources exist beyond the Space Surveillance Network (SSN), and solutions to data fusion are beginning to emerge. For example, the Defense Advanced Research Projects Agency (DARPA) OrbitOutlook (O2) program is working toward providing a way to acquire and process large amounts of data from diverse sources—including civil, commercial, academic, and international partners—to enable "everyone monitoring space debris to better understand the quickly evolving space environment and evaluate when satellites are at risk" (DARPA 2016). In June 2016, O2 completed integration of live data feeds from seven SSA data providers that together have more than 100 sensors around the world.

# 6. Approaches to Providing Civil SSA Services

In this chapter, we discuss four approaches to providing civil SSA services to civilian, commercial, and international users. The approaches are as follows: continuing with the current JSpOC system within DOD (Approach 1 in Figure 11) or choosing an alternative wherein services are provided by a civil government entity (Approach 2), by industry itself (Approach 3), or by an international organization (Approach 4). Each approach, has its own set of strengths and challenges (summarized in Table 6). The sections that follow provide details.

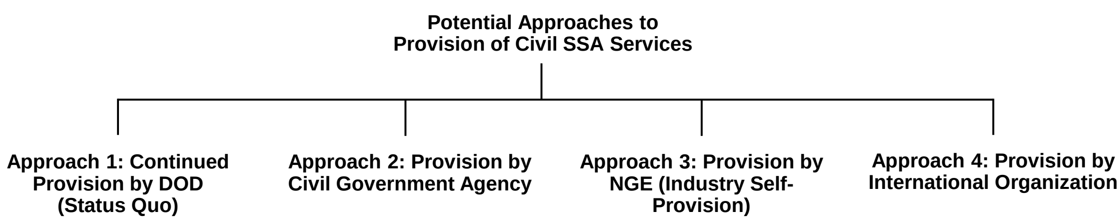


**Figure 11. Approaches Considered**

**Table 6. Strengths and Challenges of *Approaches* to Providing Civil SSA Services**

| Approach | Strengths | Challenges |
|---|---|---|
| 1. Continued Provision by DOD (Status Quo) | • Continuity in provision of services<br>• No additional latency or increased friction in system<br>• Minimizes some level of duplication that will necessarily occur if a civil agency were to provide SSA services in addition to DOD<br>• Allows the national security community to continue to exert control over SSA data to protect sensitive activities and satellites | • Inflexibility of DOD to respond rapidly to civil and commercial users' growing needs or advances especially in software technology<br>• DOD systems (JMS) delayed and not ready for full implementation<br>• Continued gap between SSA data collection agency and future regulation/oversight agencies<br>• Reduced focus on industry needs as compared with DOD mission needs<br>• Future increases in potentially hostile or threatening activities may cause de-prioritization of civil and commercial operator needs<br>• More difficult to extend to an international SSA regime |
| 2. Provision by Civil Government Agency | • Greater flexibility to respond to industry needs and collaborate internationally (e.g., add non-U.S. sensors or extend to an international regime)<br>• Greater flexibility to incorporate non-DOD data and leverage commercial advances in software<br>• Ability to mandate the use of SSA services through licensing<br>• Easier pathway to civil STM and international coordination<br>• Provides redundancy to a critical national security and public safety relevant system | • Additional costs into tens of millions of dollars annually<br>• Creates some duplication of activities<br>• Learning curve for a civil agency to develop operational expertise<br>• Need to address concerns over possible confusion stemming from multiple satellite catalogs<br>• Potentially lower ability to mask national security activities in space, particularly if using non-DOD data sources |
| 3. Industry Self-Provision | • Supports a more industry-driven community of practice<br>• Low cost for the Federal Government<br>• Provides redundancy to a critical national security and public safety relevant system | • Enforcement would be difficult<br>• Industry may be unwilling to bear the cost, particularly for new and smaller satellite operators<br>• Concerns over masking national security activities in space, particularly if using non-DOD data sources |
| 4. Provision by International Organization | • End-state an SSA system needs to be in given that it is an inherently international activity<br>• Could provide the most accurate data and services, if it included access to data from multiple countries<br>• Would create a level playing field for all countries and satellite operators, regardless of national capability<br>• Could help support the development of international standards for space traffic management<br>• Provides redundancy | • Lack of trust in international institutions<br>• High transaction costs to negotiate and implement<br>• Would need to overcome significant challenges stemming from sensitive national security activities in space<br>• Unclear which international body would have the competence, credibility, and resources to perform the service<br>• Issues of sovereignty to be negotiated and decided |

## A. Approach 1: SSA Services Provided by the Department of Defense

JSpOC has provided SSA services to civil, commercial, and international users for several years. Although JSpOC has publicly expressed interest in passing off the services for commercial providers to a civil government agency, the mission could theoretically remain with DOD in an approach similar to the GPS system described in Chapter 4. In fact, some of our interviewees suggested that one reason the Joint Interagency Combined Space Operations Command (JICSpOC) was stood up was in response to JSpOC's inability to ingest commercial and other observations.[28]

### 1. Strengths

One of the strengths of this approach is that it would afford continuity in provision of services; owner/operators would not have to learn a new method for interaction with the government for SSA services. According to some proponents, this approach would likely also provide the best chance of minimizing national security risks. Keeping all of the DOD-collected data under DOD would allow national security personnel to control access to SSA information and services (as has been the case with GPS), which, in turn, would allow DOD to protect the existence and location of sensitive national security space objects. This approach would also limit additional latency in the system created from having multiple organizations involved with providing a single service. Finally, it would minimize some level of duplication that would necessarily occur if a civil government agency were also to provide some civil SSA services, in addition to DOD continuing to provide national security SSA services.

### 2. Challenges

The downside of continuing provision of SSA services by JSpOC would be continued limitation in the ability of DOD to respond speedily to users' growing needs or to advances in technology. DOD's reluctance to open up the SSA data sets, algorithms, and processes to external review and scrutiny results in high uncertainty in the data and, therefore, a large number of false positive rates. In large part, DOD's acquisitions process causes the lack of agility. The process is not well suited to developing IT systems or for mission areas with highly volatile requirements. JSpOC's legacy software systems, SPADOC and CAVENet, were created to track incoming ballistic missiles from adversaries, not space objects, which exacerbates the problem.

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[28] Whether the activities of the JICSpOC will include the type of civil SSA services to support safety of space flight that this project focuses on is uncertain. It is more likely the JICSpOC will focus on interaction with the commercial satellite operator community to support national security SSA services, such as detection and characterization of hostile threats to satellites.

DOD's continued provision of civil SSA services may potentially entail proportionally less focus on civil and commercial needs, which would be increasingly problematic as civil and commercial satellites and space objects increase in number. DOD's mission is to protect the warfighter and national security in space, and protecting civil satellites is in DOD's interest only to the extent that it protects the space environment for smooth operation of U.S. Government assets. If JSpOC has limited resources and must choose between supporting national security assets and other users, it may be forced to shift its focus away from other users. In the event of a space-based conflict, this conflict of interests would be even worse.

This approach is also the least likely to be extensible to an international system, which would be problematic given that SSA is an inherently international issue. Lastly, given DOD's reluctance to become a global space police force, the gap between SSA data collection and regulatory authorities would remain large under this approach. Some experts argue that it is crucial to have both the SSA and STM capabilities unified under a single civil agency so that the entities performing oversight, licensing, and regulation have the data necessary to inform their rulemaking and enforcement. As long as DOD retains the authority for SSA provision, there will be a continued gap between regulation and agencies doing data collection and dissemination.

## B. Approach 2: SSA Services Provided by a Civil Government Agency

If SSA for civil, commercial, and international use is deemed an inherently governmental function but outside the scope of the military, then a civil agency could augment SSA services that DOD now provides. Options within this approach depend on whether the civil agency plans to use only government software and personnel or a mixture of non-governmental entity (NGE) software and personnel. These options are discussed in detail in Chapter 7.

Several civil agencies or departments, either existing or newly created, could provide SSA services to the civil and commercial sector. Entities currently under discussion include the Office of Commercial Space Transportation (AST) as part of FAA or directly under the Department of Transportation (DOT); the Federal Communications Commission (FCC); the Department of Commerce (DOC); or a newly created agency under which many safety, regulatory, and oversight functions could be centralized, perhaps like a Coast Guard for space.[29]

FAA/AST has potential because it currently has authority over launch vehicles and DOT already handles transportation on Earth, which some say provides the agency with a

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[29] For a more complete discussion of this notion, see Bennett (2011).

similar mission when dealing with "transportation" in space. FCC has potential due to its current licensing of satellites communicating with Earth. The Office of Space Commerce within the DOC would be a reasonable choice because it has a clear mission to promote economic development and commercial activities in space (Pace 2016).[30] Finally, an entirely new space agency could bring all currently separated parts of U.S. space oversight into one agency. This would allow a single point of contact to have both regulatory and operational experience, compared to current agencies that have either regulatory (e.g., FAA and FCC) or operational (e.g., NASA) experience (Bennet 2011).

### 1. Strengths

The strength of this approach is that the civil agency would be more likely to pay due attention to the burgeoning needs of industry and international partners, and thus would enable accurate and timely delivery of SSA services, making civil services more actionable than those DOD currently provides.

The approach would also allow for on-orbit STM authority to a civil agency more readily than under the current system. A civil agency that has data on private sector space activities would be better positioned to provide oversight of those activities. Additionally, the civil agency, if given regulatory authority by Congress, could *mandate* the use of SSA services by U.S. commercial entities. Requiring use of SSA services could increase responsible behavior in space, making space safer for all active satellites and future on-orbit activities such as commercial human space flight and satellite servicing. Additionally, having SSA services completed outside of DOD would allow greater flexibility to incorporate non-DOD data and leverage commercial advances in software. This approach could make international collaboration easier, especially when adding international sensors, and standardizing best practices across all space users. Finally, provision of civil SSA services by a civil agency or non-DOD source would provide a level of redundancy for DOD's provision of national security SSA.

With this approach, a civil agency would be able to certify NGEs to provide SSA services to commercial entities, as is the case under privatized air traffic control systems. This approach would support the commercial SSA industry, while protecting civil space assets through government oversight. A set of government-created guidelines could provide standards each NGE would be required to uphold. Additionally, the overseeing agency would have the purview to conduct safety checks on the NGE.

The strength of the certification option within this approach is that it would be a relatively low cost burden for the government. Fees associated with SSA services for

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[30] Office of Space Commerce website, "Commercial Weather Data Pilot (CWDP)," http://www.space.commerce.gov/.

owner/operators could be paid directly by the users, or they could be subsidized by the government. In either case, the government would not have to stand up a new system and processes for service augmentation. Additionally, this approach would allow for the greatest flexibility for service improvements because the process would be outside the government, allowing for more rapid development and deployment of new capabilities compared to traditional DOD acquisitions programs. To foster competition in the private sector, the government could also certify multiple providers and allow owner/operators to choose which provider to use.

### 2. Challenges

The challenges of this approach are that, at least initially, it would require duplication of some efforts between DOD and the civil agency. It also would involve a lot of organizational learning. The civil agency would need to develop the capability to process SSA data, maintain a database, and provide services that are trusted by end users. In addition, potentially adding data sources other than the SSN to improve the quality of SSA products would introduce complications in maintaining control of data on national security space objects. Finally, this approach would potentially decrease a service provider's ability to mask national security activities in space, particularly if using non-DOD data sources.

Certifying NGEs to provide SSA services to owner/operators would introduce several policy challenges related to whether the provision of SSA services and information is an inherently governmental function;[31] who would bear the cost of SSA services from certified NGEs; and how potential liability incurred by a certified NGE for providing SSA services would be resolved.

## C. Approach 3: Self-Provision of SSA Service by a Non-governmental Entity (NGE)

An NGE similar to the Space Data Association (SDA), or the SDA itself, working with a vendor (or set of vendors) that provides SSA data, analysis software, and analytic reports on conjunctions, could begin providing the full suite of SSA services. With this approach, a licensing requirement could be placed on all U.S. Government-licensed spacecraft to obtain membership in an SDA-like entity. The approach would require some concessions from DOD on its sharing of data at a higher level than the publicly available TLEs. The NGE could choose to purchase data from any vendor (or set of vendors), and change providers as per its needs. This approach could uphold a set of industry-derived best practices for SSA data collection, processing, and products.

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[31] The term *inherently government function* refers to an activity that Federal Government employees must perform (not contracted out) because "it is so intimately related to the public interest." We discuss this concept in detail in Chapter 9, Section A.

### 1. Strength

One benefit of this approach is that it would support a more operator-driven community of practice. It would also be a low-cost approach for the Federal Government because U.S. industry is likely to pay in full for fees associated with self-provision. Finally, this approach would provide redundancy to a critical system relevant to national security and public safety.

### 2. Challenges

A challenge associated with industry self-provision would be that some companies may be unable or unwilling to bear the cost for the service. This would be particularly difficult for new and smaller satellite operators, potentially leading toward non-compliance. Options would also be limited for requiring foreign satellite operators to comply, potentially creating an additional competitive burden on U.S. satellite operators. In theory, this approach would also lack provisions for enforcement for non-compliant actors, making the situation more difficult. Finally, this approach would likely restrict open access to data, which could hinder scientific study, innovation in analytics, and transparency.

## D. Approach 4: SSA Services Provided by an International Organization

An international organization could become a holding cell for SSA data provided by governments, industry, and academia. An existing international organization, such as the UN Committee on the Peaceful Uses of Outer Space (COPUOS), could be given the responsibility, or it could be given to a new organization (similar to the Minor Planet Center [MPC] discussed in Chapter 4). All member states would be encouraged to provide SSA data to this international organization at the level at which they are comfortable. This approach is not mutually exclusive from the U.S.-centric approaches previously discussed, and can be created in addition to a U.S. domestic civil SSA regime that would then become the U.S. provider to the international organization.

Calls for such an international organization to be established are most notable in the proposals for the International Space Object Data Exchange (ISODEX) (Skinner 2015). ISODEX would be an entirely participant-funded (i.e., not hosted or run by an existing organization like the UN or NASA) cloud-based data exchange of SSA information. Participants, who could be nation states, provincial or local governments, NGEs, commercial companies, or academic researchers, would share their SSA data in the exchange, and benefit from access to the data of all other participants. The organization is analogous to the MPC, but with additional processing in the database itself—ISODEX could not only collect raw metric SSA data from participants, but it could also combine them into processed outputs.

### 1. Strengths

The strength of this approach is that it would bring the international community together on SSA, which is important since having a safe space environment is an inherently international goal. The international organization could also be a venue for new space actors to learn about best practices. This approach would also allow for governments with limited data collection to increase their capability for SSA, which would benefit all space actors. It would provide a more accurate set of SSA products because it would have a large diversity in data types and location and the most updated ephemerides from international owner/operators. It would also assuage the concerns of many emerging and developing countries and smaller satellite operators about the cost of either developing their own capabilities, or having to pay for a commercial service.

Another strength of this approach is that it is most likely to be decentralized and open, with the greatest potential to bring together governments, industry, and academia to solve technical challenges in SSA.[32] The international and public nature of the database would also enable greater scientific study of the space environment and the evolution of threats such as space debris.

### 2. Challenges

The challenges to having an international organization provide SSA services would be significant. The first challenge would be the high transaction costs of creating a new international organization, or adding capabilities to an existing organization. Doing so would require diplomatic negotiations and discussions that would be likely to span several years. Decisions about leadership and sovereignty might also be required.

The second challenge would be funding. The UN already faces challenges in funding many of its activities, and adding more requirements would increase the challenge. Since the body would be international, motivating participation in both membership and in contributions of data would likely be difficult. Finally, creating this international authority would heighten existing challenges with protecting national security space objects and activities, as there is currently significant international disagreement over the definition of peaceful uses of outer space.

One possible solution to the issue of how to handle classified satellites, as suggested by an expert interviewed for the project, is for this organization to anonymize each space object in the satellite database with something similar to a digital object identifier (DOI) for journal articles or data sets. This would allow owner/operators to provide detailed ephemeris data about their satellites without concern over satellite intentions becoming

[32] University of Arizona, Office for Research & Discovery website, “Space Object Behavioral Sciences (SOBS),” http://research.arizona.edu/space-object-behavioral-sciences.

public. However, doing so would still require nation states to be comfortable with releasing ephemeris data on national security space objects and divulging the existence of such objects to an international organization.

# 7. Options for a Civil Government Organization Providing SSA Services

This chapter explores four options for having a civil government organization provide SSA services (Approach 2). The preceding chapter provided a list of Federal agencies that could, in principle, provide SSA services (Chapter 6, Section B). Of these, FAA/AST is considered the leading candidate because it has shown the most interest in providing SSA services and has received the most support from stakeholders, including members of Congress. Given growing consensus that FAA/AST should be the entity providing civil SSA services (whether within FAA or directly under DOT), this chapter describes potential delivery mechanisms, scopes estimated costs to the extent feasible, and discusses the associated policy implications.

The chapter builds on estimated capabilities and prices from a survey of non-governmental entities (NGEs) who provide SSA services (vendors). (See Chapter 5 for details about the vendors surveyed and Appendix C for the questionnaires used in the survey.) The cost estimates the vendors provided help inform stakeholders of order-of-magnitude prices associated with a civil SSA system. We did not validate or verify these capabilities or price estimates; they are self-reported by the vendors themselves. It would, however, be feasible to validate and verify these capabilities, as discussed in the beginning of Chapter 5.

We identified four potential options for FAA/AST to provide SSA services to civil and commercial users.

1. *Option 1: FAA/AST service capability embedded within DOD/JSpOC.* FAA/AST has access at JSpOC to *JSpOC hardware, software, procedures, and data*. FAA's principal role would be to reduce DOD's burden by analyzing civil and commercial conjunction analyses and communicating with commercial, civil, and international operators.

2. *Option 2: Independent FAA/AST service capability using DOD software and systems.* FAA/AST would develop SSA products and services, either using its own staff or a vendor embedded on-site, *using DOD-provided, FAA-procured hardware, software, procedures, and data.* This option counts on access to the DOD catalog supplemented with commercial data to produce a high-quality database.

3. *Option 3: Independent FAA/AST service capability using commercial software and systems.* FAA/AST would develop SSA products and services, either in-

house (using its own staff or embedding vendor on-site) or at NGE facility *using non-DOD NGE software*. In this option, FAA/AST can use the DOD catalog or observation level data, if provided, or commercial data alone if DOD data are not available.

4. *Option 4: FAA/AST certifies non-governmental entities (NGEs) to provide service capability*. FAA/AST would certify one or more NGEs to provide launch, on-orbit, and reentry conjunction analyses as a service. This option implies the use of DOD data that are available publicly and commercial software and data.

Table 7 summarizes high-level details for each option. Some options include different "levels" of service, which are depicted in Figure 12, and Table 8 summarizes strengths and challenges of each. We provide details and concomitant prices in the sections that follow. It is important to note that in reporting the costs for options that involve vendor services (Options 2, 3, and 4), the costs reported come from the vendors themselves and do not account for any additional FAA/AST personnel that might be required in addition to the vendor staff already included. In addition, we did not take into account any system-wide savings that might result from the adoption of one of these options (i.e., we did not attempt to estimate any cost savings to the DOD if the civil SSA mission moved to FAA/AST's purview).

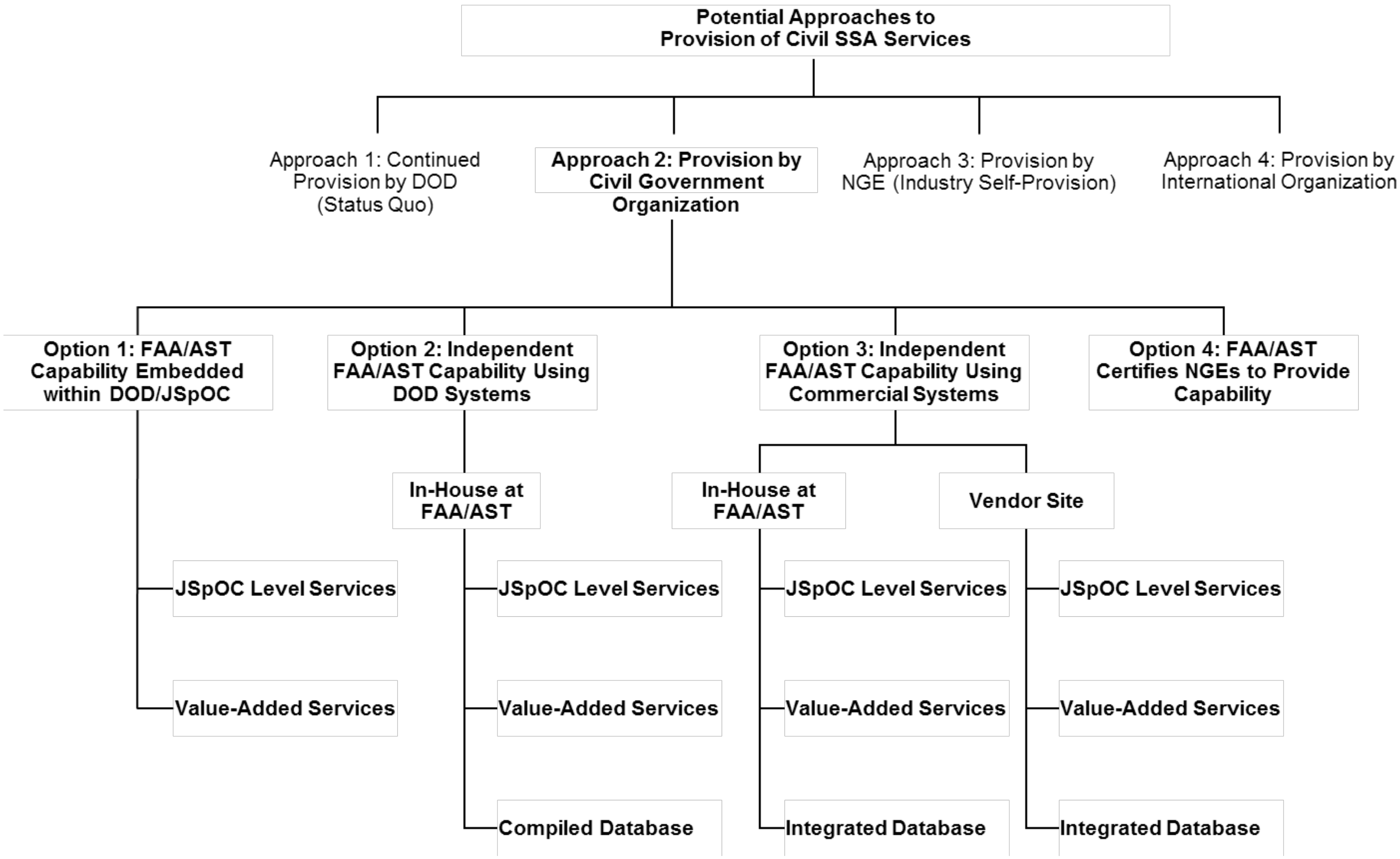
**Table 7. Summary of *Options***

| | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|
| **Description** | FAA/AST capability embedded within DOD/JSpOC | Independent FAA/AST capability using DOD software | Independent FAA/AST capability using commercial software | FAA/AST certifies NGEs to provide capability |
| **Sensors used** | DOD | DOD, commercial | Commercial, DOD | Commercial |
| **Analyst** | DOD, FAA/AST | FAA/AST | FAA/AST, NGE | NGE |
| **Interface with owner/operators (non-national security)** | FAA/AST | FAA/AST | FAA/AST | NGE |
| **Timeframe of availability** | 2018 or later* | 2018 or later* | Immediate | Immediate |
| **Primary data source** | DOD Catalog | DOD catalog and commercial | DOD observations or catalog and commercial | Commercial |
| **Software** | DOD JMS \ | DOD JMS | Commercial | Commercial |
| **Resulting database** | None | FAA/AST Compiled Database | FAA/AST Integrated Database | NGE Database |
| **Location** | JSpOC | FAA/AST** | FAA/AST** or NGE | NGE |

*Sources*: Compiled database supplements DOD HAC and includes maneuver and other data from commercial sources. Integrated database fuses data from DOD observations and commercial data.

* Assumes JMS would be available by 2018.

** Contractors can be embedded on-site as with current JSpOC operations.




*Note*: See Table 8 for a summary of the strengths and challenges of each option.

**Figure 12. *Options* for Provision of SSA Services by FAA/AST as the Civil Government Organization (Each Has a Different Set of Costs and Policy Implications)**

**Table 8. Strengths and Challenges of *Options* (within Approach 2) for FAA/AST Provision of SSA Services**

| Option | Strengths | Challenges |
| --- | --- | --- |
| 1. FAA/AST Embedded within DOD/JSpOC | • Expected to somewhat reduce JSpOC's workload not related to national security mission<br>• Preferred by stakeholders who would like to: minimize near-term cost, reinforce the role of USSTRATCOM as primary hub for SSA, remove possible confusion of a competing FAA/AST database, and reinforce political backing for improvements to JSpOC's core hardware and software | • Capabilities subject to the limitations of JSpOC's software and data<br>• Flexibility and innovation limited to improvements in JMS<br>• Continue to have significant restrictions on ability to share data with commercial and international customers<br>• FAA has little value added compared to DOD's current service provision |
| 2. Independent FAA/AST Capability Using DOD Software and Systems | • Only slightly changes the status quo<br>• FAA/AST has more insight into the DOD SSA process<br>• May better prepare FAA/AST for a future role in STM | • FAA/AST would face significant hurdles to make modifications to any processes or software that DOD has<br>• Unclear how difficult it will be for FAA/AST to add value-added software services and a database on top of the DOD architecture<br>• Dependence on DOD data (by not being able to augment with commercial data) could be detrimental if FAA/AST loses data stream<br>• Potential challenges in linking JMS data on SIPR to FAA/AST capabilities on DOT networks |
| 3. Independent FAA/AST Capability Using Commercial Software and Systems | • FAA/AST has significantly greater control and flexibility to align service with civil and commercial requirements<br>• Changes to the system based on NGE software will likely be lower priced than changes to DOD software (long term prices will likely be lower than Option 2)<br>• If properly designed, could promote greater flexibility and rapid development of software than utilizing DOD software and data<br>• Likely the best option to prepare FAA/AST for a future role in STM | • Increased upfront costs over previous two options<br>• Using a different database than the DOD catalog could lead to conflict across agencies<br>• If systems are customized (i.e., do not remain commercial), would deter quick/agile improvements<br>• Liability concerns when using NGE software |
| 4. FAA/AST Certifies non-Governmental Entities (NGE) to provide services | • Supports commercial SSA industry while still protecting civil space assets through governmental oversight<br>• Low cost burden for government<br>• Greatest flexibility for service improvements | • Not appropriate if SSA services are deemed to be governmental functions<br>• May not meet the requirements for government oversight under international obligations<br>• Unclear who would bear the cost of services: government or users<br>• Liability concerns<br>• May cause issues with current international partners<br>• Owner/operators may choose the least restrictive or expensive vendors, which could be counterproductive to safety in space |

Figure 13 provides a conceptual block diagram of how civil SSA services can be provided. The red boxes and arrows represent the inputs, which are data from multiple sources including awareness of space weather, and radio frequency interference. DOD would determine what DOD data will be shared with a civil system. The blue boxes and arrows represent the analytic engine of the system, which undertakes four primary functions: creation and management of space object database; analysis of data to create conjunction analyses; visualization and reporting out the data to owner/operators; and, maintenance of an archive of historical objects. Finally, the green boxes and arrows represent the outputs that consist of analyses and messages provided to customers, and additional sensor tasking if needed. Conceptually speaking, FAA/AST's role in this SSA diagram is within the grey box. As noted before, FAA/AST will only be a subset of the entire U.S. SSA regime, focusing on civil SSA analysis, reporting and visualization, archiving, and database management.

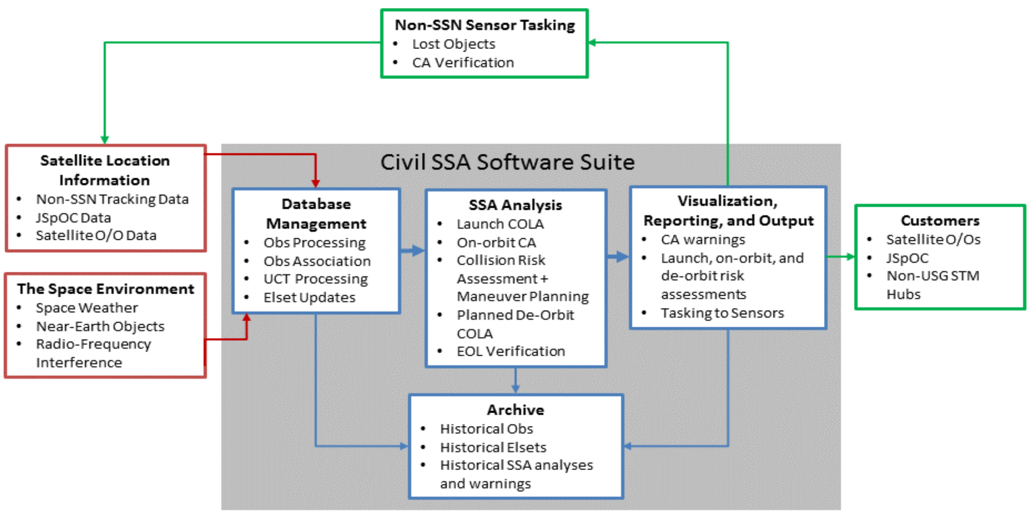



**Figure 13. Conceptual Civil SSA Architecture**

As shown in Figure 12, SSA services can be provided at multiple levels for some options.

**Level 1 (Basic).** The first level is provision of SSA services at the same level JSpOC provides them today. FAA/AST's role would be to ingest JSpOC data provided to it as indicated in the red box in Figure 14; process the data using either DOD or NGE software into conjunction analyses warnings (for launch, on-orbit, and reentry) as shown in the blue boxes; and, finally report these products to customers as shown in green. This level is applicable to Options 1, 2, and 3.

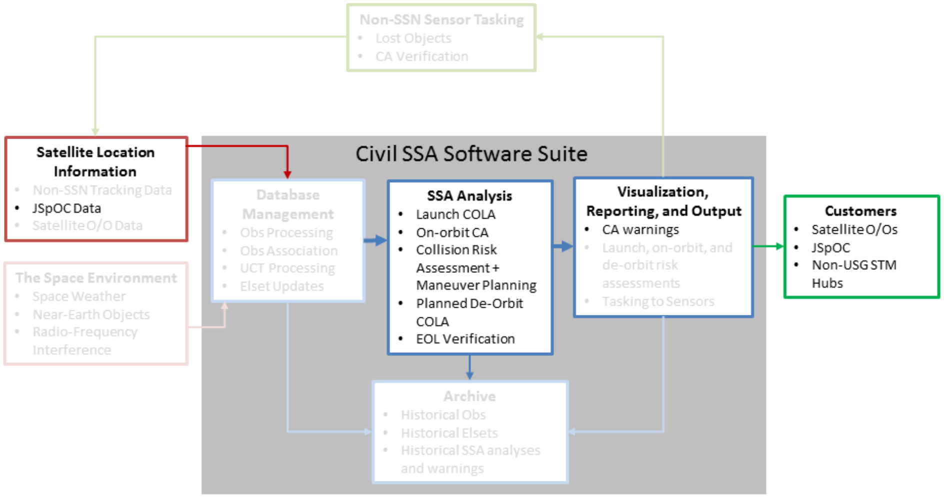



**Figure 14. Level 1: Basic SSA Provision Architecture**

**Level 2 (Value-Added)**. The second level is provision of SSA services as provided today plus the value-added improvements of risk analyses, improved user interface, and better product presentation. FAA/AST will complete the same process as described in level 1 with the additional processing for risk assessments as shown in blue and an improved reporting system (user interface) in green. This level is applicable to Options 1, 2, and 3. See Figure 15.

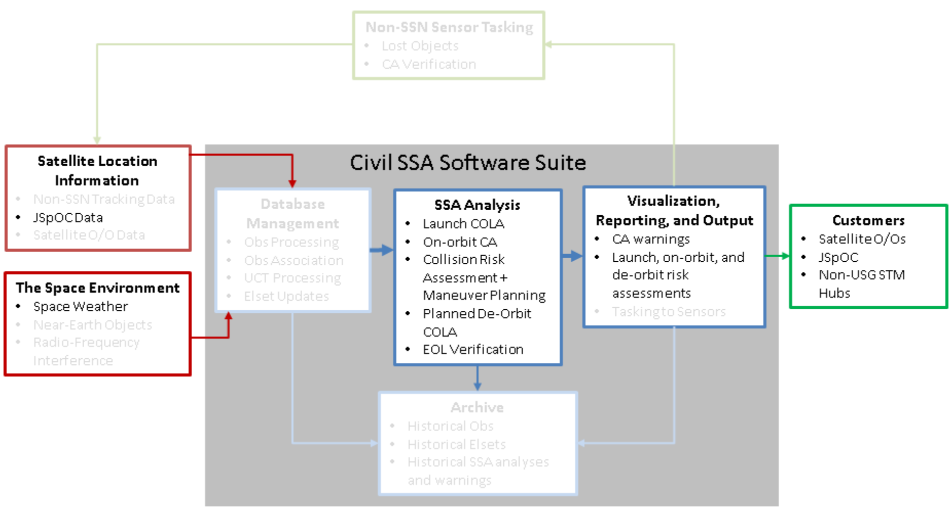



**Figure 15. Level 2: Provision of SSA Services with Value-Added Improvements**

**Level 3 (Creation of Independent Database).** The third and final level not only includes value-added improvements but also the creation of an independent FAA/AST or NGE database. Having an independent database allows FAA/AST to ingest JSpOC, non-SSN, and satellite owner/operator ephemeris data as shown in red. This additional information greatly increases the ability for enhanced processing of timely and actionable SSA products. As shown in blue, this option also expands FAA/AST's software needs due to catalog management and data archiving. This level is applicable to Options 2, 3, and 4 (Figure 16).

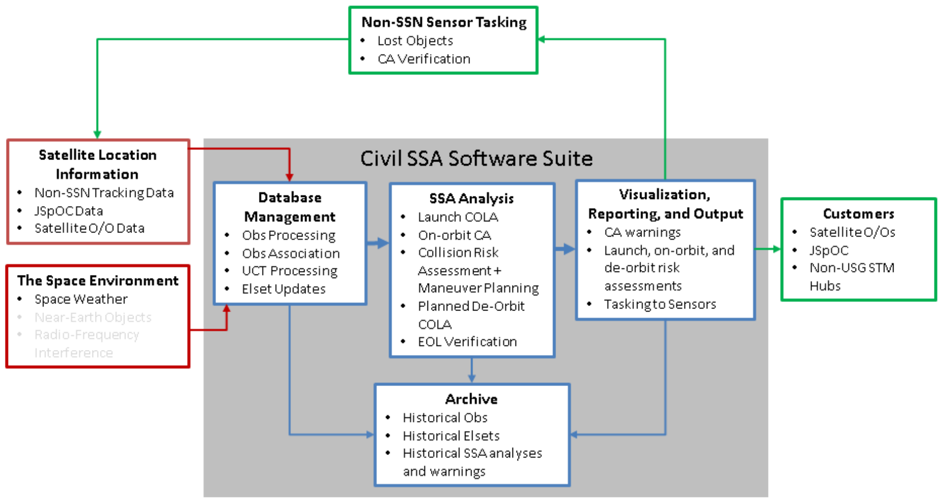



**Figure 16. Level 3: Provision of SSA Services with Value-Added Improvements and Independent Database**

As shown in Figure 12, and will be evident in the discussion below, Options 2 and 3 can enable provision of all three potential levels of capability for FAA/AST, while Option 1 only allows for Level 1 (Basic) and Level 2 (Value Added) because FAA/AST will not be able to create an independent database within JSpOC. Option 4 does not have three levels because an NGE will need all levels (basic software, value added improvements, and a database) to provide SSA services independent of JSpOC. The following subsections provide more details on each option and level.

## A. Option 1: FAA/AST Embedded within DOD/JSpOC

Under this option, the main analytical capability and data sets would continue to reside with JSpOC. DOD will continue to process all conjunction analyses daily, however, FAA/AST will analyze commercial, civil, and international conjunctions in depth, send warnings to these users, and act as the interface with non-DOD or national security users.

FAA/AST has two potential levels for provision of services from JSpOC. The first is Level 1, meaning FAA/AST would provide the same service JSpOC currently provides using DOD hardware, software, procedures, but with FAA/AST being the point of contact for companies, rather than JSpOC. Within Level 2, FAA/AST would augment JSpOC mainly through better coordination with licensees, provision of risk analyses on conjunctions, and improved user interface and product presentation.

As discussed in Chapter 3, currently, the computer systems used by JSpOC are the legacy SPADOC and CAVENet systems, which are in the process of being replaced by JSpOC Mission System (JMS).[33] While JMS is predicted to greatly improve these capabilities over the existing SPADOC and CAVENet systems, its actual performance is still an unknown, and the schedule for delivery has slipped several times. Currently, the astrodynamics core of JMS is slated for release in the Increment 2 delivery in 2018. If FAA/AST proceeds with this option, they will likely need to wait for capability until 2018 at the earliest.

## 1. Estimated Cost to FAA/AST

### a. Level 1: Basic Service Provision

Based on interviews with experts, we estimate that FAA/AST would need to devote fewer than 10 full time equivalent (FTE) employees to work at JSpOC. This estimate is based on an assumption of time required for on-orbit, reentry, and launch conjunctions analyses compared to personnel currently devoted to these functions within DOD. The work performed for each screening involves communicating with non-DOD users on launch, reentry, and on-orbit conjunctions. For launch conjunction analyses, FAA/AST will receive the planned trajectories, conduct the screening and analyzing the results, communicate the results to the launch operator, and conduct any re-screening for changes to the planned trajectory due to a potential conjunction. For reentry, FAA/AST will utilize end of life plans for each satellite and track de-orbit or graveyard placement. Finally, for on-orbit, FAA/AST will analyze relevant non-DOD conjunction analyses to determine which are true close approaches that require user notification. Then FAA/AST will interface with non-DOD customers.

In addition to the actual time spent conducting the conjunction screenings, the FTEs would have additional duties including establishing relationships with the commercial space flight licensees and international partners, and answering questions about the COLA, CA, and maneuvering processes, as part of an effort to develop better customer service for commercial end users of JSpOC data and services. New personnel would require comprehensive training for 6-10 weeks to be sufficiently familiarized with the theory and practice necessary for SSA analyses.

JMS is a web-based architecture that can be accessed from any terminal with access to the Secret Internet Protocol Router Network (SIPRNet) or the Joint Worldwide Intelligence Communications System (JWICS), making it feasible for FAA/AST personnel to access it from anywhere on-site without incurring additional cost. The only cost would

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[33] An overview and evaluations of these systems and the upgrade effort can be found at Abott (2015), James and Hyten (2015), and Weeden (2012).

be the purchase of a workstation to run the JMS software, which at a minimum requires a Quad core processor, 8 GB RAM, and 2 GB video card. Table 9 summarizes the estimated costs for Option 1, Level 1. The total cost of Option 1 is $5,000 upfront for equipment, and $150,000 per FTE annually (and about $1.5 million annually assume 10 FTEs) for having FAA/AST personnel on-site at JSpOC.

**Table 9. Approximate Cost Estimate for Option 1**

| | Up-Front Cost | Annual Recurring Cost | Description |
|---|---|---|---|
| FAA/AST Personnel | none | $150,000 per FTE | Cost of a maximum of 10 U.S. Government civil servants at the GS-13 level |
| Facilities | none | None | Facilities requirement would be space for a single individual |
| Equipment | $5,000 | None | Equipment costs Include purchase, installation, and maintenance for a desktop computer with a quad core processor, 8 GB RAM, and 2 GB video card (minimum) |

#### b. Level 2: With Value-added Improvements

In this level, FAA/AST offers additional value added services compared to Level 1 basic provision such as additional risk analyses, improved user interface, and better product presentation. We did not ask companies that were part of the market survey to provide prices for this option due to the limited insight on JSpOC's current and future software capabilities. Limited insight on these topics makes it difficult to accurately estimate integration feasibility and costs between commercial value-added software and DOD software. However, several companies indicated it would be possible to provide such software, which would be similar to what they already provide to assist some clients in assessing CSMs.

### 2. Strengths

Interviewees that preferred this option desired to minimize near-term cost, reinforce the role of USSTRATCOM as the primary hub for SSA, remove possible confusion of a separate RSO database, and reinforce political backing for JMS.

This option will also reduce some of JSpOC's workload not related to national security, such as communicating with U.S. commercial space flight licensees, civil government agencies, and international partners. This option allows DOD to keep control while reducing some of its workload.

Compared to other approaches that would require standing up an SSA operation at FAA/AST or elsewhere, this approach is likely to necessitate the least additional expense.

### 3. Challenges

As discussed previously, the weaknesses of this option are that FAA/AST will not have flexibility to significantly improve the product or process. Value added improvements from FAA/AST will help provide a better product to users, but it will be a superficial change since the underlying analytical processes will remain the same as before. FAA/AST will face many of the same challenges as JSpOC in expanding services as the number of satellite operators increases, which may severely impede safety of space in years to come, especially for future activities such as commercial human space flight, satellite servicing, or LEO refueling depots.

This option does provide FAA/AST with the ability to access classified information, but since FAA/AST would likely not have significant ability to develop analytic products different from what could be provided by the computer systems currently at JSpOC, it may not improve the product. It is unclear if this option provides any overall cost or efficiency savings for the U.S. Government or the user community as a whole—the main benefits would appear to be solely for DOD.

Last but not least, while this option is the least expensive, it is also the least suited to prepare FAA/AST to eventually provide STM services, or expand the domestic SSA/STM regime to an international one.

## B. Option 2: Independent FAA/AST Capability Using DOD Software

In this option, FAA/AST utilizes DOD hardware, software, and procedures to provide conjunction analyses to U.S. civil and commercial users, and international partners from an FAA/AST facility. Within this option, FAA/AST primarily uses DOD data, and receives maneuver and other data from owner/operators, but can also purchase data from commercial sources if needed. As they already do now, FAA/AST can also get data from launch providers. FAA/AST can form a “compiled database” using the DOD’s catalog as the primary database and adding objects not found in the HAC from the commercial database. DOD will still handle all classification of data. However, unlike Option 1, FAA/AST will have a parallel ability to DOD on-site at FAA/AST premises. Both will process all potential conjunctions for a given day, but FAA/AST will only analyze potential conjunctions with non-DOD active spacecraft and will notify U.S. commercial and civil users and international partners. FAA/AST will have to take over USSTRATCOM’s international data sharing partnerships.

FAA/AST can operate the system using government employees on its premises, or supervise a contractor located on its premises. Using DOD systems will allow FAA/AST to maintain a close relationship with JSpOC, and save funds by using the JSpOC architecture. However, FAA/AST will be required to wait until after JMS is delivered in 2018 before having operational capability. To increase capability before JMS Increment 2 is released, a potential interim architecture is proposed to provide FAA/AST with some operational capability immediately. The interim architecture focuses only on launch, not on-orbit traffic, because FAA/AST does not currently have authority to handle on-orbit activities. However, given the similarities, the interim option could be extended to include on-orbit CA if authorities change. This architecture could also be established as a means to grow capability before expanding regulatory purview to on-orbit activities. When access to JMS is available, the three service levels (basic service provision, providing value-added services, maintaining own database) described in the beginning of this chapter are applicable.

### 1. Interim Option

The interim architecture utilizes existing processes for launch and early orbit collision avoidance (LCOLA), which are serial in nature, highly manpower-dependent, and incapable of machine-to-machine interfaces at several steps in the process. A functional description of an interim LCOLA architecture is outlined in Figure 17.

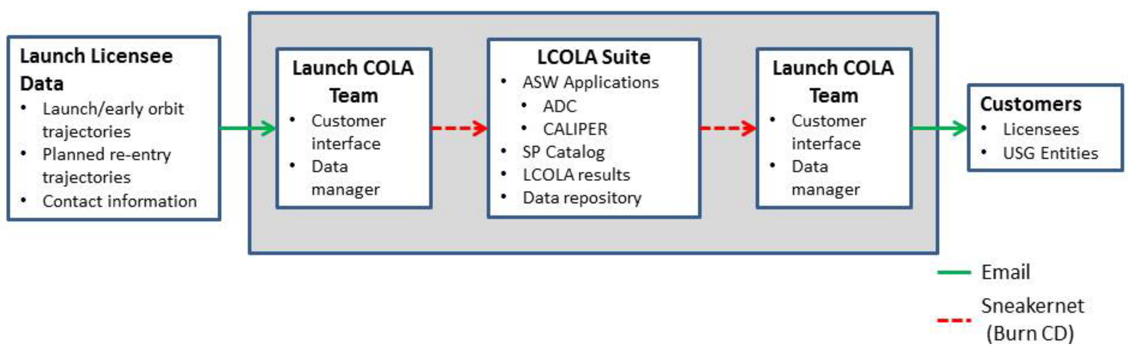



**Figure 17. Interim LCOLA Architecture**

#### a. Software

This option requires a computer system that mimics the functionality of CAVENet to run the LCOLA functions in ASW, a stand-alone computer running Linux, and a copy of ASW installed on the terminal, assuming JSpOC provides a catalog of objects to be screened. Under the interim architecture, the backend server would be the CAVENet servers in use at JSpOC. The software price estimate for the interim architecture assumes that FAA/AST can utilize a free copy of Linux and ASW for the interim architecture (Table 10). If support for installing or maintaining either operating system is required, that will be an additional cost. Note that the full suite is not necessary for the LCOLA capabilities, and it may be possible to negotiate with OMITRON a lower cost for just the LCOLA subset of the full ASW suite.

**Table 10. Software Price Estimates**

| | |
|---|---|
| Interim Architecture | |
| Linux Operating System | $0 |
| ASW Software Suite | $700,000 |
| Final Architecture | |
| Windows 7 Operating System | $150 |
| JMS | $0 |
| **Total System Price:** | **$700,150** |

### b. Database

This interim LCOLA architecture would require FAA/AST to request data from both JSpOC and launch operators. JSpOC would need to provide the catalog of space objects for LCOLA screenings. The catalog would likely need to be provided once per day, but it may be provided up to three times a day (which corresponds to how often it is updated by JSpOC). The required space object catalog is best processed at the secret classification level (to be more inclusive of all active satellites potentially at risk); however, an unclassified subset could be requested and ingested from JSpOC. Launch operators would be required to provide their planned launch and early orbit trajectories. These data would need to be inputted to the LCOLA software suite.

If operating at the unclassified level, it is possible for this to occur electronically if the machine with the LCOLA software suite has email connectivity, although this may introduce Information Assurance challenges. If the LCOLA software suite is running on a stand-alone terminal, it will need to be transferred to the terminal via electronic storage devices. After the analysis is complete, the results would need to be transferred back to a terminal with email capabilities so FAA/AST can notify end users of the results.

### c. Hardware

FAA/AST should acquire a workstation that meets the requirements for a JMS terminal for the interim architecture. This workstation should also be suitable for running ASW under the interim architecture, thus eliminating the need to purchase a new workstation when transitioning to JMS. The approximate cost of acquiring JMS-capable hardware is $2,000.

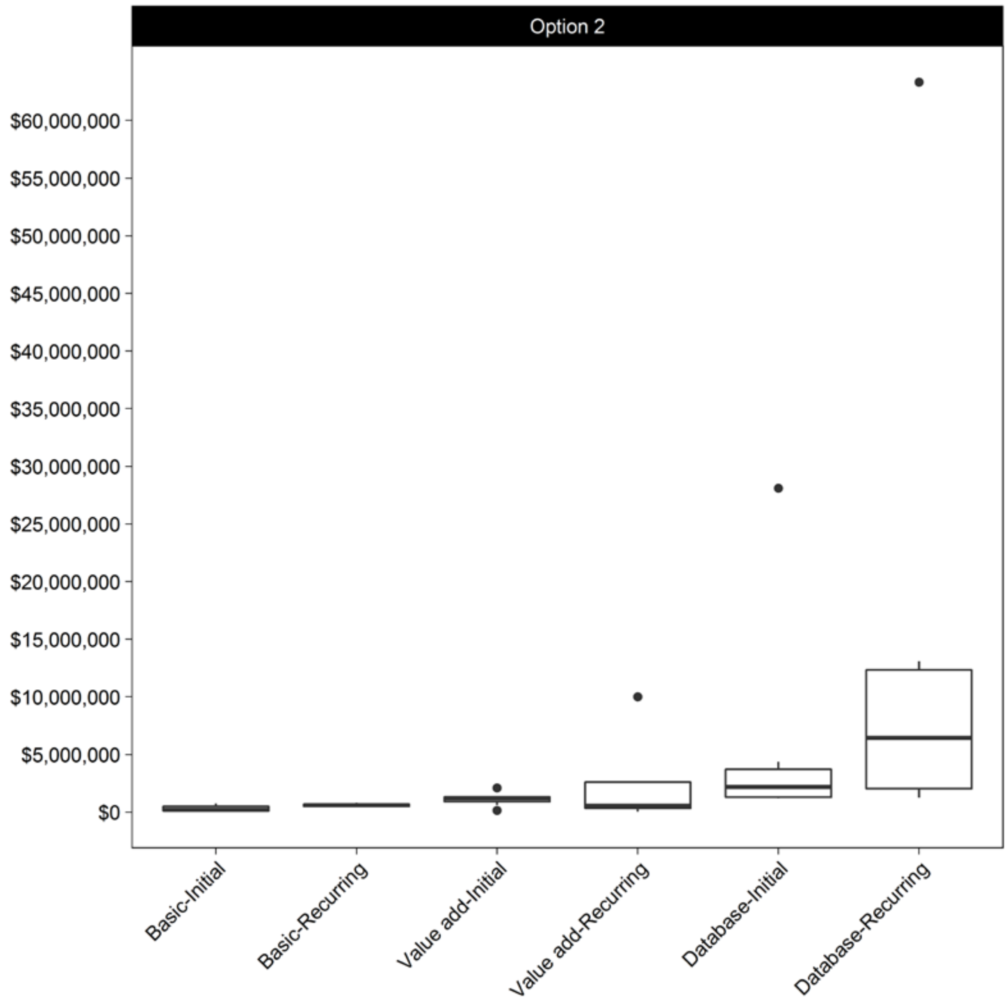
#### d. Personnel

Effective LCOLA can be accomplished with a minimum of one trained analyst, with a second trained analyst to cover planned and unplanned absences. The personnel would be at the GS-13 level, costing FAA/AST approximately $300,000 per year. A comprehensive training program lasting 6-10 weeks should be sufficient to familiarize the analyst with the theory and practice of necessary LCOLA steps.

If FAA/AST moves forward with this option, it is also recommended that a period of time be allocated for the initial FAA/AST analysts to observe LCOLA processes at JSpOC, shadow operations at FAA/AST in parallel with JSpOC, and allow for reach back on-call support during the first few months of FAA/AST as the prime LCOLA producer. As with other SSA functions, it is also recommended that JSpOC retain minimal LCOLA expertise to function as a backup center should the need arise.

### 2. Future System (Post-JMS Increment 2 Delivery)

As discussed in the introduction to this chapter, once JMS becomes active in 2018, FAA/AST can expand the capabilities described in the interim architecture to a full capability. The costs for a post-JMS full system are similar to the interim architecture; however, since this architecture includes on-orbit and reentry conjunction analyses the FTE level will be increase from 2 to less than 10. Providing approximate pricing on Levels 2 and 3 when using JMS is difficult for companies because they do not have a full understanding of the software capability. Therefore, for Level 2, many companies provided approximate prices for their established user interfaces and risk analyses software and product presentation packages, without estimating prices for interoperability or set up. These prices could be significant, and they would need to be more accurately estimated if this option is chosen (Figure 18).




*Note*: The figure illustrates the enormous range of estimates submitted by the firms. To protect company proprietary information, the data are presented as box and whiskers plots. The top of the boxplot is the upper quartile (meaning that 25% of the estimates submitted were greater than this value) of the estimates submitted by seven firms. The bottom of the box is the lower quartile (meaning that 25% of the estimates submitted were less than this value). The line cutting through the box is the median (meaning that 50% of the estimates are greater than this value). The lines outside the box represent values that are 1.5 times the interquartile range of the data (meaning the distance between the top and bottom of the boxes).

**Figure 18. Estimated Price/Cost Overview for Option 2, All Levels (Excludes Cost of Interim Solution)**

### a. Estimated Cost to FAA/AST

**Level 1: Basic Service Provision.** The software estimate for the basic service provision assumes that FAA/AST purchases a retail license for Microsoft Windows 7, and DOD provides a free copy of the JMS workstation software.

The hardware requirements of the workstation are those of a mid-range consumer desktop computer. This is due to the assumption that the workstation is connected to a server that is providing the main computational capabilities, and that the main purpose of the workstation is to provide visualization and analysis.

FAA/AST should acquire a workstation that meets the requirements for a JMS terminal for the interim architecture. This workstation should also be suitable for running ASW under the interim architecture, thus eliminating the need to purchase a new workstation when transitioning to JMS. The costs are the same as the JMS workstation for the interim architecture, approximately $2,000.

**Level 2: With Value-Added Improvements.** Seven companies proposed a software solution to add value to DOD software with improved risk analyses, visualization, and user interface. Although the product FAA/AST provides to owner/operators will be very similar to JSpOC's current product because the data and processing are identical, having these value add improvements will make a difference in product usability for the owner/operator. The price for these improvements includes an initial software purchase price with recurring commitments including personnel support, software updates, and sometimes licensing fees. The prices do not include a detailed estimate of set-up to allow for interoperability with DOD's software.

**Level 3: With Independent Database Capability.** Prices for Level 3 include those for Levels 1 and 2 because it is required for FAA/AST to gain experience in basic and value-added service provision before maintaining and using a database. The prices for a database option is greater than Levels 1 and 2 because it requires a more involved initial setup to meet FAA/AST's needs. The numbers in Figure 18 can be deceiving because the price to establish a basic database management system using DOD data is minimal: approximately $100,000 to $2,000,000 for software initialization, and $20,000 to $1,500,000 for commercial off-the-shelf hardware. The recurring fees for this type of database are for support updates, which can range from $20,000 to $75,000 per year in addition to the price of personnel.

This option becomes expensive, as seen in Figure 18 when the NGE provides prices for a completely commercial database. These prices include not only hardware, software, and personnel, but also the price for data collection from commercial sources. One NGE in particular provided a significantly higher price for initialization and recurring fees because it included an instantiation of the NGE's established commercial space operations center.

### b. Strengths

Using DOD hardware and software will likely be better received by some stakeholders, especially DOD, because it only slightly changes the status quo, and leverages DOD's prior investment in software. Compared to Option 1, having the processes completed at FAA/AST will provide FAA/AST with greater insight into the process of supplying SSA services, and this option may better prepare FAA/AST for a future role in STM or full on-orbit mission assurance.

#### c. Challenges

FAA/AST will be severely limited in its ability to make modifications to any process or software that DOD provides, including integrating commercial data and algorithms to the database or its analytic products. If, for some reason, the datalink goes down for an extended period (even a few hours), FAA/AST would not be able to perform its mission in the interim. Additionally, it is unclear how difficult it will be for FAA/AST to add value-added software services and its own database on top of the DOD architecture. This project did not look into this question, but if it is found to be relatively simple for FAA/AST, then Levels 2 and 3 will enable FAA/AST to have more control over the products handed to users. If it is too difficult to add value-added services, then the limitations of Option 2 will be similar to those of Option 1. Last, there are potential challenges in linking JMS data on SIPR to FAA/AST capabilities on DOT networks.

## C. Option 3: Independent FAA/AST Capability Using NGE Software

In this option, FAA/AST will provide SSA services using NGE-provided processing software, instead of JMS. For this option, the data, software, and systems are NGE-provided, not DOD-provided. As compared with Options 1 and 2, this option provides FAA/AST with significantly greater control over products and services delivered to users, and flexibility to make changes or updates to the system. Under Level 3 (maintenance of a database), FAA/AST will use DOD and commercial data to create either a compiled database with the HAC or will integrate the DOD public catalog with commercial sources. There are increased costs associated with this option; however, FAA/AST may find the benefits outweigh the associated costs, especially in the long-term.

Seven of the companies surveyed have the capability to provide software to enable FAA/AST to provide SSA services to users. FAA/AST would purchase NGE software capable of launch, on-orbit, and reentry conjunction analyses to produce conjunction messages for users. Some companies would provide only the basic software to do these analyses, and FAA/AST would then have the option to include value-added improvements. Under this option, FAA/AST can complete the activity either at an FAA/AST facility, run by government or NGE employees, or at an NGE site managed or overseen by FAA/AST.

### 1. Estimated Cost to FAA/AST

All companies except two were willing to support all three levels within this option. Those willing to have the service offered at the NGE facility are already completing SSA services on a larger scale today; companies unwilling to support this option are in the business of only providing software and technology support to customers, and do not currently have or are unwilling to procure the facility space to establish this service. Figure 19 provides a price/cost overview.

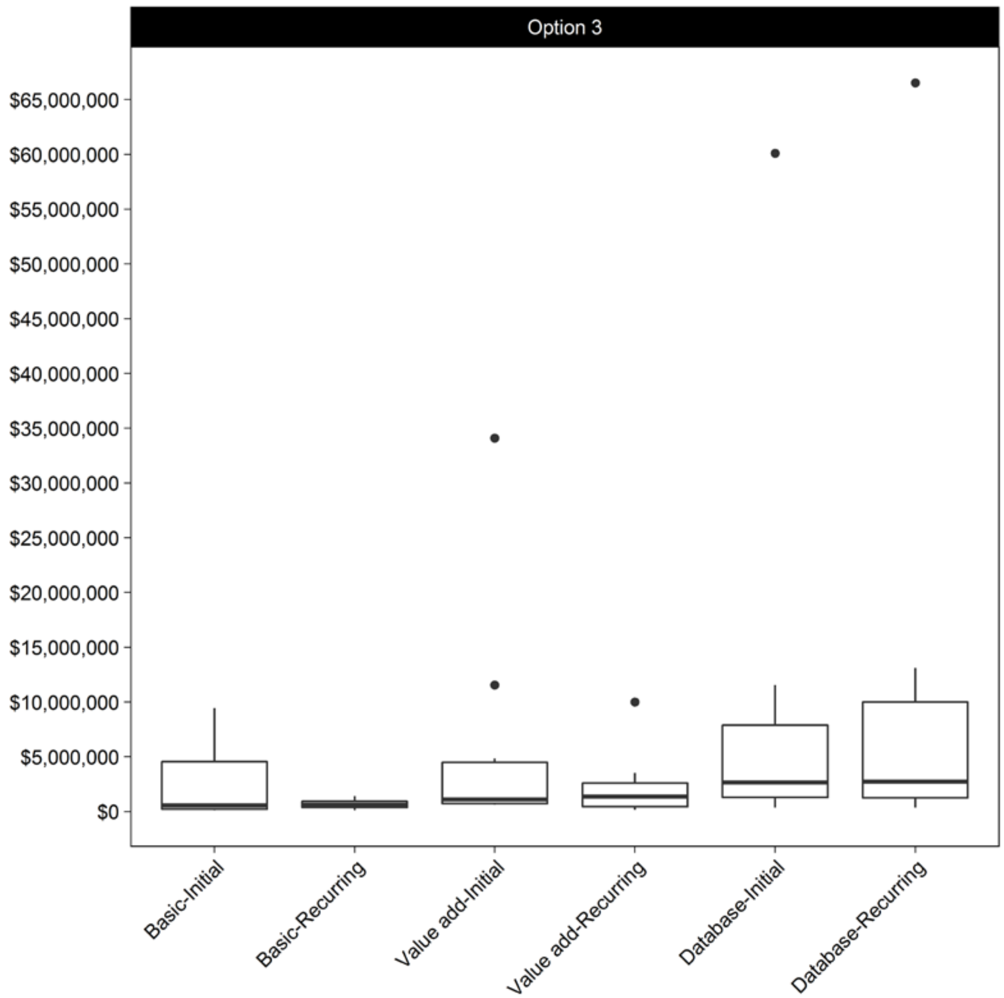



**Figure 19. Price/Cost Overview for Option 3, All Levels**

### a. Level 1: Basic Service Provision (Without Value-Added Improvements)

There is a wide range in approximate costs for this option with two outliers significantly increasing the maximum estimates. Most companies are willing to provide their basic software for hundreds of thousands of dollars or less; however, two companies provided significantly larger estimates. One NGE is charging $10 million per year in licensing, while the other has a large initial price for their software with more moderate annual licensing and support fees.

#### b. Level 2: With Value-Added Improvements

The pricing difference between value-added improvements and the basic software provision is small (Figure 19). Adding value to the level of service currently provided by DOD is relatively low cost, ranging from $700,000 to $11 million initially, to $150,000 to $10 million recurring. Similar to Level 1, Level 2 has outliers that must be taken into consideration.

#### c. Level 3: With Independent RSO Database Capability

The high prices for this option are similar to that of database provision for Option 2, Level 3. Database set-up can be moderately priced, but the prices increase significantly when adding a commercially procured catalog through an NGE. This is exemplified by one vendor which sets an estimated a maximum price of commercial catalog access at over $60 million annually.

### 2. Strengths

The benefit of this option is that it provides a significantly greater level of oversight and control by FAA/AST than Options 1 or 2. FAA/AST will be able to control the processes and products they provide to licensees. This will enable the agency to be responsive to industry's changing needs. Since this option is not built upon JSpOC's legacy systems, FAA/AST will be able to update the system using commercial software, which may be lower priced and more agile than DOD's systems, if it is designed well. Finally, this option best prepares FAA/AST for a future role in STM.

This option has support from a burgeoning group of stakeholders. For example, Representative Bridenstine in the American Space Renaissance Act announced his desire for the government to leverage commercial companies' expertise in SSA to "blend unclassified DOD data with civil data" (Gruss 2016a).

### 3. Challenges

This option will be initially more expensive than utilizing DOD's hardware, software and processes because it requires an initial investment in commercial software. However, in the long term, the benefits of agile development with commercial products may be able to make up the price difference. The question of who pays for the service, users or the government, becomes an issue that is discussed in Chapter 9.

This option may generate friction with DOD. Some DOD personnel have expressed concern about having FAA/AST "duplicate" a database that DOD is already providing in a limited form to some stakeholders. The apparent duplication could be viewed as wasteful spending. Those who support the creation of a civil database or catalog argue that there already are multiple databases (and therefore creating another is not unprecedented).

Currently JSpOC has at least three catalogs: high-accuracy catalog (HAC), special perturbation ephemerides, and public two-line element (TLE) catalog, as described in Chapter 3. The NRO has a database as well, as might other entities within the national security agencies/departments (such as Lincoln Labs, or NASIC). Industry and other organizations also have databases such as AGI's ComSpOC commercial database.

It is likely the DOD concern over "duplicate" databases is really a concern about differences between its database and a competing database, and how to handle decision-making if there is a discrepancy in the location of objects across the databases. However, this is unlikely to be an issue because FAA/AST can utilize DOD's catalog as a basis for database compilation. A compiled database will augment the observations in the HAC with commercial observational or ephemeris data. Proponents of a civil database argue that it would be more useful to use the additional databases to improve the overall accuracy of the information, and find and detect errors faster—this is similar thinking as in the ICG, wherein proponents of interoperability believed that data is "better together than separate." Interviewees for this project also suggested that a civil or commercial catalog would provide redundancy in the system and make the military systems and sensors less vulnerable.

Another reason for the DOD's concern over multiple databases is the potential for an FAA/AST database to include sensitive national security objects. As discussed in Chapter 9, the DOD excludes or restricts sensitive U.S. and allied military and intelligence satellites from its public database. An FAA/AST database, particularly one derived from non-DOD data, might include a sensitive object, particularly if the FAA/AST database were compared to the public DOD database.

This option has potential liability issues because an NGE system could be issuing information about potential collisions on behalf of the U.S. Government. The concern is over which party is liable if there is a collision in response to a conjunction summary message issued by an NGE on behalf of the government. Liability-related challenges are discussed in greater detail in Chapter 9.

## D. Option 4: FAA/AST Certifies Non-governmental Entities (NGE)

The final option for provision of SSA services is for FAA/AST to certify one or more NGE(s) to provide SSA services to users. FAA/AST could potentially require all U.S. commercial satellite operator licensees to utilize conjunction analyses services from a certified NGE. This option gives both the users and providers of SSA data and services the greatest level of control, while still allowing the activity to remain under government purview.

This option requires NGEs to have established conjunction warning processes, software and databases. The analytical capability remains with the NGEs under this option, not with FAA/AST. Additionally, it will be the NGEs that provide all communication with commercial users. It is undetermined whether civil and international users of JSpOC data will switch to a company or remain within DOD under this option. A protocol will need to be established between DOD and commercial providers when dealing with sharing sensitive or classified data or with respect to uncorrelated tracks.

Companies were asked to provide approximate costs for conducting conjunction analyses on a per-event basis. This option has only four potential companies because some companies viewed SSA service provision as inherently governmental, and they were unwilling to provide a solution that was outside the government. Other companies did not have an established set of processes at their facility to conduct analyses on a per-event or annual basis.

### 1. Estimated Cost to FAA/AST

Pricing numbers were difficult to gather for this option. NGEs that participated in the market survey were asked to price launch COLAs equivalent to 100 per year and reentry analyses equivalent to 50 per year. Launch and reentry conjunction analyses were priced at $175,000 to $500,000 per event. We did not provide the NGEs an estimate for number of on-orbit conjunction analyses per year because it is dependent on whether FAA/AST providers warnings for civil and international partners in addition to commercial users.

Additionally, as satellites and debris increase, the number of warning provided each year becomes more difficult to calculate. For reference, the Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space (SOCRATES) service that reports the top ten most probable and closest approaches in space identified 19,584 conjunctions from June 6–13, 2015. This equates to 1 million conjunctions per year; however, notifications are only provided when an analyst deems them required. The actual number of warnings provided per day is closer to 50, approximately 18,250 per year (Rendleman 2012). Since the participating NGEs were not provided an exact estimate of the number of on-orbit warnings per year, there was a wide range of prices provided, and most were deemed unreasonable. For example, some companies provided prices on a per-event basis. These numbers ranged from $10,000 to $500,000 per event. When multiplied by the number of JSpOC current annual on-orbit warnings, the annual estimates would equal $182 million to $9.1 billion per year. However, for annual pricing, companies ranged in prices from $100,000 to $1 million per satellite annually.

### 2. Strengths

According to many experts, Option 4 supports the SSA software industry, promotes innovation, and fosters competition (which in turn may create faster improvements for the government to leverage) within the United States. This option has the potential for the lowest cost burden on FAA/AST, especially if user fees are imposed. Finally, certifying an

NGE to provide the service allows for the greatest level of flexibility in service improvements. See Chapter 9 for a discussion of software innovation in the private sector.

### 3. Challenges

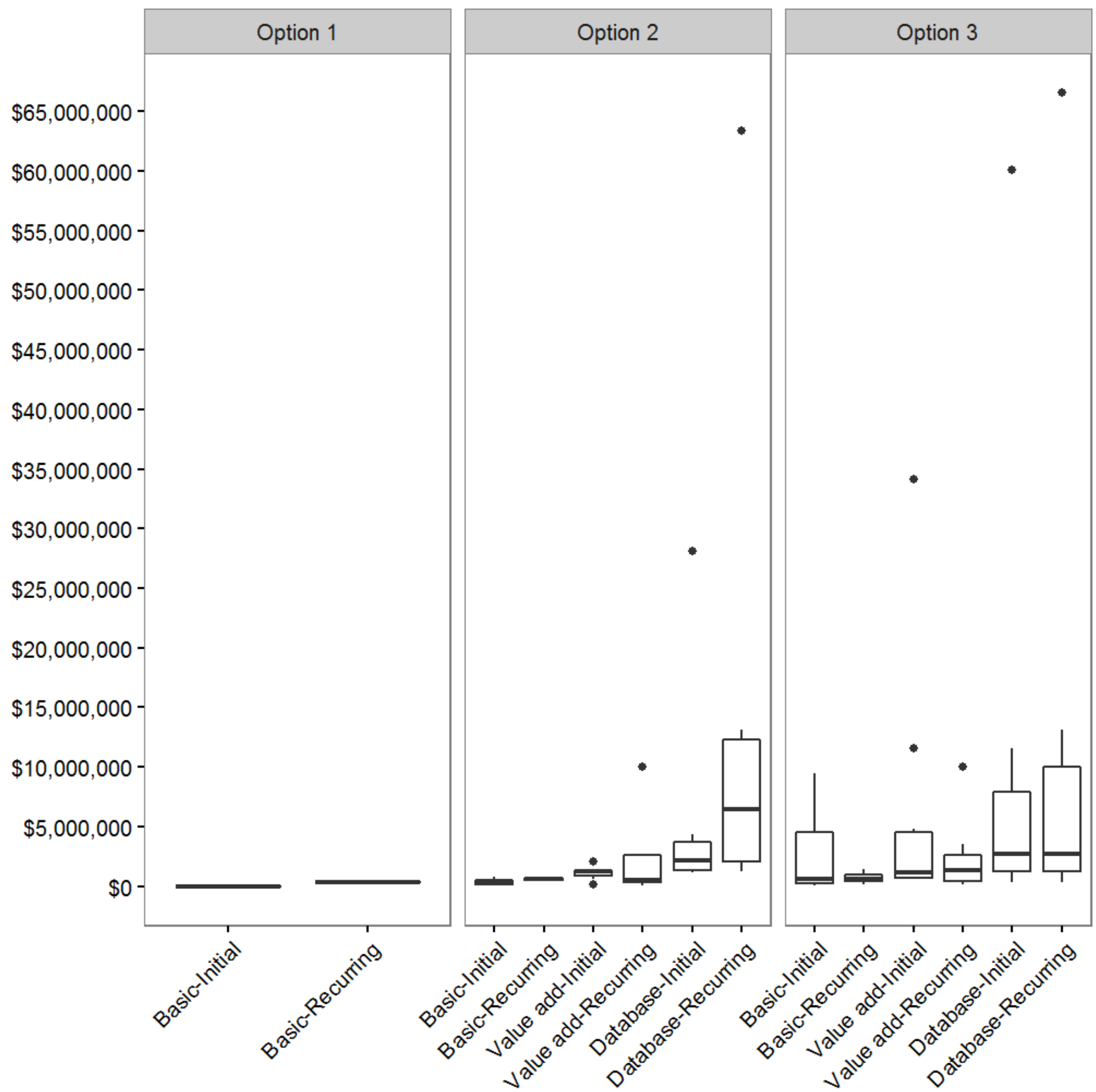
The greatest challenge with Option 4 is disagreement in the community as to whether SSA is an inherently governmental function (see Chapter 9). If it is deemed inherently governmental, then this option is not viable. If it is not inherently governmental, then the issue of who pays—whether government or the user—becomes relevant.

FAA/AST will need to choose how to fund these services, whether it is through FAA/AST's budget or user fees. If licensees are required to utilize an industry conjunction warning service and pay themselves, there will be pushback, especially from new entrants into the market that may not be able or willing to afford this service (once a service is received or expected to be received for free, it is never easy to go back and implement fees for it). At the low end of estimates, $100,000 per year or $10,000 per screening, the service would likely still be unaffordable for some commercial operators, especially emerging companies without a strong revenue base. Liability is a concern for companies considering providing this service. If FAA/AST decides to use Option 4, a liability clause will likely be needed to protect vendors from any potential harm that may come from data they provided. If this protection is not included, it will be difficult for FAA/AST to find an NGE willing to provide this service. Another challenge is the high cost associated with this option. It is ideal when the government only needs a few conjunction analyses per year, but once the market becomes more active or if FAA/AST is given on-orbit authority, the demand for conjunction analyses will exceed the limit of cost savings for utilizing this option.

Another concern with this option is that NGE-provided SSA services may not be viewed as meeting the requirements for government oversight under the Outer Space Treaty obligations. This option raises concerns of safety. If owner/operators are allowed to pick from multiple providers, they may choose the least expensive or restrictive companies, which could be counterproductive to safety in space. Finally, if NGEs provide warnings to international partners that currently have agreements with DOD, the partners may view this option less favorably than working directly with the U.S. Government.

## E. Summary of Options

There are four approaches using which SSA can be provided to civil, commercial, and international users. First, DOD can continue to provide SSA services as it currently does; second, a civil organization such as FAA/AST could provide them, either directly or by certifying an NGE; third, industry could provide them for itself, as is currently done in a limited way by SDA; and finally, they could be provided by an international organization, such as ISODEX. Figure 20 provides a cost/price summary for all options.




*Note*: The price for Option 4 is not provided visually due to uncertainty in data—the prices provided by NGEs ranged from $10,000 to $500,000 per event, while annual prices ranged from $100,000 to $1 million per satellite annually.

**Figure 20. Cost/Price of All Options (To Be Considered in the Context of Strengths and Challenges in Table 8)**

If SSA services are determined to be an inherently governmental function, then only the Approaches 1 and 2 ("Business as usual" and "provision by a civil government agency") are applicable. Establishing an international organization to provide SSA services (Approach 4) can be established simultaneously with any national SSA provision option. If a civil agency (Approach 2) is chosen, and FAA/AST is deemed the civil agency to perform SSA services, there are still a few key decisions to make that will guide which Option is most applicable.

To gain limited capability but save significant funds, FAA/AST can become embedded within JSpOC (Option 1). To have more flexibility to expand and improve while saving money, FAA/AST can use DOD's data, hardware, software, and procedures under Option 2. If FAA/AST would like greater control over SSA, they can use NGE software. Finally, if FAA/AST wants to begin providing a service with almost no initial investment needed, they can have an NGE provide conjunction warnings as a service (Option 4). Each option comes with its own strengths and challenges, which are summarized in Table 8.

# 8. Space Traffic Management

As discussed in Chapter 2, STM is distinct from SSA in that it involves actions related to the oversight, coordination, regulation, and promotion of space activities, and takes place at several distinct phases of the mission: launch, operations in space, and return from space. Many experts believe that the United States lacks a comprehensive STM regime (Pace 2016). They are correct in that currently there are no clear authorities for licensing in-orbit operations such as space tourism, asteroid mining, satellite servicing, or any number of other activities being proposed by private firms (STPI 2016). Similarly, there is no international process for activities such as coordinating the removal of orbital objects, as even unused objects (or orbital debris) are the property of some sovereign State. This has led to questions as to whether private U.S. space companies are being supervised properly as required by the Outer Space Treaty.

A full STM regime requires a strong foundation of SSA. This chapter summarizes how STM services are currently provided, examples from other domains that provide important lessons regarding approaches to STM system development, and potential ways in which a civil agency could provide on-orbit STM. While STM is not the focus of this report, exploring the topic was crucial to examine which of the SSA approaches and options would be best extensible to an STM regime.

## A. Current Provision of STM Services

Currently there is no formal, overarching STM regime in space, either within the U.S. or internationally. However, there are some aspects of STM that are being performed at national and satellite operator levels. For example, individual satellite operators make decisions to minimize the potential risk of on-orbit collisions, including whether to alter their orbital trajectory when notified of a potential conjunction. NASA, in conjunction with other space agencies, also conducts active STM of human space flight objects involved in rendezvous and docking operations with the ISS. In addition, many governments, including the United States, license specific categories of private sector space activities, which is a form of STM in that governments decide who can participate in space, and what they are allowed to do during launch, reentry, or in-orbit. Several governments, including that of the United States, also use licenses to implement space debris mitigation guidelines, which are an important tool for managing the growth in orbital space debris. They also manage some aspects of radiofrequency interference mitigation, which is considered a form of STM.[34]

Four U.S. Federal agencies currently have roles in providing STM services: NASA, FAA, FCC, and NOAA. Three of these agencies license U.S. private sector actors, and two of them conduct their own satellite operations.

- NASA: NASA operates its own fleet of robotic spacecraft in orbit around the Earth. In conjunction with other national space agencies, NASA actively controls the movements and activities of human space flight objects that are involved in rendezvous and docking operations with the ISS; i.e., it performs STM services for its own assets. NASA has developed a rigorous set of management practices to ensure the safety of the ISS and other spacecraft carrying humans.
- FAA: FAA is a regulator of space launch and reentry transportation carried out within the United States or by U.S. citizens. FAA/AST exercises this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States. In determining whether to issue a license, FAA/AST conducts an interagency policy review, a safety review and approval, a payload review and determination, an environmental review, and sets financial responsibility requirements.
- FCC: FCC is responsible for efficient and effective use of non-Federal radiofrequency spectrum domestically. Internationally it promotes the growth and rapid development of innovative and efficient communication technologies and services. It regulates satellite communications through the licensing of radio transmitters in outer space. FCC licenses may contain conditions regarding end-of-life disposal and debris-mitigation practices.[35]
- NOAA: NOAA is responsible for licensing private remote-sensing space systems. NOAA's regulations require licensees to provide and operate their

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[34] A listing of many national legal and regulatory frameworks for oversight of private sector space activities can be found on the website of the United Nations Office for Outer Space Affairs: http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/index.html

[35] At present, FCC and NOAA both require their licensees to submit their plans for end of life. NOAA requires its remote-sensing licensees to submit plans for post-mission disposition of their satellites and a casualty risk assessment for planned post-mission disposals involving atmospheric reentry of spacecraft (15 CFR Part 960). FCC licensees are required to submit mission-disposal plans for the space station at end of life, including a risk assessment if disposal involves atmospheric reentry. Applications for space station authorizations must describe the design and operational strategies that will be used to reduce orbital debris, including an assessment of the probability of the space station becoming a source of debris by collisions with debris, meteoroids, or other operational space stations. For space stations launched into a low-Earth orbit, an analysis of the potential risk of collision and what measures will be taken to avoid in-orbit collisions is also required (47 CFR Part 25).

systems within certain orbits, submit a plan for post-mission disposition of remote-sensing satellites, and provide a casualty risk assessment for planned post-mission disposals involving atmospheric reentry of the spacecraft.

Internationally, the main aspect of STM currently being conducted is the management of radio frequency spectrum. The International Telecommunication Union (ITU) Convention recognizes the radio frequency spectrum and specific orbital regions as limited resources and provides for their efficient and economic use and equitable access. The ITU manages radio frequency spectrum by allocating specific frequency ranges, or bands, for specific space or terrestrial applications. It also coordinates the use of geosynchronous orbit (GEO) to minimize interference between satellites orbiting next to each other in GEO and using the same radiofrequencies.

Similar to the current national licensing process in the United States, the ITU process focuses mainly on pre-launch coordination instead of active management on orbit. There is little currently done in the way of enforcement or assurance that satellites cooperate; nations must largely work this out between themselves. Also, although this coordination has a clear process internationally given ITU's set procedures, ITU is agnostic regarding the national-level implementation processes for radio frequency interference (RFI) avoidance. If there is ever an instance of "intentional RFI" or jamming of a satellite signal, the ITU has no mechanisms to prevent or penalize it, despite it being in violation of the ITU Convention.[36]

The current system for assigning and managing radiofrequencies for satellites is also facing challenges from changes in space activities. The increasing number of space-faring nations and commercial satellite launches have strained the ITU's coordination process, and the time it takes has grown accordingly (International Academy of Astronautics 2006). Given the current reporting rules, the ITU processes spend significant amounts of time on "paper" systems that governments report to them that never actually are built (International Academy of Astronautics 2006). Identifying "international RFI" has become more difficult for the ITU due increasing demand, which has caused companies to use RFI detection techniques such as those offered by the SDA or other commercial services (Rawlins 2015). The ITU process is also best suited to satellites in geostationary orbit, where coordination of both stations and frequencies at once is possible. A new wave of commercial companies are seeking to build large LEO communications constellations, using some of the same frequencies as used by GEO communications satellites, which has led to renewed discussions about how to coordinate usage of the frequencies to manage interference.

[36] International Telecommunication Union website, "What Does ITU do?" http://www.itu.int/en/about/Pages/whatwedo.aspx.

## B. STM-Relevant Examples from Other Sectors

As with SSA, space traffic management has analogies in other domains. This chapter discusses examples from other sectors in terms of their organizational structure and development. The focus here is on how these other services were developed and implemented, and what lessons they could provide with respect to how an STM system might be developed in the future.

### 1. International Civil Aviation Organization (ICAO)

One possible example is the way air traffic management is handled internationally with ICAO. ICAO is the most recent incarnation of an international treaty for managing air traffic. It emerged from the Chicago Convention in 1944, a conference of 1,000 participants from 52 nation states convened to debate and simplify the complex and conflicting sets of national regulations for air travel following World War II. The two major players were the United States and Britain. The two powers argued for ideologically opposite standards, with the United States pushing for largely open competition in airspace, while Britain wanting controlled development of aviation and an international authority to impose an equitable determination of fares, routes, and frequency among participating states.

In a final compromise, the conference agreed to found ICAO as a functional intergovernmental organization. Its mandate was limited to safety and technical (rather than commercial) matters, and could occupy only an advisory role, with its recommendations subject to approval by governments (Nayar 1995). ICAO was chartered on December 7, 1944 and officially ratified by a majority of the original 52 signatories on April 5, 1945, making it an official agency of the United Nations.

Over time, ICAO has grown to 191 member states and remains a functional U.N. agency.[37] Although its purview still excludes commercial regulation, it has increasingly provided a forum for discussion of these issues as well.

Although ICAO does not have the power to enforce its recommendations, member states tend to adopt them. This is helped by the United States, the clear superpower in aviation, consistently doing so; FAA uses the standards and procedures set by ICAO to frame its own practices (Spence et al. 2015, 1-8).

ICAO has several mechanisms by which to set policy, many of which derive from the 1944 Chicago Convention. The initial "five freedoms of the air" is one set of principles agreed to at the Convention that member states agree to adhere to in setting their national policies (Firican n.d.). ICAO also publishes objectives and annexes that contain the specific

[37] See International Civil Aviation Organization, "About ICAO." http://www.icao.int/about-icao/Pages/default.aspx.

Standards and Recommended Practices (SARPS) to which member states are expected to adhere.[38] The objectives were established at the Chicago Convention, while the annexes have been published in the subsequent decades, subject to regular amendment.

ICAO operates using a treaty-based or "top-down" approach to management and regulation. The main purpose of ICAO was to resolve disputes between countries over the coordination and management of international air traffic, and to harmonize the patchwork of national regulations. The standards and policies adopted by ICAO have no national-level enforceability, and require implementation through national laws and regulations.

Although there is some discussion of creating an "ICAO for space," it is not clear how well suited the concept would be now, particularly to on-orbit activities. Given that there are very few States with existing regulatory agencies that are actively providing oversight of private sector space activities (unlike in aviation), it is unclear what value a formal international agreement and body would have. However, if significant differences between States on how to regulate and provide oversight of private sector space activities are expected to arise, an ICAO-like approach could be a good solution to stave off conflicting national regulations. This approach could create a set of best practices for STM legal and regulatory approaches for each nation to incorporate into their own system. As with ICAO, the body could be started by the space-faring nations and expand membership as nations gain access to space. Like ICAO, it could be an international regulatory body that lacks the authority to enforce its own policies, but it could be a step in the right direction for better international SSA and potentially STM coordination.

## 2. Privatized Air Traffic Control (ATC)

Under the ICAO system, there are differences in how States implement their national air traffic control (ATC) systems. In the United States, ATC is government-run, but internationally there are varying degrees of privatization.

In the United Kingdom, for instance, National Air Traffic Services (NATS) was created as a government-owned NGE in 1994, but was converted to a for-profit public-private partnership in 2001. The government is the NGE's largest shareholder (49%), but only receives dividends, and is not involved in the day-to-day operations of the NGE or the civil ATC system (Office of Inspector General Audit Report 2015).

NATS has a 30-year contract with the UK government to provide en route ATC services, but competes with other service providers to provide these services at UK airports.

Somewhat similarly, in Germany, ATC was originally under direct government control through Deutsche Flugsicherung GmbH (DFS), but this changed in 1993 when DFS

[38] Ibid.

transitioned to a government-owned limited liability NGE. It is now run by its board of directors, which is split evenly between government representatives and employees. DFS provides services at 4 radar control facilities and 16 national airports, but the German states are responsible for obtaining ATC services at all other airports (Office of Inspector General Audit Report 2015). In 2004, Germany attempted to reorganize DFS into a public-private NGE (similar to NATS) by selling the majority of shares of the NGE to private investors. However, this process was stopped in 2006.

Australia, New Zealand, and Switzerland all have civil ATC systems that operate similarly to the German model ("Air Traffic Control Privatization" 2005).

Canada has taken privatization of air traffic control even further with Nav Canada, a private, non-profit, non-share corporation founded in 1996 with the sole mission of facilitating the safe movement of aircraft through Canada's air traffic system. The Canadian government has representatives on the NGE's board of directors (also comprised of representatives from airlines, general aviation, and unions), but otherwise has no direct role in the day-to-day operations of the NGE of management of the civil ATC system (Office of Inspector General Audit Report 2015).

There are a few salient features common to all of these "privatized" ATC models. In all cases, safety oversight and regulatory functions remain government controlled, while air traffic control functions have been separated out and commercialized. The ATC systems are financially self-supporting, primarily through the collection of user fees, but also with borrowing authority for modernization and infrastructure projects. Finally, none of the companies perform either large-scale modernization efforts or extensive aviation research and development. Instead, they implement new technologies incrementally using various methods—often by simply purchasing commercially available off-the-shelf technologies (Office of Inspector General Audit Report 2015).

There is already extensive research comparing other countries' ATC systems and operations to FAA's, and on what a privatized ATC system could look like in this country ("Air Traffic Control Privatization" 2005). The systems would serve as an equally fruitful model for how an STM system could be implemented as well. Under such a model, a private (or public-private-partnership, or government-owned) NGE could provide STM services for civil or commercial operators, obtaining and disseminating SSA data through commercially available technologies, and directing traffic to avoid collisions when necessary under the safety regulations set by the government. It could be paid for by user fees, if there was a regulation that launching a spacecraft into orbit requires buy-in to an STM system. Such a STM system could work in parallel with the government's own for their own assets with appropriate mechanisms for data-sharing or cooperation, just as private/governmental ATC coordination works in other countries. A significant challenge to implementing this kind of system lies in how to incorporate internationally owned/operated satellites.

### 3. Debris Mitigation Guidelines

Another example to consider is the way the UN space debris mitigation guidelines were developed. As was the case with the air traffic rules, the space debris mitigation guidelines began with national practice, and have received international acceptance. However, unlike with ICAO, the spread of the space debris mitigation guidelines has occurred without a legally binding treaty ("Space traffic management concepts and practices" 2004).

The United States was one of the first nations to begin research into debris mitigation in earnest, with scientific research into the issue ongoing through the latter half of the twentieth century. Following the breakup of an Ariane I second stage in LEO in 1986, which resulted in nearly 500 new pieces of debris, NASA hosted an international conference on the breakup of launch vehicle upper stages. After the conference, ESA established its own Space Debris Working Group.

In 1987, NASA and ESA met to coordinate and share their orbital debris mitigation suggestions, study results, and contact information for technical experts. Additional meetings followed roughly annually. By the end of 1989, NASA had also established similar bilateral orbital debris working groups with both the Soviet Union and Japan. In 1995, NASA was the first space agency to issue a comprehensive set of orbital debris mitigation guidelines, based on the previous decades of research.[39] Two years following, the U.S. Government published the *Orbital Debris Mitigation Standard Practices* based on these NASA guidelines. Other countries and their national space agencies (Japan, Russia, France, and ESA) followed suit in the subsequent years.

The Inter-Agency Space Debris Coordination Committee (IADC) grew out of the NASA-ESA coordination meetings, and was set up as a formal organization in 1993. Originally, it included NASA, ESA, Japan, and the USSR. Today, the IADC is composed of the space agencies of 11 countries and ESA. The organization was composed of four working groups (measurements, environment and database, testing and shielding, and mitigation) and a steering group. In 2002, the IADC published a set of debris mitigation guidelines based on consensus of the national-level guidelines. Their other accomplishments include the establishment of a data exchange network for the uncontrolled reentry of satellites and the organization of campaigns for observation of untracked debris (Nicholas 2015). Since 1997, it has also provided a technical presentation at the annual meeting of the Scientific and Technical Subcommittee of COPUOS.

The IADC debris mitigation guidelines were used as the foundation for the COPUOS space debris mitigation guidelines published in 2007. The COPUOS space debris

[39] NASA Orbital Debris Program Office website, "Orbital Debris Management," http://orbitaldebris.jsc.nasa.gov/mitigate/mitigation.html.

mitigation guidelines are a simplified version of the IADC guidelines, and were endorsed by all the UN member states. In contrast to ICAO's SARPS, however, the purpose of COPUOS's guidelines is not to impose them upon member states. Rather, the guidelines were meant to reflect the common recommendations of national-level mitigation strategies and the underlying technical content and established definitions. The document is subject to periodic review and revision based on new research by member states and other organizations.

Similar to ICAO, neither IADC nor COPUOS has the authority to enforce adoption of their guidelines. However, since the guidelines are based entirely on existing research, they largely reflect what is already being done for mitigation, rather than set new policy.

The development of the debris mitigation guidelines illustrates a "bottom-up" approach to establishing regulation, in contrast to the "top-down" approach exemplified by ICAO. Whereas ICAO has sought from the beginning of the aerospace industry to dictate guiding principles that would shape the field through regulation, the IADC/COPUOS debris mitigation guidelines emerged after many decades of research already being done in the field, and are meant to only reflect work already done by subject matter experts.

Many advocate this kind of bottom-up approach, as they believe focusing on legal issues before there is widespread international acceptance of the technical foundations could actually delay adoption of the guidelines—countries might be reluctant to accept debris mitigation measures, for example, if they are still under legal examination.

### 4. Maritime Domain Awareness

A particularly informative model for the development of both SSA and STM may be Maritime Domain Awareness (MDA). MDA is the understanding of developments in the maritime environment that impact safety, security, the economy, or the environment.[40] As previously noted, air traffic policies and supporting systems have been imposed on the industry nearly since its inception, guided by ICAO and implemented by participating countries. In contrast, maritime policies and supporting systems have had many centuries to develop *ad hoc* without any kind of unifying governing body—in this way, "maritime security is burdened by thousands of years of history and tradition" (Nimmich and Goward 2007). Recently, however, the security and knowledge of sea traffic has been receiving increased scrutiny. Any work currently being done on MDA could therefore be quite valuable for considering systems of both SSA and STM, as maritime security issues touch

[40] Derived from the definition of MDA (IMO MSC.1/Circ.1343, amendments to the International Aeronautical and Maritime Search and Rescue (IAMSAR) Manual, 24 May 2010, International Maritime Organization 2010).

on both knowledge of seafaring traffic (situational awareness) and licensing, regulation, and governance (traffic management).

On the management side, there is essentially no centralized management of the maritime domain—in 2004 there were at least 18 Federal agencies responsible for regulating some aspect of U.S. maritime transportation, and that there was little to no coordination between their efforts (National Academies of Science 2004). Additional involvement from organizations and individual states or cities (e.g., port authorities, private facility operators, marine exchanges, etc.) complicates the landscape even further (Nimmich and Goward 2007).

On the awareness side, it is difficult to even know how many crafts are currently at sea, let alone accurately track their movements. There are over 13 million recreational vessels that only need be licensed by individual States (where registration practices are often lax or nonexistent), and there is no simple method of exchanging or verifying information across State lines (Nimmich and Goward 2007). Meanwhile, 8,000 foreign ships make 50,000 U.S. port calls annually, and 95% of all U.S. foreign trade is conducted through 361 ports. National security remains a perennial concern given 70% of the country's population resides along 95,000 miles of U.S. coastline (Goward 2008).

History offers clear reasons why MDA to-date has been so limited. First, the use of the seas long predates centralized government regulation, which complicates the imposition of new authorities and systems. In addition, a longstanding culture of secrecy colors the maritime regime—those shipping commodities do not want competitors to know their cargos and destinations, fishermen do not want their fishing spots to become overcrowded, ownership of vessels is often kept concealed, etc. (Nimmich and Goward 2007, Goward 2008). Any MDA system must work against this culture of secrecy.

The policy importance of implementing MDA seems to be well-understood, but any system for doing so remains in flux. In September 2005, the U.S. Government released the National Strategy for Maritime Security, as directed by the National Security Presidential Directive-41/Homeland Security Presidential Directive-13 (December 2004) (Department of State. 2005). The National Strategy was supported by eight implementation plans, including the National Plan to Achieve Maritime Domain Awareness (October 2005) (Department of Homeland Security. 2015). Since the plan's approval, the interagency process it outlines has developed an MDA Concept of Operations (CONOPS) (December 2007), which established a national MDA governance structure (made up of stakeholders from DHS, DOE, FBI, the Coast Guard, Navy, and others) and an architecture for information sharing across the Global Maritime Community of Interest ("National Concept of Operations for Maritime Domain Awareness" 2007). The CONOPS also outlined the desired final state of MDA.

In the years since, DHS agencies have made some progress in facilitating cooperation and information-sharing amongst the MDA stakeholders, according to the framework laid out by the CONOPS. However, shortfalls still remain—a 2014 GAO report found that the technology acquisitions managed by the Coast Guard to gather MDA information still leave large holes in the desired final state of MDA, and thus have not yet fully achieved their intended purpose (Caldwell 2014). MDA remains in a state of active growth; DHS and the Coast Guard opened the Center of Excellence on Domain Awareness in 2015 to continue to make strides in the field.

Although MDA is arguably no farther along in its development than any SSA/STM system for the United States, it is a potentially fruitful area to watch for lessons and best practices. As with space traffic, marine traffic has already evolved for years with minimal tracking or management systems imposed, involves participation and/or vested interest both from several agencies within the government and from civil and commercial players, and has a significant international component. The high seas provide interesting parallels to space, where national governments often are viewed as responsible internationally for the actions of private crafts from their state. The challenges of licensing, controlling, and tracking ships in MDA as it evolves may provide helpful best practices for potential SSA/STM systems. Table 11 summarizes lessons and best practices relevant to STM from the four domains examined.

**Table 11. Summary of STM-Related Lessons/Best Practices from Other Domains**

| Example | Lesson to be Learned Regarding Approach to Management |
|---|---|
| ICAO | “Treaty-based” international standards for national systems to implement |
| Privatized ATC | Private companies being able to provide services to civil and commercial operators, paid for by user fees |
| Debris Mitigation Guidelines | “National-level-first” development of system that is then endorsed and emulated internationally |
| MDA | Interagency participation for governance structure, national responsibility for private/commercial craft in international space |

## C. Options for Future Provision of STM Services

While this study does not attempt to develop an architecture for a national or international STM regime to the same level of detail as SSA, it does examine several conceptual ways to implement a comprehensive STM regime. In this report, we present four: augmenting current licensing processes to include new on-orbit activities; supporting industry safety standards for preventing collisions; establishing government-set “rules of the road” for space traffic direction and collision avoidance; and, finally, establishing an authority with direct control over space traffic. The levels build on each other and are not mutually exclusive. Given the infancy of thought on the topic, costs were not estimated for any of the options. However, it is clear that they increase as STM efforts become more active.

### 1. Licensing On-Orbit Activities

The United States already licenses space objects for launch and reentry of spacecraft, and regulates two space-based activities—remote sensing and communications. One option for creating an on-orbit STM regime is simply to expand the current licensing to include all on-orbit and deep space activities.

The idea has support. For example, the White House Office of Science and Technology Policy recently submitted a report to Congress requesting that FAA receive regulatory authority to coordinate an interagency process to review proposed private sector space activities for safety and compliance with international law, and issue licenses (Holdren 2016). Reading between the lines, this report essentially asks Congress to provide FAA with authority to oversee on-orbit activities through pre-launch licensing but not necessarily active oversight during space activities.

### 2. Supporting Industry Best Practices and Standards

The Satellite Industry Association has published best practices for responsible space operations (Satellite Industries Association 2015). Such a set of standards could be further developed in collaboration with government and industry stakeholders in the United States in addition to international parties. The theory behind industry-set standards is that industry has the incentive to set safety standards that are high enough that the space environment is safe and usable in the long-term. The self-regulating approach could be very successful in GEO where most owner/operators have a strong profit-motive in keeping the environment safe; however, it is more likely to fail in more common and easily accessible orbits such as LEO.

The principal limitation of this option is that there may not be consequences or repercussions for actors that do not follow the rules, aside from peer or social pressure. This could become increasingly likely as more low-cost satellites are launched. These "free riding" entities are less likely to follow industry-set rules because they may believe that the adverse effects of bad behavior will not affect them in the long-term.

### 3. Government-Set Regulations for Preventing Collisions

Another way to implement an STM regime would be for the Federal Government to set "rules of the road" for space that dictate if and when a satellite must maneuver. This type of regulation will likely include rules that limit orbits for non-propulsive spacecraft such as CubeSats. In this scenario the Federal Government, while it provides SSA services, will not actively instruct owner/operators to move. Instead, the onus will be on the owner/operators to understand the rules and self-enforce or face penalties, such as denial of a future license. This system will likely increase membership at organizations such as SDA or the need for services from SSA companies.

The practical rules for STM could be very similar under this option as they would be under Option 2. The primary difference is simply in who is setting the rules, which affects how the relevant authorities could penalize noncompliance.

### 4. Active Space Traffic Control

The final option discussed here for SSA provision is active space traffic management, akin to air traffic control, whether governmentally controlled as in the United States or privately controlled as in Canada and other countries. The controlling authority will be responsible for continually knowing where all objects are in space, and also for instructing at least U.S. licensee satellites (and possibly others, depending on if other nations acquiesce to the controlling system) when and how to move. If properly created and managed, it could result in the safest space environment. It also has the most onerous regulatory regime as compared with the previous three options. Table 12 compares differences across various forms of regulation.

There are two major concerns with this approach. The first is that the U.S. Government only has authority over the activities of U.S. private sector entities. While this would include a significant proportion of current and planned future satellites, there would still be many satellites over which the U.S. Federal agency managing STM would not have control. If other countries created their own national regulators, and also gave them active control authority, then the U.S. entity could then interface with these other entities, as is the case in air traffic management. However, the prospects of this happening in the near future are slim, given that most countries do not have even a basic space law in place.

The second major concern with this approach is liability. Commercial satellite operators may hold the U.S. Government liable for directing actions that result in damage or destruction to their assets, or for actions that turn out to be unnecessary. This is discussed in further detail in Chapter 9.

**Table 12. Comparison of Regulatory Mechanisms**

| | Government Led | | | Industry Led | |
|---|---|---|---|---|---|
| | **Prescriptive** | **Performance- or Process-Based** | **Co-regulation** | **Third-Party Regulation** | **Self-Regulation** |
| Government and Industry Roles | Government incurs cost of issuing and enforcing regulation. Industry bears cost of implementing regulation. | Government incurs cost of developing regulatory framework. Industry bears costs of implementing regulatory framework. Government incurs costs of enforcing. | Government and private industry share costs of developing, implementing and enforcing regulatory framework. | Private industry incurs cost of developing, implementing and enforcing voluntary consensus standards (framework?) Government may expend human resources participating in process. | Private industry incurs cost in developing and implementing voluntary standards. Government may expend human resources participating in process |
| Authorities to Issue, Administer, and Revise Regulation | Government has authority to issue and amend regulations and ensure compliance | Government has authority to issue or amend regulations and ensure compliance | Government maintains oversight authority but industry has authority to develop standards based upon consensus | Third party has authority to develop voluntary standards subject to industry acceptance/approval | Industry has authority to develop voluntary standards |
| Conditions for Application of Approach | Safety requirements necessitate specificity. Hazard reduction and mitigation are well defined and technological improvements can be adopted incrementally with few changes to core technologies or designs. | Methods for quantifying hazards are well developed and agreement on safe levels can be reached but there are multiple potential routes to determine how to meet those standards. | Requires independent industry representative(s), industry and government transparency and resources, and government oversight role. | Third party with autonomy from individual companies, sufficient industry resources, transparency and public accountability exists and considered more effective standards developer than government | Industry has committed resources and development of voluntary standards is a shared common goal. |

| | Government Led | | | Industry Led | |
|---|---|---|---|---|---|
| | Prescriptive | Performance- or Process-Based | Co-regulation | Third-Party Regulation | Self-Regulation |
| Compliance Mechanism<br>Does one exist and if so, who has oversight?<br>Are there consequences for non-compliance? | Government oversight provides strong mechanism for compliance.<br><br>Enforcement mechanisms may include audits, certification, revocation of license or permit, fines or penalties | Government oversight provides strong mechanism for compliance<br><br>Enforcement mechanisms may include audits, certification, revocation of license or permit, fines or penalties | Government oversight provides strong mechanism for compliance<br><br>Enforcement mechanisms may include audits, certification, revocation of license or permit, fines or penalties | Third party can provide oversight<br>Mechanism for compliance may include audits, accreditation, certification, or expulsion from membership | No third-party mechanism for compliance<br><br>If public aware of non-compliance, it may impact potential participants' choice or availability or cost of insurance |
| Flexibility<br>Length/complexity of process to change regulations<br>Who can initiate change process? | Most prescriptive approach. Changes to safety standards require rulemaking.<br><br>Government can initiate changes to regulation in response to industry request or government identified need for change | Changes to standards or process require rulemaking but the industry can best determine how to meet standards.<br><br>Government can initiate changes to regulation in response to industry request or government identified need for change | Changes can be made to implementation of standards without rulemaking.<br><br>Flexibility for industry to continually revise standards to reflect changes in state of the technology | Flexibility to continually revise standards to reflect changes in state of the technology subject to determination of appropriateness by third party | Flexibility to continually revise standards to reflect changes in state of the art of technology |
| Transparency<br>Regulation development process<br>Compliance and non-compliance with the regulation | Rulemaking process requires transparency and opportunity for public comment<br><br>Enforcement actions may be public information. | Rulemaking process requires transparency and opportunity for public comment<br><br>Enforcement actions may be public information. | Rulemaking process requires transparency and opportunity for public comment<br><br>Enforcement actions may be public information | Level of transparency varies based upon practices of third party | Level of transparency depends upon practices of individual companies |

*Source*: Eisenstadt et al. 2016.

# 9. Overarching Issues

As Chapter 5 illustrates, regardless of the approach adopted, the estimated cost of operating a civil SSA system outside DOD to provide safety of space flight services is likely to be significantly lower than the military's annual spending on SSA (Government Accountability Office 2015, 7). Cost is not the only metric of interest, however. In each of the approaches for SSA services discussed in Chapter 5, for example, there needs to be buy-in from key stakeholders to build or acquire the basic architecture and provide SSA services to civil, commercial, and international owner/operators of spacecraft in Earth orbit. Further, the decision to select an option will be predicated on certain assumptions, some of which are ideological. For example, whether or not SSA is considered an inherently governmental function will affect whether the certification option can go forward. Similarly, whether commercial systems are brought within government or left outside government (i.e., choosing between branches in Option 3 or selecting Option 4) will depend on whether policymakers believe that innovation occurs faster and better outside government organizations and in the private sector. In this chapter, we discuss eight such overarching issues.

## A. Inherently Governmental Functions

The term *inherently governmental function* is defined in the Federal Activities Inventory Reform Act of 1988 (Public Law 105-270, Section 2(1)(A)) as "a function that is so intimately related to the public interest as to require performance by Federal Government employees." Typically, inherently governmental functions are those that require either value judgments for the Federal Government or discretion in applying Federal Government authority.

Inherently governmental functions include interpreting and executing laws that bind the United States to: (1) take some action by policy, regulation, authorization, or order; (2) determine, protect, and advance U.S. economic, political, territorial, property, or other interests; (3) significantly affect the life, liberty, or property of private persons; and (4) exert ultimate control over the acquisition, use, or disposition of the property of the United States.

In performing an inherently governmental function, agencies are also required to ensure that a sufficient number of Federal employees are dedicated to the performance or management of critical functions to maintain control over their mission and operations. A critical function is defined as a "function necessary to the agency being able to effectively perform and maintain control of its mission and operations."[41]

Given the differences between them, SSA and STM cannot be treated with the same broad brush. SSA and STM can *both* be inherently governmental, STM can be inherently governmental but SSA not, and neither STM nor SSA need be (we assume there is no realistic scenario where SSA is inherently governmental and STM is not). As a result, STM and SSA as inherently governmental functions are discussed separately.

### 1. SSA as an Inherently Governmental Function

Experts who believe SSA is an inherently governmental function contend that proper SSA helps enhance national security, public safety, and societal benefit that comes from smooth operations in space. Chapter 4 presented models of data collection and provision that are considered inherently governmental and retained within the government and are reliable and well-functioning from a consumer's point of view (e.g., GPS).

Experts who believe SSA is not inherently governmental contend that SSA is simply provision of data to parties of interest, and if the private sector can provide the data efficiently and without harming national interest (e.g., they could be required to eliminate certain security-related objects from publicly released data), it should do so. Some experts also believe that private sector may be a better steward of innovation in the system (see Section H below), provide resilience and redundancy to DOD-led SSA provision, and create an entirely new commercial sector, promoting economic growth and development. Chapter 4 presented models of data collection and provision that are not considered inherently governmental and not retained within the government and yet are reliable and well-functioning (e.g., Minor Planet Center).

### 2. STM as an Inherently Governmental Function

As with SSA, there are several reasons to consider STM an inherently governmental function. Properly implemented, STM can ensure public safety and societal benefit that

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[41] In 2011, the Office of Management and Budget (OMB) Office of Federal Procurement (OFP) issued Policy Letter 11-01 2011 outlining guidance for identifying inherent governmental functions. This policy was partly in response to a 110th Congress charge to OMB to review whether existing definitions were ensuring that only government personnel are performing inherently government functions and to develop a single consistent definition. The OFP letter sets forth two primary tests: (1) a nature-of-the-function test that characterizes functions involving the exercise of U.S. sovereign power as an inherent government function regardless of the level of discretion, and (2) an exercise of discretion test (EOP 2011). Office of Federal Procurement Policy Letter 11-01 2011; Luckey and Manuel (2013). In addition, to the FAIR Act and the Policy Letter, other sources of law and policy guidance on inherent governmental functions include OMB Circular A-76 and the Federal Acquisition Regulation.

come from smooth operations in space; enforce behavior (and penalize if violations occur); meet international treaty obligations; and correct for market failure.[42]

Experts who believe STM to be inherently governmental contend, as with SSA, contend that government provision of STM services promotes safety of space flight occupants and U.S. and foreign assets, and protects third-party persons and property on the ground or in space. In addition, it can prevent or at least minimize collisions that would compromise essential functions such as communication, Earth observation, or reconnaissance, which would have deleterious effects on the functioning of other assets in space, including those relevant to national security. In addition, if the space environment is safe and secure, it will promote space commerce and other societally beneficial uses of space.

Second, considering STM a governmental function also implies the ability to instruct parties as to what they may or may not do, or must do. For example, in the likelihood of two space objects colliding, the government determines whether an object needs to move to avoid a collision, and which will have to invest resources to change trajectories. Government managing space traffic can also ensure greater compliance with standards or best practices developed at a national or international level. Authority to compel a U.S. (or even foreign) space operator to change its trajectory to avoid a collision is certainly viewed by many a government function. Government involvement would also be needed to compel compliance or levy a penalty for non-compliance.

Third, establishment of an international STM framework requires government involvement, much like ICAO and COPUOS. United States foreign policy decisions will play a major role in developing this framework. Formulation and execution of foreign policy is an inherently governmental function. In addition, according to some experts, U.S. oversight of SSA and STM is integral to our obligations under the Space Treaty. The United States also has an interest in improving SSA and STM to reduce U.S. liability exposure under the Space Liability Convention for U.S. private operator mishaps.

Arguments against STM being an inherently function focus on the societal cost of the regulation outweighing its benefits. Even if STM were deemed a public good, as it likely is, there is no reason it must be provided by the government. Private parties can provide it as well, as has been shown in examples such as privatized air traffic control in Canada and Europe. Some of the experts consulted for the project specifically pointed to other models

[42] A long-standing rationale for U.S. Government regulation is market failure. Under market failure theory, government regulation is commonly used to implement collective action to provide public goods. Public goods provide benefits that are typically non-appropriable (public access to government data or the benefits derived from basic scientific research are standard examples) and as a result there is a socially suboptimal level provided. Market theory also supports government regulation to mitigate undesired externalities, i.e., social regulation that addresses adverse impacts on third parties (Baldwin et al. 2012, 15–23; Orbach 2012; Stiglitz 2009, 11).

of self-regulation such as maritime safety, and suggested that it would be best for the nascent commercial space industry to evolve its own STM regime based on needs.

## B. Who Pays

Today, the costs associated with maintaining a catalog of space objects and providing SSA services are paid for almost entirely by DOD. There is no cost-sharing with other Federal agencies, and no fees or other charges are levied on U.S. commercial space flight licensees or other international recipients of SSA information. An overarching policy question if the services is provided by an entity other than DOD is who should pay for SSA information and services—the government or the user that will benefit from the service.

Part of the answer to the question hinges on whether the services are considered inherently governmental. If SSA and STM are inherently governmental functions, the government will most likely pay for the service. If not, the government can still pay (for example, if government retains the function but contracts out the mechanics of the work to the private sector). However, it need not, if, for example, industry self-provides the services.

An added complication to the issue of who pays for SSA is the openness of the data. If SSA data are provided by the private sector, they will have a strong incentive to not make the data publicly available and charge for access instead. Doing so would hinder innovation in analytics and services based on the data, as well as scientific research. Maximizing innovation in how SSA data can be used and analyzed would require providing open access to the data, which could undermine the business model. This is similar to the challenges faced in other space sectors where commercial entities provide, or could provide, data, such as remote sensing and weather.

It is important to note here that the question of who should bear the cost of a dual-use system with multiple governmental and non-governmental users is not a new one. A classic example is the debate over cost sharing for GPS. As discussed in Chapter 4, GPS was created for military users, and over the last few decades has had a wide range of civil, commercial, and international users. Over the course of the GPS program, debates have erupted about whether civil agencies should bear a portion of the cost for adding civil functionality, and whether users should be charged for use of the system. While the U.S. maintains a strong commitment to not charging fees to users of GPS, civil federal agencies have begun to provide limited funding to support new features added to GPS to support civil requirements.[43]

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[43] See http://www.gps.gov/policy/funding/2016/.

## C. Data Sharing and Protecting Sensitive Data

A primary consideration in transferring future SSA and services out of DOD is protection of sensitive government and private sector data. For government, sensitive data primarily stems from national security concerns regarding both capabilities and limitations of government SSA sensors and the locations, or existence, of specific government space objects. In the case of the private sector, concerns are related to accidental or deliberate release of proprietary information, which could affect a firm's ability to provide a specific service, plans to provide future services, and operational innovations.

The JSpOC currently deals with sensitive government data through use of an exclusion list and a restricted list. The exclusion list covers very sensitive U.S. space objects, and excludes data on those objects from all normal data processing and analysis activities in JSpOC. The restricted list covers less sensitive objects from both the United States and some allied governments, and restricts publication of element sets for those objects in the publicly available Space-Track.org website. The SDA currently deals with sensitive commercial data by acting as a trusted "black box" for participating satellite operators. The SDA does not share data provided by satellite operators with all the other operators. It uses that data to perform analyses, and it is the analyses that are shared. The SDA has also put in place strong legal protections for misuse or abuse of the data satellite operators shares with it, and it shares with other entities.

Implementing a restricted or exclusion list process for a civil agency or non-governmental SSA system would require the operators working within it to be cleared for handling classified data (Weeden 2014). In addition, the software used by the system would be required to protect classified data while still providing unclassified data to non-government and international customers. Both of these requirements would greatly increase the cost and complexity of the system, and re-introduce many of the same complications and challenges JSpOC currently faces.[44] Many of the experts surveyed for this project advised against going this route, and instead recommended that a civil agency system specifically deal only with unclassified data. This is feasible, as long as JSpOC retains the responsibility and capability to provide for safety of flight for the exclusion and restricted objects lists, in addition to their other national security SSA requirements. However, it is unclear how this solution would be compatible with the national security community's desire to block all publication of any data on the existence of sensitive space objects, as doing so requires knowledge of those sensitive objects.

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[44] Working with classified data would require additional hardware and software to protect the data during transmission and processing. In addition, it is unclear whether it is possible to process classified data and produce unclassified analytical products to the end-user that remedy national security concerns associated with releasing information which may be used to derive classified SSA assets.

Another issue is the handling of uncorrelated tracks (UCTs).[45] The handling and processing of UCTs presents a significant challenge for a civil STM system. On one hand, processing UCTs is necessary to detect, track, and catalog new space objects from launches, separations, maneuvers, and breakups so that they can be included in CA and safety of flight. However, UCTs may also be the result of national security space objects and activities that are being protected by exclusion and restricted protocols or other methods of operational security. Processing those UCTs could result in disclosure of classified or sensitive information, and potentially disruption of national security activities.

A civil or non-governmental SSA system whether operated by FAA/AST, or any other entity, will need to have a data policy and concept of operations in place for dealing with UCTs. One possible way of handling the issue is to process UCTs, but not to make any attempts to determine the nature of the object that generated them, nor its mission or owner/operator.

It should be noted that in many cases, continuing to protect sensitive national security data would likely hinder the overall effectiveness of the system. The protection measures currently used by the DOD are a significant contributor to the lack of innovation and flexibility to increase SSA capabilities to meet emerging challenges. It is likely that there will need to be a compromise between the national security community's desire to continue existing data protection practices and the push to develop a more open data sharing model, in order to meet the challenges of a more congested space environment.

## D. Stakeholder Buy-In

Regardless of the option picked, even maintaining status quo, any SSA system will need buy-in from the principal stakeholders that are vested in and fine-tuned to the DOD-run current system, or find the status quo to be unacceptable. As has been discussed throughout this report, stakeholders include the national security community, other civil agencies, Congress, and both domestic and international users.

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[45] UCTs are observations from sensors that do not match any of the elements sets in the existing catalog. UCTs are not rare. One of the data set providers interviewed for this project stated that their network of optical telescopes generates approximately twice as many UCTs as they do correlated tracks. UCTs could be the result of any one of a number of causes: a space launch that placed one or more new objects in orbit; an active satellite that may have maneuvered far enough off its predicted trajectory that the association process could not correlate the observations of its new trajectory to the old; a breakup generating one or more pieces of space debris that need to be cataloged as new space objects; tracking conditions that may have changed to allow a sensor to collect data on an object that is usually beyond their threshold to detect. The UCTs may be correlated to a space object that is in an orbit or has other characteristics that make it difficult to maintain custody of, such as high area-to-mass ratio objects that have highly unpredictable orbital perturbations. The UCTs could also have been anomalies generated as the result of an error in the sensor, and may not represent a real object at all.

### 1. National Security Community

The primary concern the national security community will have about changing the current system to provide SSA information will be the ability to protect information about sensitive U.S. and allied national security satellites and activities in Earth orbit. As discussed in Chapter 3, SSA data comes at many levels, ranging from observations to analysis products. Even if the data provided by JSpOC are stripped of all exclusion and restricted list objects, there will still be a concern about the data collected from nonmilitary sources as they may be able to identify sensitive U.S. and allied national security satellites and activities in Earth orbit, or include UCTs that correlate to sensitive national security satellites. Because of this community's concerns about disclosure of the existence or location of its military space objects or insights into its capabilities to detect other nation's military space objects, it is unlikely that JSpOC will share any non-public data with other parties without top-down directive such as an Executive Order or congressional mandate.

Any options other than the status quo would require that the civil SSA entity work with DOD to develop a data sharing agreement that includes the DOD's provision of redacted SSN data or the high-accuracy catalog, as well as the civil entity's provision of other data back to DOD. The agreement would need to specify which data will be made available to satellite operators and which will be made public. The agreement would also need to delineate a process for the handling of UCTs that is acceptable to DOD and the intelligence community.

A separate concern for Air Force Space Command is the potential threat that other entities' ability to provide SSA information and STM services could pose to the ongoing JMS upgrade. AFSPC has invested significant political capital and budgetary dollars in developing JMS. Both AFSPC and USSTRATCOM see JMS as a critical piece to their ability to perform national security space activities. If they believe that a separate civil system would undermine continued support for and investment in JMS, it is likely they would actively oppose the system.

### 2. Civil Agencies

On the civil side, NASA and NOAA are the primary U.S. Government entities that use existing SSA data and services. NASA's Space Asset Protection Program uses JSpOC data to protect both its robotic spacecraft and human space flight activities in Earth orbit. NASA's CARA Mission at Goddard Space Flight Center protects approximately 65 spacecraft in Earth orbit.

As Chapter 3 discusses, NASA is heavily invested in and integrated into the current JSpOC system. For example, NASA Goddard funds several contractors who reside at JSpOC and are responsible for performing CA screenings for CARA-supported missions. NASA has also invested significant resources in its own software and hardware that interface closely with JSpOC systems. Both these investments give NASA a high degree of influence in the current system. As a result, NASA could be concerned about potential disruptive effects of another entity establishing SSA capabilities, especially if they were asked to work with them rather than JSpOC. NOAA has similar equities in the current system.

Establishing a capability to provide SSA information or services outside of JSpOC could also trigger other interagency competition or conflict, which could hinder or even block the functioning of such a system. Other Federal agencies already have competence for SSA services or rely on existing SSA services. Without careful handling and planning, attempts to create capabilities outside DOD could trigger defensive reactions from those invested in the current system, which in turn would likely lead to obstacles in the interagency process for creating such a service.

### 3. Congress

Recent years have brought an awareness of SSA and STM in Congress outside the national security context,[46] but questions posed by congressional leaders at relevant hearings indicate a gap in knowledge on the issue.[47] For example, neither NOAA, one of the key agencies for implementing the space debris mitigation guidelines, nor NASA, the primary source of scientific research on space debris in the U.S. Government, were called to testify at the 2013 hearings on STM.

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[46] Congress has traditionally addressed SSA and STM through the annual military budget process, because the U.S. military has historically been the only U.S. Government entity active in SSA and STM. As a result, congressional knowledge about SSA and STM is limited to aspects related to military spending and national security. Over the last decade, the national security aspects of SSA and STM have gotten greater congressional attention, particularly the S-Band Space Fence and JMS. The S-Band Space Fence is a $900 million acquisitions program to build a tracking radar located on Kwajalein Atoll in the Pacific, with a potential follow-on radar located in Australia. Details on JMS are harder to discern, but the available data suggest an investment of around $950 million between 2007 and 2015. Both the S-Band Space Fence and JMS have had their share of controversies. AFSPC shut down the original Space Fence, which the Air Force inherited from the Navy in 2002, in 2013. This was ostensibly due to budget sequestration, but outside analysis suggests the politics of getting DOD approval for the S-Band Space Fence played a role. The Space Fence replacement program itself had once ballooned to an estimated cost of $6 billion, and critics questioned the placement of the first site on Kwajalein, a location which already hosted several U.S. military tracking radars and did not address critical SSA coverage gaps in the Southern Hemisphere. JMS has also has struggled with cost and schedule and has undergone at least two serious “reboots” to put it back on track, with the last being a shift in strategy toward incorporating more commercial-off-the-shelf and government-off-the-shelf software components. Even the new strategy has faced significant delays, however.

[47] On May 9, 2014, the House Subcommittee on Space held a hearing that focused on STM (http://science.house.gov/hearing/space-subcommittee-hearing-space-traffic-management-how-prevent-real-life-gravity). The main topic of the hearing was the current U.S. Federal Government roles, responsibilities, authorities, and coordination mechanisms for dealing with space debris (http://science.edgeboss.net/sst2014/documents/5.9.14_charter.pdf).

The first major challenge FAA/AST will therefore have in dealing with Congress is overcoming an attitude that may be skeptical of, and potentially hostile to, making changes to the current system. Congress may initially question why any other entity needs to perform this function, since the U.S. military already does it. Congress may also be reluctant to accept the finding that a proposed alternative system would perform as well as, or perhaps even better than, JMS in certain limited areas when its cost is orders of magnitude lower. Congress may need justification as to why it should spend additional taxpayer dollars on providing a service already provided by JSpOC, and explain how these efforts would be complementary to those of DOD.

Title 10 U.S.C. § 2274 expressly authorizes DOD to provide SSA services to both governmental and non-governmental operators. It is feasible that Congress does not perceive Title 10 U.S.C. § 2274 as providing DOD with the *exclusive* authority to provide SSA information or services. If Options 2–4 were to be pursued, buy-in on this change would be needed from relevant congressional committees. An initial analysis suggests that an effort to create a civil system that includes procurement of a civil SSA system, coordination between the civil entity and JSpOC, integration between space and air traffic management, and changes in regulatory authority and oversight of private sector space activities may affect at least 11 committees and subcommittees:

- House Armed Services Committee
  - Subcommittee on Strategic Forces (oversight of USSTRATCOM and national security space)[48]
- House Committee on Space, Science, and Technology
  - Subcommittee on Space (oversight of NASA, space commercialization, international cooperation, Department of Commerce and Department of Transportation space activities) [49]
- House Committee on Transportation and Infrastructure
  - Subcommittee on Aviation (oversight of FAA/AST and aviation safety)[50]

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[48] U.S. Senate Committee on Armed Services website, “Subcommittee on Strategic Forces,” http://www.armed-services.senatearmedservices.house.gov/about/subcommittees#index.cfm/strategic-forces.

[49] U.S. House of Representatives Committee on Science, Space and Technology website, “Subcommittee on Space,” http://science.house.gov/subcommittee-space-and-aeronautics.

[50] U.S. House of Representatives Transportation and Infrastructure Committee website, “Aviation,” http://transportation.house.gov/subcommittees/subcommittee/?ID=107417.

- House Appropriations Committee
  - Subcommittee on Defense (funding for all defense programs)[51]
  - Subcommittee on Commerce, Science, Justice, and Related Agencies (funding for NASA and Department of Commerce and Department of Transportation space activities)[52]
  - Subcommittee on Transportation, Housing, and Urban Development, and Other Related Agencies (Funding for DoT, including FAA/AST)[53]
- Senate Committee on Commerce, Science, and Transportation
  - Subcommittee on Science and Space (oversight of civilian aeronautical and space science and policy) [54]
  - Subcommittee on Oceans, Atmosphere, Fisheries, and Coast Guard (oversight of NOAA space activities)[55]
  - Subcommittee on Aviation Operations, Safety, and Security (oversight of civil aviation, FAA, and air traffic safety)[56]
- Senate Armed Services Committee
  - Subcommittee on Strategic Forces (oversight of USSTRATCOM and national security space)[57]
- Senate Appropriations Committee
  - Subcommittee on Defense (funding for all defense programs)
  - Subcommittee on Commerce, Science, Justice and Related Agencies (funding for NASA and DOT civil space activities)

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51 U.S. House of Representatives Committee on Appropriations website, “Defense,” http://appropriations.house.gov/subcommittees/subcommittee/?IssueID=34795.

52 U.S. House of Representatives Committee on Appropriations website, “Commerce, Justice, Science, and Related Agencies.” http://appropriations.house.gov/subcommittees/subcommittee/?IssueID=34794.

53 See U.S. House of Representatives Committee on Appropriations website, “Transportation Subcommittee Jurisdiction.” http://appropriations.house.gov/about/jurisdiction/transportationhud.htm

54 U.S. Senate Committee on Commerce, Science, and Transportation website, “Science, Science, and Competitiveness.”See http://www.commerce.senate.gov/public/index.cfm?p=ScienceandSpace.

55 U.S. Senate Committee on Commerce, Science, and Transportation website, “Oceans, Atmosphere, Fisheries, and Coast Guard,” http://www.commerce.senate.gov/public/index.cfm?p=OceansAtmosphereFisheriesandCoastGuard.

56 U.S. Senate Committee on Commerce, Science, and Transportation website, “Aviation Operations, Safety and Security,” http://www.commerce.senate.gov/public/index.cfm?p=AviationOperationsSafetyandSecurity.

57 U.S. Senate Committee on Armed Services website, “Subcommittee on Strategic Forces,” http://www.armed-services.senate.gov/about/subcommittees#forces.

– Subcommittee on Transportation, Housing, Urban Development, and Related Agencies (funding for FAA/AST)[58]

Not all these committees and subcommittees may choose to play a role the creation of a civil system. It will likely depend on the details and scope of the proposal and the politics of the issue. If the issue sees a sudden rise in visibility, such as through a highly publicized event in space or a space event affecting aviation or ground safety, it is likely to draw more interest and attention from more committees and subcommittees.

### 4. Commercial Launch Providers and Satellite Owner/Operators

The primary concern regarding any change to the current system from the commercial operators is that any SSA information or services provided by any entity other than JSpOC could be less reliable, more expensive or less timely than what they currently get from JSpOC. Although the current SSA information and services provided by JSpOC are not ideal for commercial satellite operators, they exist, and satellite owner/operators find the current analyses and warnings provided by JSpOC useful (despite little data on the accuracy of these warnings).

A related concern from the private sector is that a government initiative to provide SSA information and services is a gateway to more aggressive regulation. As exemplified by the on-going debates with FAA/AST's Commercial Space Transportation Advisory Committee (COMSTAC), elements of the private sector have voiced significant concerns over any revised or new U.S. Government regulation for space launch, commercial space flight, and on-orbit activities. Of particular concern is reduction in data latency, imposing additional fees or mandating on-orbit collision maneuvers, which are currently viewed as a business economics decision and not a Federal mandate.

A second major concern for commercial operators is data policy. From their perspective, sensitive data primarily stems from proprietary information and competitiveness. It includes problems or situations that may impact their ability to provide a specific service, plans to provide future services, and operational innovations. To gain owner/operator buy-in, there would need to be a data policy for the provision of SSA services that provides appropriate protection to sensitive private sector data. It is worth noting that FAA/AST already has experience dealing with proprietary commercial data, and has experience handling similar concerns with launch operators.

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[58] U.S. House of Representatives Committee on Appropriations website, "Transportation, Housing and Urban Development, and Related Agencies," http://www.appropriations.senate.gov/subcommitteessubcommittee/transportation-housing-and-urban-development-and-related-agencies.

### 5. Foreign Governments and International Organizations

The final group of critical stakeholders is foreign governments and international organizations. Like commercial satellite operators, the members of this last category do not have any formal say in the establishment of an alternative SSA service. However, the growing international awareness of, and interest in, SSA and widespread reliance on the United States for SSA information and data means foreign governments and international organizations are an important end user of a civil SSA service.

The first challenge is to develop an understanding of what their needs and interests are. This is complicated by the relatively new nature of the civil SSA issue for most countries. Only in the last decade have countries other than the United States and Russia ventured into any serious considerations of SSA and STM, and for the most part the motivation has been national security. The second challenge is to navigate relationships and agreements that have already been forged between USSTRATCOM and foreign governments. A significant portion of this challenge is an interagency coordination exercise. Services provided by any entity other than DOD will have to work with USSTRATCOM and the State Department to determine how to integrate the new system into existing agreements and relationships and negotiation of new ones.

The third challenge will be convincing foreign governments and international organizations that the new entity will provide better service than that currently provided by the JSpOC. Some of these entities, such as ESA, have already invested significant resources in validating the JSpOC analytical products and harmonizing their own processes with those of the JSpOC.

## E. Limitations of Existing Agreements, Policy, and Regulations

### 1. Legislative Authorization

No civil agency currently has the legal authorization to regulate on-orbit safety of flight. Congressional legislation would be required any government entity to provide it. FAA/AST has authority pursuant to Title 51 U.S.C. § 509 to license the launch and reentry of nongovernment vehicles carried out within the United States or by U.S. citizens. This authority may be sufficient for at least FAA/AST if not other agencies to provide launch and early orbit collision-avoidance analyses and controlled reentry COLA analyses. It would be prudent, however, consult with Congress regarding its view of Title 10 U.S.C. § 2274.

Since FAA/AST already regulates safety of flight for launch and reentry space transportation vehicles, an extension of their current jurisdiction would likely be the least politically contentious way to regulate on-orbit safety of flight. However, FAA/AST does not currently have any statutory authority over on-orbit activities after the initial launch and last commanded operation on-orbit. FAA/AST could be granted jurisdiction over U.S. registered nongovernmental spacecraft, U.S. Government spacecraft, or other spacecraft subject to U.S. jurisdiction. In addition, authorization should take into account the need for international coordination of on-orbit safety of flight operations, and grant the regulatory agency the ability to enter into international agreements to effectuate its on-orbit safety of flight regulatory mission.

## 2. Space Launch Regulations

FAA's current regulations require launch operators to obtain a collision-avoidance analysis for each launch from USSTRATCOM.[59] The analysis is run against manned orbiting objects (and those that could be manned) to ensure that the launches or payloads do not pass closer than 200 kilometers. Applications for reusable launch vehicles and for a reentry license also require a collision-avoidance analysis.[60] FAA/AST works with U.S. Space Command to ensure COLA analysis is performed for all habitable orbiting objects before each of its licensed launches or reentries.

If there is a change to the current system, and especially if FAA/AST is deemed the entity to provide SSA services, FAA would need to revise its current regulations so that it, or a certified non-governmental entity, rather than USSTRATCOM, provides the collision-avoidance analysis for launches or reentry. By either regulation or internal procedures, FAA would need to establish procedures to protect sensitive commercial proprietary data such as ephemeris and planned maneuver data. Similar provisions would be required for SSA for on-orbit activities.

## 3. Interagency Arrangements

Currently, there is no agreement in place for the transfer of SSN data or the high-accuracy catalog/special perturbation catalog from the JSpOC to any other entity. An agreement between DOD and the SSA service-providing entity would be needed for the provision of redacted SSN data or the high-accuracy catalog. The agreement would also need to delineate a process for handling of UCTs that is acceptable to civil parties, DOD, and the broader intelligence community.

A Memorandum of Agreement (MOA) on safety for space transportation and range activities in force between FAA and the Air Force clarifies their individual roles and responsibilities for overseeing safety of commercial space launch and reentry.[61] The purpose of the MOA is to minimize the regulatory burden on the U.S. commercial space

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[59] Title14 CFR Sections 417.107(e) and 417.121(c).

[60] Title14 CFR Section 431.43 and Part 435.

[61] FAA and Department of the Air Force (2007).

sector by delineating Federal agency responsibilities and providing a stable framework for the U.S. space launch industry. If any changes to the current system are made, the current MOA would need to be revised to reflect assumption of responsibility for civil SSA services for launch, reentry, and on-orbit activities.

At present, FCC and NOAA both require their licensees to submit their plans for end of life. If a new entity is going to collect end-of-life information from its licensees, it should consult with FCC and NOAA to explore ways to coordinate the collection and sharing of this information in those cases in which an owner/operator is subject to multiple license requirements. The entity may need an MOA with FCC and NOAA regarding the sharing of end-of-life verification.

### 4. 2010 National Space Policy

The 2010 National Space Policy assigns the provision of all SSA information services to DOD. The policy states that DOD and the Office of the Director of National Intelligence (ODNI), in consultation with other interested agencies "will maintain and integrate space surveillance, intelligence and other information to develop accurate and timely SSA. SSA information shall be used to support national and homeland security, civil space agencies, particularly human space flight activities and commercial and foreign operations."

The National Space Policy also states that DOD, in consultation with ODNI, NASA, and other agencies, may collaborate with industry and foreign nations to maintain and improve space object databases; pursue common international data standards and data-integrity measures; and provide services and disseminate orbital-tracking information to commercial and international entities, including predictions of space-object conjunction.

If entities other than DOD develop the capability to provide SSA information and services to U.S. commercial space flight licensees or international partners, the National Space Policy would need to be updated to reflect this new entity's role and its responsibility to commercial operators.

### 5. Changes in International Agreements

As of June 2016, USSTRATCOM has signed SSA sharing agreements with eleven foreign countries or international organizations, and fifty with commercial parties. Any changes in roles and responsibility would necessitate an amendment of the existing agreements. DOD may wish to retain some of these agreements because of their national security implications.

## F. Liability Issues: U.S. and International

Liability is a concern for both current and future SSA activities. Provision of SSA activities may be a potential cause for liability because any actions taken in response to the

SSA data that result in damage to space assets or injury to persons could incur liability for the data provider in addition to the owner/operator; STM activities have an even clearer causality link because either the Federal Government or a non-governmental entity will have mandated the movement of a satellite. For the purpose of this report, liability is defined as a legal obligation under U.S. or international law to pay a claim for bodily injury or property damage to third parties.

### 1. Liability under U.S. Law

Under U.S. law, the U.S. Government has sovereign immunity, and may not be sued unless it has waived its immunity or consented to be sued. Although the U.S. Government has provided a limited waiver of its immunity for certain negligent acts committed by its own employees under the Federal Tort Claims Act, the Act does not apply to conduct that is uniquely governmental or to claims based upon performance or failure to perform a discretionary function or duty.

### 2. Liability for Provision by Other Organizations

Title 10 U.S.C. § 2274, the statute that authorizes DOD to provide SSA services, contains an immunity provision that may also apply to the provision of SSA services by other government organizations.[62]

JSpOC also includes language in its user agreements reiterating U.S. immunity for the provision of SSA services under 10 U.S.C. § 2274. JSpOC further protects itself from liability under contract or tort law by including language in its user agreements stating that the "U.S. Government does not warrant the accuracy or completeness of the website or that the website will be uninterrupted, error free, that defects will be corrected, or that the website or server will be free of viruses or other technical problems." Under these provisions, the operator assumes the risk in relying upon the information furnished by JSpOC.

Any civil agency that takes over SSA provision should assess that 10 U.S.C. § 2274 provides it with sovereign immunity for the provision of SSA services to its licensees. In addition, they should consider using language similar to that used by JSpOC in its license conditions, user agreements, or website, to limit its exposure to liability under both U.S. tort and contract law.

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[62] Section 2274(g) provides immunity to JSpOC or persons acting on its behalf for the provision of SSA services. It provides that the "United States, any agencies and instrumentalities thereof, and any individuals, firms, corporations, and other persons acting for the United States, shall be immune from any suit in any court for any cause of action arising from the provision or receipt of space situational awareness services or information, whether or not provided in accordance with this section, or any related action or omission."

### 3. Liability for Provision by NGE Certified by FAA/AST

Vendors can take out insurance to protect themselves, however the cost of doing so (protecting oneself against potentially hundreds of millions of dollar losses a year) would in turn likely drive the cost of the service provided up to a level that would make it unaffordable. Alternatively, the government could provide an indemnification clause in their contract with the service provider so that the government agency retains liability and would be the party to potential legal recourse, which would mostly resolve this issue. However, it is unclear if FAA or any government body can do this.

In addition, commercial offerings that exist in this nature, such as AGI's ComSpOC, currently do not guarantee the data and analyses so as to prevent liability. For example, the ComSpOC warns on its login page "for informational purposes only."

### 4. Liability under International Law

There are two potential sources of liability under international law. The first is the United States' potential liability for the activities of U.S. commercial space flight licensees. Under the Outer Space Treaty, the United States is liable for the outer space activities of both its governmental and non-governmental operators, and such activities require authorization and continuing supervision (the authorization and continuing supervision requirement will be discussed later in this chapter). Under the Outer Space Treaty and the Convention on International Liability for Damage Caused by Space Objects (Space Liability Convention) the United States is absolutely liable for launch and reentry activities that result in damage to third parties' persons or property *on the ground or in flight* caused by U.S. operators. The United States is also liable for damage to third parties' persons or property *in space* if the United States or its operator was at fault. Such claims must be brought by one party to the treaty against another—a private party cannot file a claim under the Treaty or Convention. Minimizing this existing liability is a potential rationale for FAA/AST to play more of a role in SSA information and STM services.

The second international liability issue is whether the U.S. Government would be liable for any SSA information and services provided by FAA/AST or other U.S. entities. Given the historical definition of "space activities," the provision of SSA information probably does not constitute a "space activity" under the Outer Space Treaty or the Space Liability Convention. SSA services could be characterized as information service provided on Earth to space activities, rather than a space activity itself, but a formal analysis would likely be warranted. If SSA services are not deemed space activities, the provision of such services would not incur additional liability under the Outer Space Treaty or Space Liability Convention.

Any organization involved in SSA provision should assess independently of this report whether provision of SSA services is within the scope of the Outer Space Treaty or Space Liability Convention.

## G. International Commitments and Leadership Issues

As discussed above, under Article VI of the Outer Space Treaty, the activities of non-governmental entity in outer space require "authorization and continuing supervision" by the appropriate party to the treaty. There is no consensus within the legal community as to what that means regarding responsibility for SSA, especially going forward as the number of space-based activities such as commercial human space flight, asteroid mining, or others grow.

According to some experts, whether (and which) space-based activities fall under Article VI's requirement for provision of authorization and continuing supervision is a policy determination rather than a legal one.[63] Just as the question of what constitutes continuing supervision requires policy judgments, so does the question of what constitutes an activity requiring authorization. According to these experts, since Article VI is not self-executing (see, generally, Medellin v. Texas, U.S., 128 S.Ct. 1346 (2008)), and because it is not clear that any given activity in outer space creates a gap in compliance with Article VI, Congress may need to analyze whether considerations of safety, national security, or other concerns require regulation. Indeed, at least one expert interviewed for this report opined that existing international space treaties do not require parties or their space operators to share SSA data or warn other operators of potential collisions.[64]

However, other legal experts believe that the United States is not currently meeting its obligations for authorization and continuing supervision of its current space activities, a problem that will be exacerbated as these activities become more diverse in the coming years.[65] The current system for authorization (i.e., the licensing systems currently in place) is adequate to meet the requirements of the Outer Space Treaty for launch and reentry. However, some legal experts argue that the current regime needs to be extended or modified to allow for authorization of on-orbit activities to be fully in accordance with the treaty, particularly for "new" activities such as active satellite servicing and debris removal, which might involve changing course and mission on-orbit. Similarly, some legal experts argue that "continuing supervision" generally indicates a high level of regulatory control and often implies the ability of the regulator to take over and/or terminate operations in short order (casinos and banks, for example, are under this type of continuing supervision). Because of the definition of "national activities," continuing supervision in this case would require the possibility of equivalent governmental control over both governmental and non-governmental actors. Under the current system, the only control the government can exert is to revoke licenses and issue orders to shut down ground operations.

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63 Personal correspondence with expert.

64 However, doing so is well within the principles established by the existing international space treaties, and the United States has established a policy of informing all satellite operators about potential collisions since 2010.

65 Personal correspondence with expert.

Any SSA/STM system is highly relevant to addressing Article VI provisions, as high-quality SSA data would need to be available to even allow for the possibility of "continuing supervision" under this definition, and, depending on the conclusions reached in the legal community, the ability of the government to practice active STM may also be implied.

However, even if there are no legal requirements for a more robust SSA and STM framework, there may be other drivers. One is the increased national and international focus on space safety and sustainability. In recent years, there has been increased discussion in the international community on space safety and sustainability issues. In 2007, the Inter-Agency Space Debris Coordination Committee (IADC) published international guidelines to mitigate space debris, which were based in large part on work previously done at the national level in the United States. A version of the IADC debris-mitigation guidelines was endorsed by the United Nation General Assembly in 2008. The Scientific and Technical Subcommittee (STSC) of UN COPUOS is currently negotiating a set of guidelines for promoting the long-term sustainability of space activities, including guidelines covering on-orbit activities and SSA data sharing (UN COPUOS 2014). Here again, many of the guidelines being discussed are modeled on practices and research pioneered in the United States.

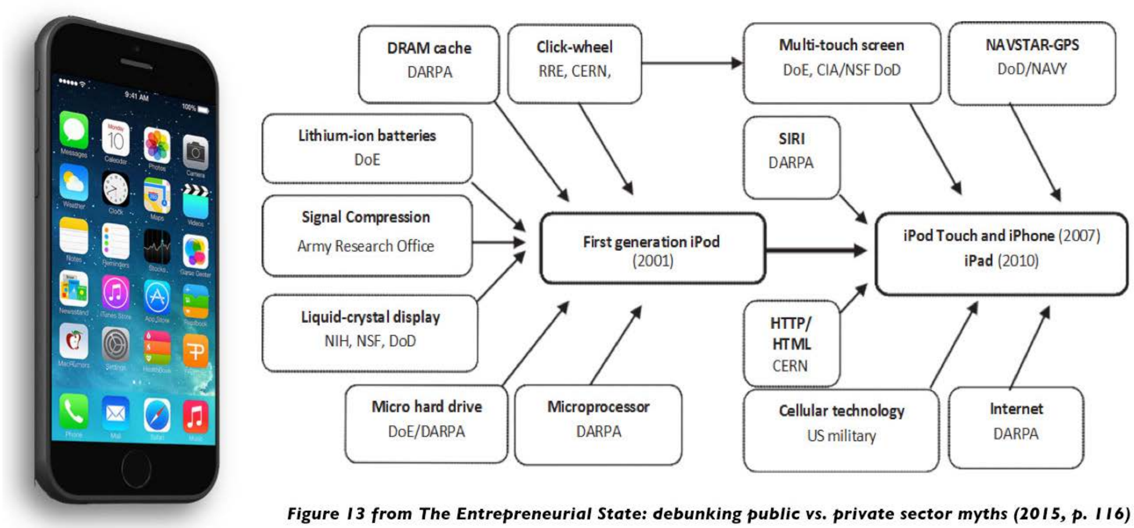
In addition to providing services and disseminating orbital-tracking information to commercial and international entities, civil provision of SSA services could serve as a model for other countries or an international distributed SSA network. The United States could better help other countries implement end-of-life verification and compliance measures. Future international forums may seek ways to enhance international sharing of SSA information; develop space collision-warning measures; or take other steps to maintain the space environment for the responsible, peaceful, and safe use of space.

In other words, enhancing a civil agency's role in SSA (and STM) may be an opportunity for the United States to establish the standard for how Article VI requirements may be applied to emerging commercial space activities. Doing so would signal the importance of SSA for safety of space flight beyond the national security considerations. It would also provide useful real-world practice that would, in turn, help inform international efforts to identify best practices and norms, such as the United Nations Long-Term Sustainability of Space Activities Working Group (Johnson 2014).

## H. Role of Government in Product Development and Software Innovation

An important issue in SSA service provision relates to the role of the government in enabling product development and software innovation. There is debate, in particular, as to whether the software and systems for SSA service provision should be developed or enhanced in-house within government or purchased from commercial parties.

There is strong agreement that the government plays a vital role in funding basic research and early stage research and development, which are typically areas where there is little to no private sector investment. Indeed, there are multiple examples of military organizations pioneering technologies such as the ARPANET, GPS, and voice-activated "virtual assistants." Academic scientists in publicly funded universities and labs developed search engines, the touchscreen on computers and hand-held devices, the World Wide Web, and the HTML language (Mazzucato 2013). However, in each of these cases, the technologies or applications were eventually taken over by the private sector, which resulted in continued innovation. In cases such as microprocessors and smartphones, market forces ended up accelerating innovation far beyond was initially thought possible. Figure 21 summarizes this information visually for a particular example, the iPhone. While almost all the component technologies of an iPhone were government funded, it was Apple (leveraging technology from other companies such as Xerox-PARC, and Blackberry, among others) that brought them together to make a product that has revolutionized society.




*Source*: Mazzucato (2013).

**Figure 21. Component Technologies of the iPhone**

Developing functioning SSA algorithms, software and services involves little basic research or technology development. Some experts believe that the emerging commercial SSA sector indicates that SSA has reached a point where continued government development may be less efficient than purchasing commercial products or services rather than developing them in-house. This is particularly true for software and hardware systems used to do SSA analysis.[66]

The literature on IT systems supports this view, showing that the government can benefit from leveraging the investments and advances of the commercial sector for technical procurement, even in areas where the technology or product may have national security relevance. In fact, in these areas, it if even more imperative that the government 'ride the commercial wave' as that is the only way the government can be at the cutting edge of technology over the long term, particularly for products where there is a sizeable (or growing) commercial market.

An example is the rise of Google's internet-based suite of services.[67] Starting in 2009, when Google introduced Google Apps for the Federal Government, a number of Federal agencies have moved to from using Microsoft and IBM enterprise software to the Google platform (Boulton 2010). This shift has brought a number of advantages including lower cost per customer (Google charges the government the same price that it charges its premier commercial customers), improved system efficiencies (which includes a harmonizing of software products across different agencies including GSA's use of Lotus Notes, a software from the 1980s), and leveraging the constant improvements to the software suite delivered by Google through the cloud. The General Services Administration estimated that moving to a cloud-based email service using Google would reduce the costs of that function alone by 50% annually.[68]

Another example comes from the world of computing hardware, advanced computing systems or high performance computers used by the national security labs for stockpile stewardship and by the basic science labs and agencies for modeling and simulation related to scientific discovery, that used to use supercomputers based on custom microprocessors built by Cray, IBM and others. This has given way to the use of 'commodity clusters' (clusters of commodity hardware in lieu of specialized and customized high performance hardware) for high performance computing systems. This was coincidental with (and motivated by) a big shift in the computing market in the late 80s and early 90s with the

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66 The evidence is less clear for hardware or the sensor systems, where DOD still may have a significant role to play in funding large-scale or exquisite systems.

67 Google sees itself foremost as a data company. Google's model is to give away free services, but bundle them with other applications in a way that can be monetized. While they are not the only company to adopt this model, few have been able to successfully execute it. Since Google began offering a free operating system and computer software, sales for Microsoft Windows and Office have slowed and, in the long term, threaten to die out. An example of innovation driven by mass market needs (Ross 2015). http://www.investopedia.com/articles/markets/111015/apple-vs-microsoft-vs-google-how-their-business-models-compare.asp.

68 See Google Apps for Government website, "Everything your Organization Needs." https://www.google.com/work/apps/government/benefits.html.

emergence of growing commercial and personal computing, spurring faster development cycles and mass production of microprocessors.

Other experts believe that purchasing software for a service that has national security equities and public safety concerns, and is inherently governmental, may be problematic. As one expert interviewed for the project asserted, “what happens if the company goes out of business?” As with other sectors such as remote sensing and weather, where commercial entities provide, could provide, or would like to provide data and services, this topic remains actively debated in the community.

## I. Conclusion

The options identified in this report are complex, and there are likely additional options, issues, and concerns that were not addressed. A decision on the best course of action with respect to both SSA and STM is similarly complex, as it will require balancing many competing interests and overcoming political hurdles. Ultimately, the decision about the shape of the future civil SSA regime should be made based on what is best for the United States’ long-term strategic interests, and not just the near-term economic costs and political winds. Whether related to SSA or STM, U.S. leadership in this domain is crucial, for a range of reasons not the least of which is our desire to retain our strategic advantages in space.

# Appendix A.
# Foundational Documents

STPI researchers conducted a literature review to identify policy issues related to space situational awareness (SSA) and space traffic management (STM). While the general literature on the topic is significant, STPI researchers identified four studies on STM that contained useful insight on policy issues associated with standing up and operating an STM system. A summary of key policy issues identified in these studies follows:

- International Academy of Astronautics (IAA), *Cosmic Study on Space Traffic Management* (International Academy of Astronautics 2006): This document asserts that the best approach for an STM system is via an international intergovernmental agreement monitored by the United Nations Committee on the Peaceful Uses of Outer Space and the United Nations Office for Outer Space Affairs. The policy issues in this document stem from the need for international consensus and agreement, standardized definitions, and the supervision of space activities pursuant to Article VI of the Outer Space Treaty.
- *Space Situational Awareness* (Space Generation Advisory Council 2012): This report identified data sharing, liability, and cost recovery as critical policy issues. Data sharing raises national security classification and proprietary information concerns; provision of SSA services raises questions of liability for both owner/operators and SSA service providers; and cost recovery raises questions of whether users of SSA services should be charged or whether SSA services should be offered free, as a public good.
- Interagency Pre-decisional White Paper Implementation Action Plan (PPD4): This white paper identifies three potential options that would allow the United States Government to provide STM services (EOP 2010).
  - Coordinated, Distributed Governance: This option would require every U.S. Government entity with capability, authority, or responsibility to coordinate resources and to cooperate on issues such as licensing, technical and procedural standards, and norms of behavior. This option would be relatively easy and inexpensive to implement. However, it would be complicated and cumbersome for non-U.S. Government owner/operators, as well as U.S. Government agencies, and would maintain "stove-piping," which may foster organizational parochialism and protectionism.

- Federal Agency Coordinating Body: This option would establish a coordination mechanism or coordinating body composed of representatives from U.S. Government entities with responsibilities, authorities, resources, and funding relevant to providing STM services. Establishing this storefront would simplify external users' access to the U.S. Government, potentially reducing the burden on industry, and would require only a minimal change in regulatory authorities or agency missions. Without the appropriate processes in place, however, immediate decisions would likely be difficult to attain and internal changes would rely upon agencies' goodwill.
- Lead Federal Agency: This option would designate a single U.S. Government department or agency or establish a new organization as the lead for providing STM services. This approach would establish a single interface, simplifying external users' access to the U.S. Government, and consolidate policy, strategy, and resourcing within one agency. However, it would require statutory changes to existing roles and responsibilities and adjustments of oversight responsibilities for one or more agencies.

- *FAA—Space Traffic Management* (D'Uva 2014): In this report, an option that designates a lead Federal agency to handle STM services is promoted. D'Uva argues against an international command-and-control STM system, in part due to perceived challenges of modifying existing treaties and negotiating new treaties. Among the policy issues raised are national security and dual-use concerns, verification of data, frequency of data refresh, and whether space traffic management includes radio frequency interference.

| STM Services | | DOD | NASA | FAA | FCC | NOAA |
|---|---|---|---|---|---|---|
| SSA observational infrastructure | Authorities: | 2010 National Space Policy | 2010 National Space Policy | | | |
| | Responsibilities: | "Develop, maintain, and use space situational awareness (SSA) information from commercial, civil, and national security sources to detect, identify, and attribute actions in space that are contrary to responsible use and the long-term sustainability of the space environment" | "The administrator of NASA shall pursue capabilities, in cooperation with other departments, agencies and commercial partners, the detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-risk planetary objects" | | | |
| | Capabilities: | Search, discover, track and maintain custody of space objects and events, distinguish between objects, and categorize objects | NASA is not permitted to collect intelligence, however NASA can take advantage of the information provided by STRATCOM to help defend NASA space systems | | | |
| Maintenance of Catalog | Authorities: | DoDD 3100.10 | | | | |
| | Responsibilities: | "Maintain accurate Space Object Catalog. The ability to determine strategy, tactics, intent and activity, including characteristics and operating parameters of all segments (ground, link and space) of space systems, particularly foreign and adversary, and threats posed by those systems" | | | | |
| | Capabilities: | Collision avoidance, conjunction analysis, space object identification, improve satellite safety, make educated choices, characterize space environment, provide risk management assessment, create a protect zones for traffic, ensure education and training standards are met | | | | |
| Launch and Early Orbit Collision Avoidance (COLA) | Authorities: | 10 USC 2274, Unified Command Plan, AFI 91- | | Commercial Space Launch | Communications Act of 1934, as | 1992 LRSPA and 15 CFR 960: applies to |
| | Responsibilities: | Space Situational Awareness Operations, Sharing SSA Information | Safety and mission assurance | License responsibility ends with payload separation and sating of upper stage | Review/approve/disapprove license requests for U.S. non-federal government space stations | License permits operations in specific orbits and altitudes. Private operators are required to notify NOAA of orbit changes |
| | Capabilities: | Space Surveillance Network, JSpOC TLE and CSM, HQ USSTRATCOM SSA Sharing Mission, www.space-track.org; space weather awareness | Share information on NASA spacecraft maneuver planning and execution; collision avoidance awareness to Russian partner for ISS maneuver control; spacecraft/vehicle communication and tracking services | Verify pre launch COLA; verify operations of safety systems, verify compliance with licensence or permit Terms and Conditions. Investigation and enforcement of violations. | Public notice and public data base maintenance. | Use of regulation, license, enforcement tools to monitor, audit, and inspect all activities globally. |

| STM Services | | DOD | NASA | FAA | FCC | NOAA |
|---|---|---|---|---|---|---|
| On-Orbit Conjunction Assessment (CA) | Authorities: | DODI 3100.10, AFI 1-217, 2010 National Space Policy | NPR 8715.6A: (Requirement 56892); NPR 8715.6a | 14 CFR Section 417.107 | | |
| | Responsibilities: | | Conjunction assessment analyses shall be performed using the USSTRATCOM high-accuracy catalog as a minimum; NPR requires routine CA for all NASA assets with maneuvering capability; GPD 7120.1a requires all GSFC-managed missions to use CARA team (CODE 590) as service provider. | FAA's regulations require launch operators to obtain a collision avoidance analysis for each launch from United States Strategic Command or from a Federal range having an approved launch site safety assessment | | |
| | Capabilities: | Conjunction analysis and Collision avoidance date (e.g. STS, X-37, Hyabusa re-entry capsule), "Foster the development of space collision warning measures" | NASA maintains liaison with the Department of Defenses JSPOC for data delivery, monitoring and identification of potential conjunctions and developing possible maneuvers | | | |
| Risk Assessment and Maneuver Planning | Authorities: | DoD Instruction 3100.12, Space Support; AFI 91-217, Space Safety and Mishap Prevention Program; DoDI 8581.01 | NPD 8700.1, NASA Policy for Safety and Mission Success; Title 51 United States Code Section 10101 | | | 1992 LRSPA and 15 CFR 960: applies to only to private remote sensing satellite system operations |
| | Responsibilities: | Provide infrastructure to operate and | Safety and mission assurance | | | Private operators are required to |
| | Capabilities: | Establish alternative yet equitable standards and enforcement of regulations for National Security Space, regulate on-orbit maneuvers, maintain satellite constellation, manage timely constellation replenishment. Reconstitution, ensure education and training standards are met | Develop and/or oversee guidelines and operations related to NASA spacecraft, acquired commercial launch services, debris mitigation, orbital insertion, maneuvers, end-of-life activities, manned system operations and space mishap investigations | | | CRSRA regulate, license, monitor, audit and inspect activities; impose Shutter Control |
| Controlled de-orbit COLA (approval for reentry mission) | Authorities: | DODI 3100.10, AFI 1-217 | NPD 8700.1, NASA Policy for Safety and Mission Success | Commercial Space launch Amendments Act 2004 and CFR Part 400, Parts 431, 433, 435 | Communications Act of 1934, as amended | 1992 LRSPA and 15 CFR 960: applies to only to private remote sensing satellite system operations |
| | Responsibilities: | Provide infrastructure for re-entry functions | Safety and mission assurance | Ensure Public safety | regulatory enforcement function | Licesning of remote sensing satellites |
| | Capabilities: | Planned/unplanned re-entry, observe safety standards, provide warnings. Notices, monitor non-US re-entries, provide C2 for re-entry as applicable, approve re-entry mission planning, ensure proper disposal of hazardous materials, coordinate with international agencies. | Develop and/or oversee guidelines and operations related to NASA spacecraft reentry or end-of-life activates | Verify functionality of safety systems prior to reentry, enforcement available if violations of license occur | Public notice and public data base maintenance. | NOAA works with licensee at time of deorbit by reviewing plans, verifying expected casualty calculations and notifying appropriate agencies of the activity. |

| STM Services | | DOD | NASA | FAA | FCC | NOAA |
|---|---|---|---|---|---|---|
| **EOL verification** | Authorities: | AFI 91-217, DoD 3100.10 | NPD 8700.1, NASA Policy for Safety and Mission Success; NPR 8715.6A, NASA Procedural Requirements for Limiting Orbital Debris | Commercial Space Launch Amendments Act 2004 and CFR | Communications Act of 1934, as amended. | 1992 LRSPA and 15 CFR 960: applies to only to private remote sensing |
| | Responsibilities: | Awareness of disposal orbits, safety procedures; provide infrastructure for Disposal Ops | Safety and NASA policy compliance | Ensure Public safety, compliance with International Treaty Obligations | Awareness of disposal orbits, safety procedures | NOAA is responsible for the approval of all disposal plans, monitors plans for changes and works with the licensee at time of deorbit and potential reentry |
| | Capabilities: | Manage C2 for disposal Ops, ensure adequate end of life plan for spacecraft, plan disposal maneuvers, approve slot for super-synchronous orbit | NASA spacecraft/objects end-of-life planning and execution, and commercial launch vehicle stage disposal | | Public notice and public data base maintenance; feck collects and provides NASA with information on disposal of FCC-licensed geostationary satellites for annual reports | NOAA through regulations, license, works with licensee at time of deorbit by reviewing plans, verifying expected casualty calculations and notifying appropriate agencies of the activity |
| **Reporting to end users** | Authorities: | 2010 National Space Policy | | | | |
| | Responsibilities: | "The Secretary of Defense, in consultation with the Director of National Intelligence, the Administrator of NASA, and other departments and agencies, may collaborate with industry and foreign nations to: maintain and improve space object databases; pursue common international data standards and data integrity measures; and provide services and disseminate orbital tracking information to commercial and international entities, including predictions of space object conjunction" | | | | |
| | Capabilities: | | | | | |

# Appendix B. Interviewee List

| Affiliation | Name |
|---|---|
| a.i. Solutions | David McKinley |
| | Ryan Frigm |
| | Mike Mason |
| Aerospace | William Ailor |
| | Eric George |
| | George (Rick Vazquez) |
| Aerospace Industries Association | Frank Slazer |
| Analytical Graphics, Inc. | T. S. Kelso |
| | Paul Walsh |
| | Jeff DeTroy |
| Applied Analytics Solutions, Inc. | Joyce Stivers |
| Avanti Communications Group | Lorenzo Arona |
| Bigelow | Mike Gold |
| Blue Origin | Bretton Alexander |
| Boeing | Mark Skinner |
| California Polytechnic State University, San Luis Obispo | Jordi Puig-Suari |
| CelesTrak | T.S. Kelso |
| CS Information Systems/Orekit | Nicolas Frouvelle |
| Department of Defense | |
| Executive Agent for Space | Ellen Pawlikowski |
| Joint Space Operations Center | John Giles |
| Office of Space Policy | Douglas Loverro |
| | Josef Koller |
| Space Command | John Hyten |
| U.S. Strategic Command | John Raymond |
| Principal DOD Space Advisor Staff | Darin Lovett |
| | Troy “Krusty” Endicott |
| U.S. Air Force | David Finkleman |
| U.S. Air Force Research Laboratory | Paul Schumacher |
| | Moriba Jah |
| Eutelsat | Unknown |
| ExoAnalytic | Clinton Clark |
| Federal Communications Commission | Karl Kensinger |
| Inmarsat | John Mackey |
| | Dean Hope |

| Affiliation | Name |
|---|---|
| Intelsat | Patricia Cooper |
| | Joseph Chan |
| | Ron Busch |
| Kratos Technology and Training Solutions | Vic Gardner |
| Lockheed Martin | Travis Blake |
| | William McShane |
| Massachusetts Institute of Technology, Lincoln Laboratory | David Chen |
| NASA/Goddard | Lauri Newman |
| National Oceanic and Atmospheric Administration | Mark Mulholland |
| National Reconnaissance Office | John Moss |
| North Star | Bob Maskell |
| Omitron | Mark Leblanc |
| Orbital | Frank Culbertson |
| Schafer | Mark Brown |
| Space Data Association (SDA) | Ron Busch |
| Seesat | Unknown |
| SES | Charles Law |
| Sierra Nevada Corporation | Christopher Allison |
| Solers, Inc. | Samantha Moore |
| SpaceX | Stephanie Bednarek |
| SpaceNav | Matt Duncan |
| Star One | Erika Antonio de Souza Erisouz |
| TASC Engility | Kyle Charles |
| Union of Concerned Scientists | Unknown |
| Virgin Galactic | William Pomerantz |
| Vulcan Aerospace | Chuck Beames |
| White House | |
| Office of Science and Technology Policy | Richard DalBello |
| National Security Council | Chirag Parikh |
| XL Insurance | Chris Kunstadter |

# Appendix C.
# Survey Questionnaires

This appendix provides the three questionnaires STPI team used to collect information for the market analysis (Chapter 5) and vendor pricing (Chapter 7). In 2015, we sent one questionnaire to space situational awareness software vendors and one to SSA end users. In 2016, we sent a follow-up questionnaire to vendors.

## Software System Vendor Questionnaire

### STM Software System Vendor Questions

**Introduction**

The Federal Aviation Administration (FAA), Office of Space Commercialization (AST), asked the Institute for Defense Analyses (IDA) Science and Technology Policy Institute (STPI) to conduct a study on existing public and private collision avoidance (CA), space situational awareness (SSA), and space traffic management (STM) services and capabilities and identify a top level STM operational architecture involving data inputs, processing & analysis, and report outputs to service the needs of the community. As a potential vendor of any future STM system operated by the FAA, we solicit your inputs as we develop the reference operational architecture and system performance requirements for the STM system. Your inputs and those of others will not be shared and will be non-attributional to your company. All inputs will be 'rolled-up' into a consolidated reference architecture and consolidated set of system performance requirements. If you have interest in participating in the FAA's future activities, request you provide answers to the following questions;

**Operational architecture:**

1. Please review and comment on the top-level operational architecture view (attached).
    a. What end products do you propose as meeting the current AND future needs of the on-orbit, air traffic management, and flight vehicle users of STM system products? Please list all end users envisioned.
    b. What data would be required from the current existing data providers of JSPOC, COMSPOC and others to meet the needs of STM output products? Please list all sources of data envisioned.
    c. Please comment on the major functions of the internal STM system to ingest data, analyze/process results, and produce reports? Is this sufficient, if not please proposed your own functions required by the STM system and explain each.
    d. Please provide any other observations regarding the overall operational architecture provided. If you propose your own, please put in the context of inputs, outputs and the STM system itself.

**System Performance Characteristics & Constraints**

2. Please review and comment on the attached system performance characteristics and constraints (attached).
    a. What performance characteristics do you recommend incorporating into the overall performance requirement set for a future STM system?

b. What constraints and limitations do you feel should be included in the overall performance requirements set for a future STM system?
c. What concerns or recommendations do you have regarding the overall system performance characteristics for a future STM system? Please explain.

**Current Capabilities:**

3. Does your organization currently provide any STM services involving data ingest, processing/analysis, and/or report/message outputs to end-users? If so, please explain and/or provide any CONOPs, operational architectures, and performance requirements you currently meet in the conduct of the service provided.
    a. If applicable, where and how do you get the data? From whom?
    b. If applicable, where and how do you process/analyze the data for reports? For whom?
    c. If applicable, where and how do you produce the reports? For whom?
    d. If applicable, are you also a data provider and/or end user? Please explain?
4. What, if any, gaps or shortfalls exist in the current STM system involving data ingest, processing/analysis and report generation?
    e. Please attribute these shortfalls to law/regulation/policy, business processes, equipment/technology or other reasons.
    f. How could the STM process today be improved?

**Capacity to Provide a Future STM System:**

5. Do you <u>currently</u> have the capabilities required to support development of the proposed STM system within 12 months as shown on the attached draft operational architecture and draft performance requirements? Within 24 months? What conditions would be required for each?
6. Do you currently have the capabilities to provide operations and support to the proposed STM system within the time frame provided?
7. What questions & suggestions do you have to improve both the effectiveness and efficiency of the draft operational architecture to meet future STM needs?
8. Will you rely on government data or systems as part of your capability to support, if so please elaborate? Please list all sources of data or systems you envision supporting a future STM capability?
9. What do you see as the future (5 years, 10 years, 15 years) for CA, SSA, and/or STM services? Please list all current and future end-users of STM services?
10. How will the Space Fence program capabilities improve CA, SSA, and/or STM? How do you see private sector end-user benefiting from these improvements?

11. If funding is a limitation, what recommendations do you have for a block or spiral approach to system development would you recommend in order to achieve an preliminary initial operating capability during FY17/18?
12. What, if any, other drivers exist for your organization to provide CA, SSA, and/or STM system capabilities?

**External Developments**

13. What, if any, developments have you seen outside of the U.S. for CA, SSA, and/or STM services that should be considered in the future?

**Sharing and Processing Data**

14. What, if any, redistribution restrictions do you place on data, notifications, analysis, and/or services provided?

**Legal, Regulatory, and/or Policy Insights**

15. Do you have any or do you forecast any issues with current law, regulation, or policy governing CA, SSA, and/or STM services and capabilities?

**Suggestions**

16. Do you have any other thoughts you'd like to share on this subject?

**Contacts**

17. Do you have recommendations on others that we should speak with?

# Software Product User Questionnaire

## STM Product End-User Questions

**Introduction**

The Federal Aviation Administration (FAA), Office of Space Transportation (AST), asked us, the Institute for Defense Analyses (IDA) Science and Technology Policy Institute (STPI), to conduct a study on existing public and private collision avoidance (CA), space situational awareness (SSA), and space traffic management (STM) services and capabilities to identify an STM architecture involving data inputs, processing & analysis, and report outputs to service the STM needs of the community. As a data provider supporting public and/or private CA, SSA, and/or STM services and capabilities, it would be useful to hear your perspectives on gaps or shortfalls in service, tool and dataset limitations, and other potential issues. Your responses will be non-attributional. To aid in your responding to this survey, we have attached the baseline mission descriptions, a top level operational architecture view, and future system characteristics & constraints.

**End Users of STM Products**

1. You have been identified to be an end-user of STM products & services. To the best of your knowledge, are there any other end-users we should contact?
2. Some end-users are also data providers to the STM system. As an end-user of STM products & services, do you consider yourself to also be a data provider as well? If so, please explain and request a data provider interview from us separately.

**End-User Reports & Message Traffic Outputs**

3. What reports do you currently rely on from the STM system? Do you also get data and then post-process to produce your own reports?
4. For each report please address;
    a. What are your current and future report product sources?
    b. Do you process reports after you receive them or are they in final state? If processed further, how and why?
    c. What is the format of the reports? Are they highly tailored or standardized, what are your druthers?
    d. How do you receive your reports & messages (email, fax, phone)? How often do you receive the reports? Are the reports pushed or pulled from the STM system? Of the reports, do you have any real or near-real time messages requirements and if so, please elaborate on criticality?

e. How often do you obtain reports?

f. Do you screen reports for errors?

g. Is any information in the reports not useful?

h. With whom do you currently share your reports?

i. What, if any, redistribution restrictions do you place on reports, notifications, analysis, and/or services provided?

5. Is all or part of your reports available to the general public or do you limit to certain communities? Do you charge a fee for your reports? Please explain your business model.
6. Do you think the current STM system has the right data at the right time to provide your products? Do you think it is a lack of data or processing issue if not?
7. Do you know if your reports are redundant to others' reports?
8. What, if any, are gaps or shortfalls do you see in currently offered CA, SSA, and/or STM services?
   a. Shortfalls and gaps in data
   b. Shortfalls and gaps in processing & analysis
   c. Shortfall and gaps in report output products
   d. Shortfalls and gaps in law, regulation, or policy
9. How could your reports be provided more effectively and efficiently, through process improvements, technical means or changes in law/regulation or policy?

**Process**

10. Please describe the process of obtaining your reports and notifications from the STM system. How, if at all, could this process be improved? Do you have specific performance recommendations for a future STM analysis/processing system?
11. Do you have a decision tree or process by which you take action (or not) on collision risks/reports?

**Costs and Benefits**

12. What are the costs for your organization for receiving reports and notifications? Please describe with specificity (financial dollar amounts if possible).

**Future Services and Capabilities**

13. What do you see as the future (5 years, 10 years, 15 years) for CA, SSA, and/or STM services and report products generally?

14. How will your end user report & notification products change in the future (5 years, 10 years, 15 years)?

**Other Drivers**

15. What, if any, other drivers exist for your organization to receive CA, SSA, and/or STM end-user report products?

**Developments**

16. What, if any, developments have you seen outside of the U.S. for CA, SSA, and/or STM services?
17. What, if any, developments have you seen from the private sector for CA, SSA, and/or STM services?
18. What, if any, technological developments do you see happening in the near future that will improve existing CA, SSA, and/or STM services?
19. How, if at all, do you see the development of increasing data sources for SSA impacting services and reporting products?

**Legal, Regulatory, and/or Policy Insights**

20. Do you have any or do you forecast any issues with current law, regulation, or policy governing CA, SSA, and/or STM services and reports?

**Suggestions**

21. Do you have any other thoughts you'd like to share on this subject?

**Contacts**

22. Do you have recommendations on others to whom we should speak?

# Software System Vendor Follow-Up Questionnaire

STPI is conducting a follow-up market survey of SSA software and data vendors for the FAA/AST provision of SSA services. As before, our goal is to get rough order of magnitude level information, rather than detailed cost estimates. This is not a procurement related activity.

SSA services included are: (1) LCOLA/ On-Orbit/ Re-Entry Conjunction Analysis, (2) Catalog Maintenance, (3) Product Presentation, (4) User Interface, and (5) Risk Analyses. In addition, we'd like to learn about the "service" option, in particular data and CA. Please answer questions that are applicable to your company. Rough Order of Magnitude (ROM) cost estimates are sufficient.

## Options for Service Delivery

For context, there are seven potential options for SSA delivery by the FAA/AST. Vendors are being asked to focus on Options 3-7

1. FAA has access at JSpOC using JSpOC Data only
   a. Option 1: Without value add improvements (e.g. risk analyses, user interface, etc. )
   b. Option 2: With Improvements to risk analyses, user interface and product presentation
2. Operated by FAA/AST at FAA/AST DC-based Facility using DoD-provided hardware, software, and procedures.
   c. Option 1: Without value add improvements
   d. Option 2: With risk assessment, updated user interface and product presentation
   e. Option 3: With value added software and an independent catalog (option requires JSPOC to share OBS data)
3. Operated by FAA/AST at FAA/AST Facility using vendor software
   a. Option 1: Without value add improvements
   b. Option 2: With risk assessment, updated user interface and product presentation
   c. Option 3: With value added software and an independent catalog (option requires JSPOC to share OBS data)
4. Operated by Contractor under control of FAA/AST- at FAA/AST Facility DoD-provided hardware, software, and procedures.
   a. Option 1: Without value add improvements
   b. Option 2: With risk assessment, updated user interface and product presentation
   c. Option 3: With value added software and an independent catalog (option requires JSPOC to share OBS data)
5. Operated by Contractor under control of FAA/AST- at FAA/AST Facility using vendor software
   a. Option 1: Without value add improvements
   b. Option 2: With risk assessment, updated user interface and product presentation
   c. Option 3: With value added software and an independent catalog (option requires JSPOC to share OBS data)
6. Operated by Contractor under control of FAA/AST- at Contractor Facility using vendor software
   a. Option 1: Without value add improvements
   b. Option 2: With risk assessment, updated user interface and product presentation
   c. Option 3: With value added software and an independent catalog (option requires JSPOC to share OBS data)
7. Certification by FAA/AST of vendor to provide launch, on-orbit and re-entry conjunction analyses as a service

## Provider Questions

1. Please provide an overview of your company's activities in SSA and any relevant updated capabilities since the previous market survey from STPI.

**LCOLA/ On-Orbit/ Re-Entry Conjunction Analysis Software Providers**

1. Is your company's LCOLA conjunction analyses software an independent capability from on-orbit or controlled de-orbit (CA) screening capability?
2. Please provide rough order of magnitude (ROM) costing information (initial and recurring) for provision of pre-launch COLA screening software against the following number of resident space objects (RSOs):
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
3. If applicable, please provide ROM costing information (initial and recurring) for provision of controlled de-orbit screening software (if the de-orbit software is different from standard conjunction assessment software) against the following number of resident space objects (RSOs):
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
4. If applicable, please provide ROM costing information (initial and recurring) for provision of on-orbit conjunction screening software against the following number of resident space objects (RSOs):
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000

iv. 500,000

5. Please provide hardware requirements and estimated costs for provision of LCOLA, on-orbit and CA screenings.
    a. At FAA/AST facility
    b. At contractor facility

**Catalog Providers**

1. What experience does your company have with catalog management?
    a. Has your company interacted with JSpOC High Accuracy algorithms?
2. Where does your company obtain non-SSN data from? (if your company collects data, please see "Data Providers" section below)
3. Using JSpOC Data. Using JSpOC High Accuracy algorithms with JMS upgrade, what are the initial and recurring ROM costs of a developing and maintaining a catalog of RSOs of the following sizes?
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    c. What are the general hardware requirements for supporting a catalog of RSOs of the following sizes?
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    d. What are the expected ROM personnel costs to develop and maintain the catalog of RSOs of the following sizes? Does the expected number change depending on location of the catalog maintenance?
        i. 10
            1. Upfront (training) costs:
            2. Recurring costs:
        ii. 1,500
            1. Upfront (training) costs:
            2. Recurring costs:
        iii. 20,000
            1. Upfront (training) costs:
            2. Recurring costs:
        iv. 500,000
            1. Upfront (training) costs:
            2. Recurring costs:

4. Commercial Catalog. What are the initial and recurring ROM costs of a developing and maintaining an independent, commercial catalog of RSOs of the following sizes?
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    c. What are the hardware requirements for supporting a catalog of RSOs of the following sizes?
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    d. What are the expected ROM personnel costs to develop and maintain the catalog of RSOs of the following sizes? Does the expected number change depending on location of the catalog maintenance?
        i. 10
            1. Upfront (training) costs:
            2. Recurring costs:
        ii. 1,500
            1. Upfront (training) costs:
            2. Recurring costs:
        iii. 20,000
            1. Upfront (training) costs:
            2. Recurring costs:
        iv. 500,000
            1. Upfront (training) costs:
            2. Recurring costs:
5. Is your company interested in providing a pre-curated catalog to the FAA/AST? If applicable, please provide costing estimates for providing this service.
    a. Upfront costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000
    b. Recurring costs:
        i. 10
        ii. 1,500
        iii. 20,000
        iv. 500,000

**Product Presentation**

1. How can the end product delivered to customers be improved from JSpOC's conjunction summary messages (i.e., more intuitive, graphical, easy to understand, supportive of timely decision making)? How does your company plan to improve end product delivery?
    a. If applicable, please provide ROM costing for end product delivery improvements.
        i. Upfront Costs:
            1. 10
            2. 1,500
            3. 20,000
            4. 500,000
        ii. Recurring Costs:
            1. 10
            2. 1,500
            3. 20,000
            4. 500,000
    b. Are there any external software packages you suggest adding to your company's software to improve product presentation?
2. Is there a particular type of hardware required to run your company's software?

**User Interface**

1. How does your company's user interface improve upon JSpOCs conjunction summary messages?
2. How would you handle data processing and distribution? Would it require separate security domains (hence require a cross-domain solution)?
3. Cross Domain Solution Provider: ex: eXMeritus' HardwareWall
    a. What is the ROM prices of your user interface software?
        i. Upfront Costs:
            1. 10
            2. 1,500
            3. 20,000
            4. 500,000
        ii. Recurring Costs:
            1. 10
            2. 1,500
            3. 20,000
            4. 500,000
4. Are there any external software packages you suggest adding to your company's software to improve product presentation?
5. Is there a particular type of hardware required to run your company's software?

**Risk Analyses**

1. What tools are available to augment existing JSpOCs products to assess relative risk between alternative launch and risk to on-orbit assets? If you company provides risk analyses, please provide ROM costing.
    a. Upfront Costs:
        i. 10
        ii. 1,500

iii. 20,000
iv. 500,000

b. Recurring Costs:
   i. 10
   ii. 1,500
   iii. 20,000
   iv. 500,000

2. Are there any external software packages you suggest adding to your company's software to improve product presentation?
3. Is there a particular type of hardware required to run your company's software?

**Data Providers**

1. Does your company provide unique sensor observations? If so, what is the ROM price for purchasing sensor observations from a private sector provider for the following orbit regimes:
   a. Near Earth (orbital period of 225 min or less)
   b. Deep Space
2. Are there unique data to provide for LCOLA, on-orbit, or CA conjunction analyses?

**Conjunction Analyses Service Providers**

1. Please provide a ROM cost estimate for a service providing the following:
   a. 50 annual pre-launch COLA screenings of a planned launch trajectory above 150 km, one or more parking orbits, and/or a geosynchronous transfer orbit (and associated risk analysis, visualization, and reporting) against the following number of resident space objects (RSOs):
      i. 10
      ii. 1,500
      iii. 20,000
      iv. 500,000
   b. 20 annual CA screenings of a controlled de-orbit trajectory from 2,000 km to an altitude of 150 km (and associated risk analysis, visualization, and reporting) against the following number of resident space objects (RSOs):
      i. 10
      ii. 1,500
      iii. 20,000
      iv. 500,000
   c. Access to a satellite catalog that is continually maintained and updated by a private sector provider and includes the following number of RSOs:
      i. 1,500
      ii. 20,000
      iii. 500,000
2. A commercial launch operator contracting with a private sector service to provide the following on a per instance basis:
   a. Pre-launch COLA screening of a planned launch trajectory above 150 km, one or more parking orbits, and/or a geosynchronous transfer orbit (and associated risk analysis, visualization, and reporting) against the following number of resident space objects (RSOs):
      i. 1,500

ii. 20,000
iii. 500,000

b. CA screening of a controlled de-orbit trajectory from 2,000 km to an altitude of 150 km (and associated risk analysis, visualization, and reporting) against the following number of resident space objects (RSOs):
    i. 1,500
    ii. 20,000
    iii. 500,000

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# Abbreviations

| | |
|---|---|
| AGI | Analytical Graphics, Inc. |
| ASAT | Anti-Satellite |
| AST | Office of Commercial Space Transportation |
| ASW | Astrodynamics Support Workstation |
| CA | conjunction assessment |
| CAVENet | Correlation, Analysis, and Verification of Ephemerides Network |
| CARA | Conjunction Assessment Risk Analysis |
| CCICS2S | Combatant Commanders' Integrated Command and Control System |
| CD | compact disk |
| CDES | Cross Domain Enterprise Services |
| COLA | collision avoidance |
| ComSpOC | Commercial Space Operations Center |
| COPUOS | Committee on the Peaceful Uses of Outer Space |
| DARPA | Defense Advanced Research Projects Agency |
| DOD | Department of Defense |
| DOC | Department of Commerce |
| DOI | digital object identifier |
| DOT | Department of Transportation |
| ESA | European Space Agency |
| EUMETSAT | Exploitations of Meteorological Satellites |
| EOP | Executive Office of the President |
| FAA | Federal Aviation Administration |
| FAIR | Federal Activities Inventory Reform |
| FFRDC | federally funded research and development center |
| FTE | full-time equivalent |
| GAO | Government Accountability Office |
| GEO | geosynchronous orbit |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| HAC | high-accuracy catalog |
| IDA | Institute for Defense Analyses |
| ICG | International Committee on Global Navigation Satellite Systems |
| ISODEX | International Space Object Data Exchange |
| ISSA | Integrated Space Situation Awareness |
| IT | information technology |
| JICSpOC | Joint Interagency Combined Space Operations Center |
| JMS | JSpOC Mission System |

| | |
|---|---|
| JSpOC | Joint Space Operations Center |
| LCOLA | launch collision avoidance |
| LEO | low Earth orbit |
| MOA | Memorandum of Agreement |
| MPC | Minor Planet Center |
| NASA | National Aeronautics and Space Agency |
| NDPP | Non-traditional Data Pre-Processor |
| NGE | non-governmental entity |
| NOAA | National Oceanic and Atmospheric Administration |
| NRO | National Reconnaissance Office |
| NSF | National Science Foundation |
| O/O | Owner/Operator |
| O2 | OrbitOutlook |
| ODNI | Office of the Director of National Intelligence |
| OMB | Office of Management and Budget |
| OSA | Orbital Safety Analyst |
| OSTP | Office of Science and Technology Policy |
| OFP | Office of Federal Procurement |
| PNT | position, navigation, and timing |
| PPS | Precise Positioning Service |
| RAIDERS | Rapid Attack Identification and Reporting System |
| RF | radio frequency |
| RFI | radio frequency interference |
| RSO | resident space object |
| SA | Selective Availability |
| SDA | Space Data Association |
| SDC | Space Data Center |
| SPADOC | Space Defense Operations Center |
| SPS | Standard Positioning Service |
| SSA | space situational awareness |
| SSN | Space Surveillance Network |
| STM | space traffic management |
| STPI | Science and Technology Policy Institute |
| TLE | two-line element |
| UN | United Nations |
| USSTRATCOM | United States Strategic Command |

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**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

In recent years, space has become increasingly congested. Space situational awareness (SSA)—knowing where space objects are, communicating the information to stakeholders, and developing regimes for ensuring safety of space flight—is more crucial now than it has ever been in the past. Concerned about the possibility of overextending across conflicting missions in a fiscally constrained environment, DOD leadership has publicly noted a desire to move non-national security-related SSA services out of its purview. In recognition of the need to both improve the quality of SSA services and enable DOD to focus on its core mission, the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) asked the IDA Science and Technology Policy Institute (STPI) to identify and evaluate potential approaches for providing SSA services for civil and commercial operations in space. STPI identified seven distinct approaches/options to provide SSA services, estimated costs to the extent feasible, and identified policy implications and strengths and weaknesses of each. STPI also identified 4 approaches to STM.

**15. SUBJECT TERMS**

orbital debris; space situational awareness (SSA); space traffic management (STM)

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