Evaluating options for civil space situational awareness (SSA)

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Abstract

In recent years, the number of active satellites and human-made orbital space debris has increased dramatically. An expansion of activities in space, as is currently being proposed by many commercial and international entities, is expected to further exacerbate this challenge. The 18th Space Control Squadron under the Department of Defense (DOD) United States Strategic Command provides space situational awareness (SSA) services to users outside the national security community at no cost. International and commercial users demand better SSA service than is currently feasible, and the demand 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 SSA services not related to national security out of DOD purview.

Responding to a request from the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST), researchers at the Science and Technology Policy Institute (STPI) identified and evaluated potential approaches for providing SSA services for civil and commercial operations in space. In this paper, we summarize the report [1] and present the pros and cons of four approaches to the provision of civil SSA services in the United States: (1) maintaining status quo through continued provision by DOD; (2) provision by a civil government entity; (3) industry self-provision; and (4) provision by an international organization. Within the second approach, assuming the provision of SSA by a civil agency, STPI further identified and discussed four options: (1) civil agency service capability embedded within DOD; (2) independent civil service capability, using DOD software and systems; (3) independent civil service capability, using commercial software and systems; and (4) the government certifies non-governmental entities (NGEs) to provide service capability. All of these approaches keep military and national security SSA services within DOD. Selecting which approach or option to proceed with depends on the determination of the role of government in the domain as well as consideration of other policy challenges.

1. Introduction

In recent years, space has become increasingly congested, driven by an increase in the number of active satellites and human-made orbital space debris as well as growing numbers of spacefaring nations and commercial entities. Nearly 1,500 active satellites are in Earth orbit – approximately twice as many as there were only 12 years ago [2,3]. 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 activities by commercial entities.

Given that active satellites are concentrated in a few specific orbits that are well-suited to certain applications, on-orbit crowding in the most populous orbits is a serious concern. For example, low Earth orbit (LEO) between 700 and 900 kilometers altitude is useful for 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.

However, it is not just the growing number of working satellites that is a challenge: the problem of orbital debris is also becoming critical as hundreds of thousands of nonfunctional objects are on orbit, in addition to the active satellites [4]. These objects range from discarded rocket bodies as large as tractor-trailers to small paint chips a few millimeters in size.[1] Tracking space debris and determining the sources of these debris are enormously difficult tasks, especially with regard 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 Chinese antisatellite test in 2007 and the Iridium-Cosmos collision in 2009 have also caused dramatic spikes in the number of smaller objects. The debris created by these two events together accounts for over one third of the total objects cataloged in LEO [6].

An expansion of activities in space, as is currently being proposed by many commercial and international entities, is expected to further exacerbate the problem [7,8,9]. Thus, space situational awareness (SSA) and space traffic management (STM) – knowing where space objects are, determining whether collisions with other objects are imminent, communicating that information to stakeholders, and developing regimes for ensuring safety of space flight – are becoming increasingly crucial to the productive use of space. SSA, the topic of this paper, 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 relay to stakeholders the positions and movements of objects.

The U.S. Department of Defense (DOD) currently provides SSA services to varying degrees of precision to the global space community. As the environment and players involved in SSA continue to change, the U.S. military has faced numerous difficulties in upgrading its capabilities as a result of sometimes slow-moving procurement programs. At the same time, the private sector has demonstrated a significant increase in capabilities for providing SSA data and services over the last few years, offering many of the same or similar civil SSA capabilities as DOD's, including collecting observations on large numbers of space objects, processing the observations into a database, and providing conjunction warnings and other products to users. The continued development and maturation of private sector SSA capabilities raises important questions about the role of the government in providing civil SSA data and services.

In recognition of the need to both improve SSA services provided to private-sector entities and to 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 [1]. In addressing its charge, STPI conducted

[1] Approximately 23,000 of the objects currently in Earth orbit that are tracked by DOD 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 [2,5].

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. The report was published in August 2016 and is publicly available [see listed at the end with URL]. The sections below summarize key findings of the report. 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 we attempted to ensure that prices are comparable across vendors, it is possible that vendor services are not comparable to those offered by each other or DOD; (3) vendor pricing was self-reported and not independently validated; and (4) for options 2, 3, and 4 in Approach 2 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. It is also important to note here that we found no public data 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, *also not publicly available*, that have raised questions about rates of false positives and false negatives. One high-level recommendation of this study therefore is more openly available analysis of the relative validity/accuracy of government and commercial conjunction assessments.

2. Approaches to providing civil SSA services

Building on models outside the sector (e.g., GPS), interviews with experts, review of key government documents, and other sources, as well as a market survey of vendors that can provide data, software, and systems, we identified four *approaches* to the provision of civil SSA services in the United States: continuing with the current system within DOD (Approach 1) or choosing an alternative wherein services are provided by a civil government entity (Approach 2), by a non-governmental entity (NGE)/industry itself (Approach 3), or by an international organization (Approach 4). Note that in all four approaches, the military and national security aspects of SSA remain within the purview of DOD. The four approaches are illustrated in Fig. 1 and assessed in Section 3, "Assessments of Approaches to Provision of Civil SSA Services." Strengths of and challenges to each approach are outlined in Table 1. Digging deeper within the second approach, assuming the provision of SSA by FAA/AST, STPI further identified four *options* for implementing a civil SSA service within FAA/AST. These are discussed in Section 4: "Options for a Civil Government Organization Providing SSA Services."

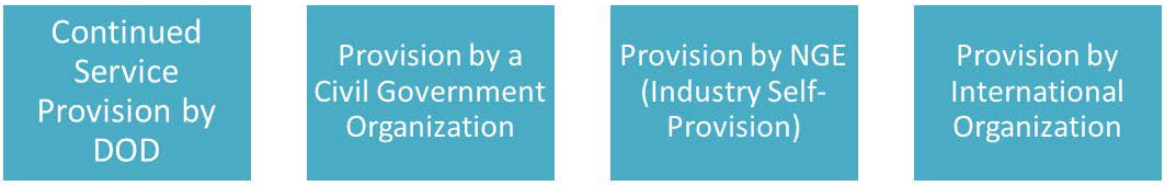

Fig. 1. Approaches to Providing Civil SSA Services

3. Assessment of approaches to providing civil SSA services

Approach 1: Continued Provision of SSA Services by the U.S. Department of Defense

The first approach we studied would maintain the status quo and have the DOD continue to provide civil and national security SSA services. This approach would afford continuity in provision of services from the user perspective; in other words, owner/operators of space-based assets would not have to learn a new method for interacting with the government for SSA services. According to some proponents, this approach is most likely to minimize 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 try to continue 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 while DOD continues to provide national security SSA services.

The downside of DOD's continuing provision of civil SSA services would be the sustained limitation in DOD's ability to quickly respond to the growing needs of users or to advances in technology, which is partially the result of its lack of agility in acquisition. 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 larger number than necessary of false positive rates. The process is especially not well-suited to developing IT systems or for mission areas with highly volatile requirements. DOD's legacy software systems, SPADOC and CAVENet, were created to track incoming ballistic missiles from adversaries, not small satellites with electric propulsion, which exacerbates the problem.

DOD's mission is to protect the warfighter and national security on the ground and in space, and in a narrow sense, protecting civil satellites is in DOD's interest to the extent that it protects the space environment for smooth operation of U.S. Government assets. Thus, DOD's continued provision of civil SSA services may 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. Facing limited resources, when DOD must choose between supporting national security assets and commercial users, it may be forced to shift its focus away from non-national security users. In the event of a space-based conflict, this conflict of interest would be even worse.

This approach is also the least likely to be extensible to an international system, which is problematic as SSA is an inherently international issue. Given DOD's understandable reluctance to assume the role of global space police force, the gap between SSA data collection and regulatory authorities would remain large under this approach.

Approach 2: SSA Services Provided by a Civil Government Agency

The second approach we studied would have the civil elements of SSA that support safety of spaceflight transferred from the DOD to a civil government agency. The main rationale for this is if SSA for civil, commercial, and international use is deemed an inherently governmental function that exists outside the scope of the military. Options within this approach depend on whether the civil agency plans to use only government software and personnel or include a mixture of NGE software and personnel. The strength of this approach is that the civil agency would be

more likely than DOD to pay due attention to the burgeoning needs of commercial industry and international partners, and thus would enable accurate and timely delivery of SSA services, making civil services more actionable than those currently provided by DOD.

This approach also has implications for USG oversight of private sector space activities and Space Traffic Management (STM), for which we refer the reader to STPI's full report [1], as it is not addressed in this paper. 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, increasing responsible behavior in space. 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 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 on the part of the civil agency as 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 Space Surveillance Network (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.

Approach 3: Self-Provision of SSA Service by a Non-Governmental Entity (NGE)

The third approach we studied was provision of civil SSA services by a NGE, most likely a private company. An NGE similar to the Space Data Association (SDA), or the SDA itself, working with a vendor or set of vendors that provide SSA data, analysis software, and analytic reports on conjunctions could provide, as SDA already does, the full suite of SSA services. With this approach, a 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 two-line elements (TLEs). The NGE could choose to purchase data from any vendor(s) and change providers per its needs. This approach could uphold a set of industry-derived best practices for SSA data collection, processing, and products.

One benefit of this approach is that it would support a more operator-driven community of practice. It would, at least in principle, also be a low-cost approach for the Federal Government because industry is likely to pay in full

the fees associated with self-provision. Finally, this approach would provide redundancy to a critical system relevant to national security and public safety.

A challenge associated with industry self-provision would be that some companies may be unwilling or unable to bear the cost for the service and may even pick lower-cost and potentially poorer service. This payment process 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 applied to 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.

Approach 4: SSA Services Provided by an International Organization

The fourth approach we studied was provision of civil SSA services by an international organization. An international organization could become a holding cell for SSA data and the resulting database provided by governments, industry, and academia. This approach is not mutually exclusive from the U.S.-centric approaches discussed previously and can be created in addition to a U.S. domestic civil SSA regime which would then serve as 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) [10]. An ISODEX-like entity 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 and benefit from access to the data of all other participants. In addition to collecting raw metric SSA data from participants, ISODEX could also combine them to produce processed outputs.

This approach would bring the international community together on SSA and could serve as a venue for new space actors to learn about best practices while allowing for governments with limited data collection to increase their SSA capabilities. 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 paying for a commercial service. Another strength of this approach is that it is the most likely to be decentralized and open, with the greatest potential to bring together governments, industry, and academia to solve technical challenges in SSA [11]. 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.

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 likely span several years, and decisions about leadership and sovereignty might also be required. The second challenge would be funding. Since the body would be international, motivating participation in both membership and in contributions of data would likely be difficult. Creating this international authority would also heighten existing challenges regarding protection

of 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 classified satellites, as suggested by an expert interviewed for the STPI project, is for the organization to anonymize each space object in the satellite database through something similar to a digital object identifier (DOI) as is used 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 public. However, doing so would still require nation states to be comfortable releasing ephemeris data on national security space objects and divulging the existence of such objects to the international organization.

Table 1. 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 • No additional latency or increased friction in system • Minimizes some level of duplication that will necessarily occur if a civil agency were to provide SSA services in addition to DOD • 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 • DOD systems (JMS) delayed and not ready for full implementation • Continued gap between SSA data collection agency and future regulation/oversight agencies • Reduced focus on industry needs as compared with DOD mission needs • Future increases in potentially hostile or threatening activities may cause de-prioritization of civil and commercial operator needs • 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) • Greater flexibility to incorporate non-DOD data and leverage commercial advances in software • Ability to mandate the use of SSA services through licensing • Easier pathway to civil STM and international coordination • Provides redundancy to a critical national security and public safety relevant system	• Additional costs into tens of millions of dollars annually • Creates some duplication of activities • Learning curve for a civil agency to develop operational expertise • Need to address concerns over possible confusion stemming from multiple satellite catalogs • Potentially lower ability to mask national security activities in space, particularly if using non-DOD data sources
3. Provision by NGE	• Supports a more industry-driven community of practice • Low cost for the Federal Government • Provides redundancy to a critical national security and public safety relevant system	• Enforcement would be difficult • Industry may be unwilling to bear the cost, particularly for new and smaller satellite operators • 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 • Could provide the most accurate data and services, if it included access to data from multiple countries	• Lack of trust in international institutions • High transaction costs to negotiate and implement • Would need to overcome significant challenges stemming from sensitive national security activities in space

Approach	Strengths	Challenges
	• Would create a level playing field for all countries and satellite operators, regardless of national capability • Could help support the development of international standards for space traffic management • Provides redundancy	• Unclear which international body would have the competence, credibility, and resources to perform the service • Issues of sovereignty to be negotiated and decided

4. Options for a civil government organization providing SSA services

Within Approach 2 – provision of SSA services by a civil government organization – several civil agencies or departments, either existing or newly created, could possibly 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 space-specific organization modeled on the Coast Guard.[2]

FAA/AST has potential because it currently has authority over launch vehicles and holds substantial and growing SSA capabilities in-house. The Office has also shown the most interest in providing SSA services and has received the most support from stakeholders, including many members of Congress. DOT also already handles transportation on Earth, which some say provides the agency with a 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 has been proposed because it has a clear mission to promote economic development and commercial activities in space [12,13] (which may or may not fit, given a potentially conflicting regulatory function). 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 [14].

Given growing consensus that FAA/AST should be the entity providing civil SSA services (whether within FAA or directly under DOT), this section describes potential delivery mechanisms, scopes estimated costs to the extent feasible, and addresses the associated policy implications.

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/18th space control (SPC).* FAA/AST has access at 18th SPC to *its 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 an 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

[2] For a more complete discussion of this notion, see Bennett (2011) [14].

service. This option implies the use of DOD data that are available publicly as well as commercial software and data.

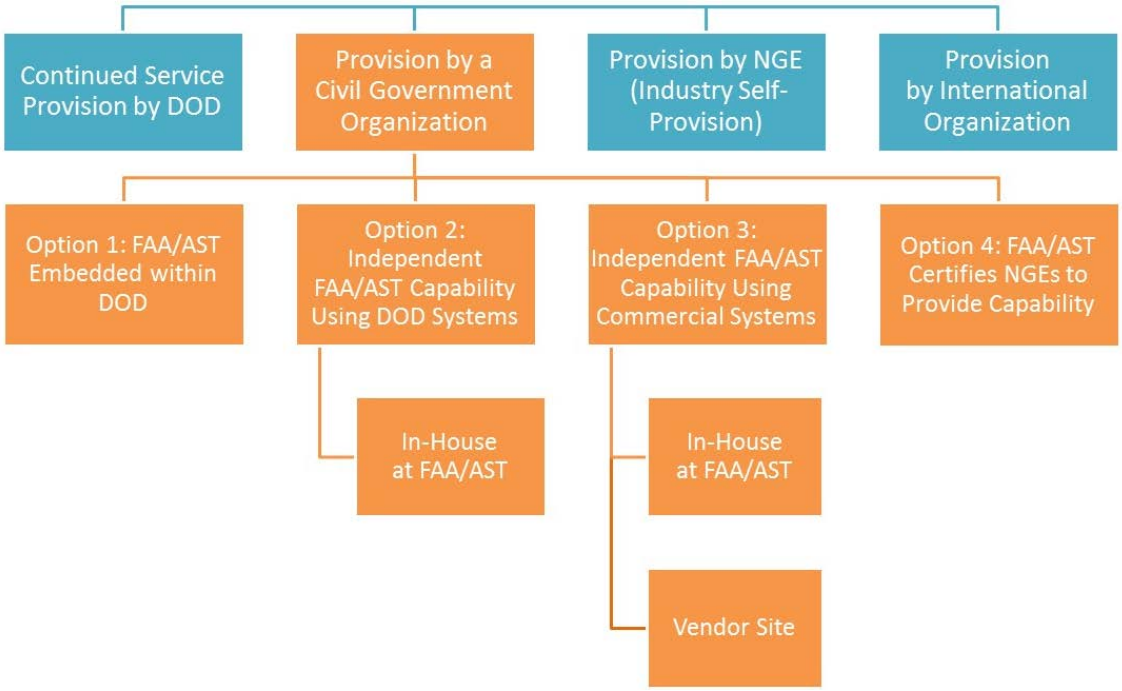

Fig. 2. Options for Provision of SSA Services by FAA/AST as the Civil Government Organization (Each Has a Different Set of Costs and Policy Implications)

Some options include different "levels" of service, which are depicted in Fig. 2. We refer to the STPI report for details on each option. Table 2 offers high-level details for each option and Table 3 summarizes the strengths and challenges of each. For example, the strength of Option 4 is that it would be a relatively low cost burden for the government. Fees associated with SSA services for 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. This option 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 utilize. 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;[3] 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.

[3] *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 examine this concept in Section 5, "Discussion: Role of Government in SSA."

Table 2. Summary of *Options* (within Approach 2) for FAA/AST Provision of SSA Services

	Option 1	Option 2	Option 3	Option 4
Description	FAA/AST capability embedded within DOD	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	18th SPC	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 DOD operations.

As Table 2 shows, the options differ in vendor engagement. Our survey of a subset of vendors revealed prices that ranged from $2 to $60 million. The price discussion is complex and we refer readers to our report. It is important to note that the order of magnitude price estimates for options that involve vendor services (Options 2, 3, and 4) 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 DOD if the civil SSA mission moved to FAA/AST's purview). We also did not validate or verify these capabilities or price estimates; they are self-reported by the vendors themselves.

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

Option	Strengths	Challenges
1. FAA/AST Embedded within DOD	• Expected to somewhat reduce DOD's workload not related to national security mission • 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 DOD's core hardware and software	• Capabilities subject to the limitations of DOD's software and data • Flexibility and innovation limited to improvements in JMS • Continue to have significant restrictions on ability to share data with commercial and international customers • 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 • FAA/AST has more insight into the DOD SSA process • 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 • Unclear how difficult it will be for FAA/AST to add value-added software services and a database on top of the DOD architecture • Dependence on DOD data (by not being able to augment with commercial data) could be detrimental if FAA/AST loses data stream • 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 • 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) • If properly designed, could promote greater flexibility and rapid development of software than utilizing DOD software and data • Likely the best option to prepare FAA/AST for a future role in STM	• Increased upfront costs over previous two options • Using a different database than the DOD catalog could lead to conflict across agencies • If systems are customized (i.e., do not remain commercial), would deter quick/agile improvements • 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 • Low cost burden for government • Greatest flexibility for service improvements	• Not appropriate if SSA services are deemed to be governmental functions • May not meet the requirements for government oversight under international obligations • Unclear who would bear the cost of services: government or users • Liability concerns • May cause issues with current international partners • Owner/operators may choose the least restrictive or expensive vendors, which could be counterproductive to safety in space

5. Discussion: role of government in SSA

As the sections above summarize, there are at least seven different ways in which SSA services can be provided to civil and international users. Each is differentiated by the level of service, the data sets being used, and the location where service activities occur. The options differ in vendor engagement and vendor-reported prices. In addition to different costs to the government, each approach and option has strengths and challenges 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. The challenge most relevant, however, to determining the provision of civil SSA services moving forward is in regard to the community's assessment of the role of government in the domain: Are safety of flight and long-term sustainability of space as imbedded in SSA and STM inherently governmental functions? If the response is yes, does that mean they need to be performed *within* government, or is it adequate if they are *overseen* by government? And if the response is no, who should perform them, and what happens if something goes wrong?

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" [15]. 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" [16,17].[4]

Experts who believe SSA is an inherently governmental function contend that proper SSA helps enhance the national security, public safety, and societal benefit that come from smooth operations in space. 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 the private sector may serve as a better steward of innovation in the system, provide resilience and redundancy to DOD-led SSA provision, and create an entirely new commercial sector, promoting economic growth and

[4] 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) [16,17]. 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.

development. We assume that these experts would also agree that if something goes wrong with the private provision, any subsequent costs to compensate for the loss of safety would be covered by the private sector.[5]

6. Further policy considerations for civil SSA

In addition to determining the role of government in SSA, other policy-related challenges that need to be resolved as we explore options for provision of civil SSA services include:

1. Regardless of who provides the services, who should pay for civil SSA services – the government or end users? What happens if some end-users are not able to pay, or prefer less-expensive but potentially less-good services?
2. How should the challenges related to sharing of sensitive national security or proprietary information on satellite location or impending conjunctions be addressed?
3. How do existing laws, agreements, policies, and regulations affect provision of civil SSA, and how might these policies need to be created/augmented?
4. Regardless of the service provider – government or the private sector – how would liability issues be addressed?
5. How would international commitments, such as the Outer Space Treaty, transfer of data agreements with DOD, and other issues such as the desire (for the U.S.) to be seen as a global leader be addressed?
6. Which approach best addresses the issue of innovation? Indeed, what is the role of government in promoting innovation – especially related to IT products and services?

7. Summary and Conclusion

Our paper begins with an important clarification, that SSA and 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 government functions. We also found that 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 DOD. Currently, this work is done 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

[5] There is historical evidence that this is not the case. In 2008, when the financial sector faced collapse, U.S. taxpayers had to step in to cover the losses to the tune of hundreds of billions of dollars. Similarly when GM and other companies faced bankruptcy challenges, the government had to step in again to cover the losses.

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. While more detailed assessments would need to confirm this, our 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 the tens of millions of dollars annually. There has been an increase in the number of private sector providers in recent years, making SSA a potentially competitive market that may drive down prices 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 U.S. to fulfill its obligations under the 1967 Outer Space Treaty, specifically the Article VI requirements related to authorization and continuing supervision.

The options and policy issues we identified 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, including whether SSA is an inherently government function – and a determination of government's role within that function. Each approach to the provision of civil SSA – and the four options within Approach 2 – has unique strengths and outlooks for future SSA innovation, collaboration, and availability (commercially and internationally), as well as the maintenance of national security, among other considerations. However, each also emphasizes different policy and regulatory challenges outlined above. 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, not just on the near- and short-term economic costs.

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