NATIONAL SPACE COUNCIL

USERS' ADVISORY GROUP

Recommendations on
Trust and Interoperability in Space Situational Awareness Data

National Space Council Users' Advisory Group
Technology and Innovation Subcommittee
September 2, 2020

The content of this paper reflects the thoughts and opinions of the subcommittee's authors, and should not be construed as a recommendation of the full National Space Council Users' Advisory Group or the official policy of the United States Government, the National Space Council, or the National Aeronautics and Space Administration

Recommendations on Trust in SSA Data
NSpC UAG Technology and Innovation Subcommittee

Purpose

Space Policy Directive-3 (SPD-3), National Space Traffic Management Policy, was issued by the White House on June 18, 2018. The first goal in SPD-3 is to advance Space Situational Awareness (SSA)[1] and Space Traffic Management (STM) Science and Technology. SPD-3 states, "The United States should continue to engage in and enable S&T (Science and Technology) research and development to support the practical applications of SSA and STM. These activities include … advancing the S&T of critical SSA inputs such as observational data, algorithms, and models necessary to improve SSA capabilities, and developing new hardware and software to support data processing and observations." In response to SPD-3, the National Space Council's User Advisory Group (UAG) Technology and Innovation Subcommittee has been studying technical issues around SSA data by consulting a number of experts in government and industry. There are many U.S. Government (USG) stakeholders in SSA data, including the Department of Defense (DoD), Intelligence Community (IC), National Aeronautics and Space Administration (NASA), Department of Commerce (DOC), Department of Transportation, and Department of State. The ability to continuously observe and track space object locations (referred to as SSA) is absolutely fundamental to critical capabilities such as orbital debris tracking and/or removal, monitoring safe operations in space for domestic regulatory purposes, and international security and transparency in the space domain. A whole-of-government approach is needed to address these challenges. This document summarizes two key recommendations from the UAG, and several observations.

Background

The United States Space Command (USSPACECOM) mission is to deter aggression and conflict, defend U.S. and allied freedom of action, deliver space combat power for the Joint/Combined force, and develop joint warfighters to advance U.S. and allied interests in, from, and through the space domain. As such, it plans, integrates, conducts, and assesses global space operations, and tracks all space objects using DoD -certified space and Earth-based optical and radar systems, providing missile warning capabilities and space object orbital location information for the protection of space assets. These certified sensors make up the Space Surveillance Network (SSN). Currently USSPACECOM also has responsibility for notifications of potential impending near misses or collisions of space objects to commercial, government, domestic and international spacecraft operators. This includes maintaining a "catalog" of known positions of space objects available to operators and researchers via a global public service (https://www.space-track.org), although some information may be redacted for national security reasons. This catalog has a wide variety of domestic and international users to include industry, government(s), and academia. Currently the orbital catalog only incorporates data from sensors certified by DoD, although USSPACECOM does have access to other sensor data. The DoD also has more than two dozen government-to-government agreements under which enhanced space object location data is provided beyond the publicly-available catalog.

[1] The DoD uses the term "Space Domain Awareness (SDA)" but this is not yet in broad use.

SPD-3 acknowledges the need for the DoD to focus on maintaining access to and freedom of action in space, and states that the DOC should be the focal point for administering an open data architecture repository and providing space collision avoidance support services. As the DoD has already found, the technical challenges to providing this type of service have been increasing to the extent that the approach must also change to meet them.

There has been rapid growth in the number of space objects such as large commercial constellations. Adding large numbers of satellites noticeably increases the likelihood of collisions[2] and increases computational complexity for collision calculations. Additionally, there are proliferating dynamic capabilities such as rendezvous, satellite servicing, and more frequent re-location of satellites. Natural and human-made space threats have been growing. Continuous, persistent tracking and custody of space objects is not possible today with the widely-spread SSN. Very small orbital debris that are nonetheless still a danger cannot be tracked (much less removed), and satellite maneuvers are confirmed hours or even days after they occur. This is further complicated by launches with hundreds or more spacecraft deployments from a single mission. This is increasingly becoming routine for U.S., Indian, Russian, and Chinese launches. In order to provide meaningful and timely situational awareness, the DoD and DOC will need to incorporate more multi-sourced information, data science, and analytics in their data repositories, and allocate or request budget to support.

There has been significant growth in global commercial and government entities using their own sensors to observe orbiting space objects. National security sensors will of course continue to support the DoD, but can feed into a DOC SSA system which also incorporates international partner and commercial data. The DoD is interested as well in using international partner and commercial data to supplement the SSN for greater space domain awareness. There are two challenges highlighted in this paper. First, a major obstacle to incorporating data from commercial and international sensors that are not certified by the DoD is trust in the reliability and accuracy of the data. Second, with so many stakeholders and a transition of certain responsibilities between the DoD and DOC, major inefficiencies in STM may occur from uncoordinated, inconsistent, and incompatible approaches to SSA data.

Trust and Interoperability

The United States Space Force (USSF) has undertaken a number of activities to evolve its own command and control system and learn how best to build trust and incorporate commercial SSA data. The DoD has created a Unified Data Library along with an SSA data storefront where data are made available to "any partner organization."[3] The models and algorithms used to propagate this data and determine orbit prediction from past observations are contained within the Standardized Astrodynamics Algorithm Library. The USSF recently announced it would share this data with the United Kingdom's Ministry of Defence[4]. USSPACECOM is currently providing

[2] NASA Large Constellation Study, *Orbital Debris Quarterly News*, Volume 22, Issue 3, September 2018
[3] https://breakingdefense.com/2019/10/air-force-hires-startup-to-build-up-mdos-unified-data-library/
[4] https://www.c4isrnet.com/battlefield-tech/space/2020/08/18/space-force-to-begin-sharing-technical-space-data-with-uk/

non-traditional sensor (i.e., not from sensors in the SSN) data inside the Combined Space Operations Center (CSpOC) and the National Space Defense Center (NSDC). While these non-traditional data are not integrated with data generated from the SSN, they provide additional insight and information which is being referred to during daily operations. There are active efforts to perform operational and engineering exercises supporting evolution to the next level of situational awareness and command and control. The DOC, Air Force Research Lab (AFRL), and USSPACECOM Joint Task Force recently conducted a global space traffic management exercise which successfully demonstrated the benefits of 24-hour global combined operations and shared data from commercial, foreign, military and civilian participants. Efforts are also underway by the USSF to develop the capability to ingest allies' space data more quickly[5].

The Defense Advanced Research Projects Agency (DARPA) has also made technology investments to facilitate non-traditional SSA data incorporation. In 2016, DARPA's OrbitOutlook (O^2) program demonstrated the ability to validate the quality of non-traditional sensor sourced SSA data in real time.[6] However, according to briefings from experts, the demonstration software was not optimized for larger scale multi-source data uptake, and the software was not immediately ready to transition to operational use. Some of the algorithms and methods have been published and incorporated into other efforts[7,8]. An interesting lesson was learned from a subsequent DARPA program started in 2018 called Hallmark, which demonstrated sophisticated SSA tools and command and control capabilities[9]. Hallmark illustrated an approach to rapid software acquisition which, according to program experts, has been welcomed by key partners in the national security SDA/SSA enterprise. During the program, it became clear that software-as-a-service[10] is having a substantial impact on how software services are being acquired. Private industry is driving this revolution; it's not clear how the changing business model will affect data and software architecture compatibility for USG programs, or the ability to shift to a new provider.

There appear to be few major technical barriers to the incorporation of commercial and international data. However, the USG must understand how to continuously evolve capabilities to keep up with changes in space operations (such as the expansion to cis-lunar space) and also provide best-in-class government services that are distinct from commercial offerings. The risk is that if the DOC and USSF choose incompatible data architecture approaches, data sharing and coordination (such as exists today between the DoD and Federal Aviation Administration [FAA] air traffic management) will be greatly hampered. The DOC should actively seek lessons learned from both the air traffic management paradigm and understand the DoD's rapidly evolving approach to data modeling, engineering, management, software acquisition, and curation architectures.

---

[5] Conversation with SMC Special Programs Directorate Space Domain Awareness Division
[6] http://www.amostech.com/TechnicalPapers/2016/SSA-Algorithms/Raley.pdf
[7] https://doi.org/10.1016/j.actaastro.2018.12.043
[8] http://arc.aiaa.org/doi/abs/10.2514/1.G002230
[9] https://www.darpa.mil/news-events/2020-03-27
[10] https://en.wikipedia.org/wiki/Software_as_a_service

Presently, commercial SSA capabilities are primarily sustained by USG purchases and going forward the DoD and DOC will continue to be significant customers of the industry. They must work together to avoid incompatible approaches so industry can organize around the products that will be needed by both organizations. American taxpayers should not be paying twice for substantively the same data in different forms due to a lack of coordination inside the USG. However, the long-term viability of a commercial marketplace for SSA data is still uncertain and could be at risk if the DoD and DOC do not define their needs in a timely manner. The DoD and DOC must define how much data is needed and develop a long-term strategy about the commercial SSA industry to clearly scope the government market limits, and/or help increase the commercial customer base.

Recommendation #1: The Departments of Defense and Commerce should work to create an interoperable approach on multi-sourced space data modeling, data sharing, and curation architectures. Both departments should study lessons learned and fund studies and research around technical solutions and processes that allow incorporation of properly vetted international and commercial data into the space object catalog for military, civil and commercial uses. We further recommend that the Departments should report to the National Space Council regularly on their progress.

Standards to Accelerate and Simplify Interoperability and Trust Approaches

The advent and growth of commercial earth remote sensing entities (many international) has required the issue of trust to be addressed by the National Geospatial-Intelligence Agency (NGA) and others in the IC. Mr. Dave Gauthier, Director of NGA's Commercial & Business Operations, explained to the subcommittee that the USG, as a regulator, requires basic data protection standards on commercial remote sensing operators licensed by the DOC. This is documented in a data protection plan, and periodically the USG checks the data submitted and the commercial physical infrastructure to validate adherence to the plan - similar to an audit of a manufacturing "supply chain." This regulatory requirement is largely in place to ensure that commercial spacecraft operating under a "U.S. flag" are able to maintain safe operations on-orbit and will not bring undue harm to national security.

In addition, the USG, as a data customer, holds commercial data providers to even higher standards through contractual language. This is documented in a security plan for each contract which documents the supply chain for the digital information sold to the USG. The security plan includes what networks transfer data, whether it is encrypted vs. unencrypted, who owns the network used (especially foreign owned or with foreign investors), how the data are protected in storage, and who applies analytics to the data. Mr. Gauthier identified two key challenges NGA has encountered with this approach. First, in some cases the slow pace of building up to full compliance can delay government access to critical data. Second, there is a need to broadly communicate the best practices in data supply chains to industry much earlier in their business development and design phases. This is because retroactively applying proper data security

measures to commercial infrastructure is at a minimum more costly and at a maximum may not even be possible.

The National Institute of Standards and Technology (NIST) has done work around data protection standards that may be applicable. The IC's Commercial Remote Sensing Working Group (CRSWG), currently chaired by Mr. Gauthier, recently proposed Enhanced Data Protection Requirements to establish guidelines and measures to protect and defend commercial imagery, data, and products by establishing standards for trust. These requirements would use USG standards from NIST and preserve the DOC licensing decisions while protecting the U.S. national security interests. This initiative builds off the NIST SP 800-171[11], with pre-tailored security controls, and avoids generating a new security standard document. It allows for reciprocal community risk assessment and authorization (A&A), resulting in creation of a commercial "trusted environment" protecting USG data that has the capability of obtaining a third-party certification. This will leverage the commercial providers' profit driven, diverse environment (i.e. non-U.S. personnel, overseas ground stations, foreign partners, foreign code, outsourced support), while balancing performance, cost, and security.

Experts have also commented on the need for a standard method for quantifying SSA sensor uncertainty. SSA data are provided with a covariance matrix that describes the uncertainty in the orbital position of the space object, but does not describe the quality of, or uncertainty in, the sensor data used to calculate that position. A standard method of expressing and comparing sensor uncertainty would assist all entities in characterizing the quality of their data - essential for trust. There has been relevant research in the community regarding improved methods of uncertainty quantification and representation[12]. Clarity on all aspects of data vetting must be agreed to by the DoD and DOC to establish thresholds for accepting the data for inclusion into the space object catalog. Establishing standards for sensor uncertainty also provides clarity for SSA businesses and international partners alike and potentially could greatly speed up the data quality vetting process.

The Consultative Committee for Space Data Standards (CCSDS) is a multi-national forum for the development of communications and data systems standards for spaceflight. It was founded in 1982 by the major space agencies of the world. NASA is very involved with CCSDS and also in the area of orbital debris tracing and monitoring, and offers substantial technical expertise and international perspectives on data standards. The DOC and DoD should leverage NASA's long history of expertise with standards and experience with the international community to avoid duplication and enable the harmonization of the DOC and DoD emerging standards with existing global standards.

Recommendation #2: The Department of Defense, Department of Commerce, and NASA should work to jointly develop standards for space data protection and security plans, space data verification, and space data uncertainty quantification.

[11] https://csrc.nist.gov/publications/detail/sp/800-171/rev-2/final
[12] Bever, M., Delande, E., Jah, M. (2019). *"Outer Probability Measures for First and Second Order Uncertainty in the Space Domain"* IAA-AAS SciTech-040, Moscow, Russia June.

Observations on Additional Areas of Study to Consider

In addition to these recommendations, there are several points that have been raised by the many technical experts we have consulted, including Mr. David Gauthier (NGA), Prof. Moriba Jah (University of Texas at Austin), Dr. Jeff Kommers (Ball Aerospace), and Dr. Jerry Krassner (independent consultant). The T&I Subcommittee makes the following observations:

1. The sensitivity of SSA data to specific types of errors depends on complex, multidimensional mathematical and physical relationships. A study to understand which parameters are most/least important to the quality and precision of the data, especially related to information needed for different use cases (see item d below), would be beneficial.
2. A frequent re-visit rate for observing space objects will also reduce risk, as new data sources can correct errors or more rapidly highlight spoofing. A study to understand the quantity, quality, type, and modality of sensors needed for persistent custody of objects would be helpful to the USG. Rules for the continuous validation of less-trusted data sources via coincident collection with trusted sources can mitigate risk.
3. In other domains, fusion of dissimilar data can create synergy, greatly increasing the precision of the combined information and reducing the risk of accepting any single source of data. A study to evaluate the best mix of optical, radar, laser, and other data may provide insight into how much of which data is optimal.
4. There are a variety of uses for SSA data, such as collision avoidance, identification, and behavior prediction. Some uses require timeliness over accuracy, and other uses may reverse the priorities. Some data may be acceptable even if not of the highest quality or vetted to the highest standards because of timeliness. Defining those use cases, and deciding ahead of time what data from what source will be accepted would be beneficial to both industry and government
5. As identified in SPD-3, there is a critical need for SSA research, to establish capabilities for developing trust in multi-sourced information, including unstructured data such as human-based semantic (non-numeric, text-based) information.
6. The long-term viability of the business model for commercial SSA data is not yet clear. The USG should scope its needs and communicate what is needed clearly to industry to ensure entrepreneurs and investors understand the size of the USG market. The USG must also provide clarity around its standards of service going forward to enable commercial product differentiation.
7. Currently, international space data are being aggregated and shared in a variety of ways. The Minor Planet Center of the International Astronomical Union (IAU) has aggregated optical and radar tracking measurements of asteroids and comets for over 70 years, from professional and amateur observatories. Techniques developed there for managing uncertainty and trust in data from diverse sources can be applied to the SSA effort. Orbital position computations require fundamental earth positional data that are aggregated by the International Earth Rotation Service (IERS) located in Paris, France using data from

observatories around the world. A study could look at these successful models for insight into an approach to international SSA data pooling.

Closing Thoughts on U.S. National Interest

Despite the very high quality of individual sensors in the SSN, the U.S. is unable to maintain persistent custody of all space objects. This affects the quality of the current space object catalog, resulting in risks to government and commercial space operators. This is one reason other countries are pursuing development of their own catalog capability.[13]

The U.S. is currently the world leader in SSA, but a lack of coordinated effort may soon cause us to fall behind. We have learned from the space-based synthetic aperture radar (SAR) commercial experience that operational limitations put on industry will only lead to other countries taking leadership in these capabilities. If we lose leadership in this critical arena, we will have less influence in overall domestic and International space operations, which will impact our ability to be the leader in spaceflight development.

Increased trust and collaboration across the SSA enterprise enables closer collaboration and trust amongst allies and presents new options for diplomatic engagement with other participants. A whole-of-government approach with clarity on roles and responsibilities is needed to enable a host of urgent needs in secure and sustainable operations in space for the United States, our industry, and our allies.

[13] Lal, B., Balakrishnan, A., Caldwell, B.M., Buenconsejo, R.S., Carioscia, S.A. *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM),* Institute for Defense Analyses Science and Technology Policy Institute Document D-9074, April 2018.