Improving Space Situational Awareness

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Executive Summary

Space plays an important role in the global economy as a critical medium for commercial, civil, and national security data services. There are more than 1,000 active satellites orbiting Earth operated by more than 70 countries and international organizations. Space-based capabilities play critical roles in global transportation, banking and financial systems, communications, monitoring and utilization of natural resources, and disaster management. Satellites are also cornerstones of national and international security, providing vital intelligence and enabling real-time communications with military operations anywhere in world.

The growing number of space actors and their increased reliance on satellites generate significant challenges for the continued, sustainable use of space over the long-term. These challenges include the threat of collisions and radio frequency interference, either of which could lead to mishaps, misperceptions or mistrust between satellite operators. Space situational awareness (SSA), broadly defined as characterizing the space environment and its impact on activities in space, can provide this information and is a fundamental requirement for successfully tackling the many challenges related to the long-term sustainability of space activities.

Currently, the U.S. military provides the vast majority of SSA capabilities and services for all space actors. It operates the largest, most capable network of SSA sensors in the world and offers without charge a close approach warning service for all satellite operators. However, the U.S. military has fallen short of the policy objectives for SSA and space sustainability as set forward by the U.S. national space policy. The end users of its SSA services in the national security, civil, and commercial sectors have expressed concern with the quality and responsiveness of the SSA services provided by the U.S. military. Moreover, these core capabilities are being developed without input from the many commercial companies and foreign governments who are being asked to rely on them, undermining their trust in the services.

Based on literature research and interviews with key stakeholders across several space sectors, this report provides specific policy recommendations to be considered by the President's National Security Staff[1] to improve SSA capabilities and sharing for the U.S., and thus all space actors, in the short-term. These recommendations include making more accurate positional data on space debris objects available to all satellite operators, involving a broader set of stakeholders in the development of U.S. SSA capabilities, and better inclusion of best practices and international standards. The report also recommends that the U.S. government transfer responsibility for core SSA activities such as maintaining a catalog of space objects and performing close approach warnings to a non-military U.S government organization. The authors believe that these steps will allow the U.S. to improve its SSA capabilities to support national policy objectives as well as improve trust in said capabilities by other space actors and ultimately enhance the long-term sustainable use of space by all.

[1] The Obama Administration refers to the National Security Staff as the merged components of the Homeland Security Council and the National Security Council (Cooper, 2009)

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Background and Problem Description

Space situational awareness (SSA) was originally conceived as space surveillance during the Cold War. The space surveillance mission was conducted by the militaries of the United States and Soviet Union to detect threats from space, including orbiting nuclear weapons and nuclear warheads traveling through space (Weeden, 2012b). In recent years, this capability has been rebranded as SSA and expanded to include more types of information as well as additional services. SSA activities include detecting, tracking, and monitoring all man-made objects in orbit around the Earth, predicting and warning of close approaches between two space objects that could result in a potential collision, and detecting and monitoring space weather events created by the interaction of the Sun's heliosphere and the Earth's magnetic sphere, as well as a range of national security functions for detecting and characterizing threats in space.

This rebranding and expansion of space surveillance and SSA is largely due to the challenges created by humanity's expanding use of space. Over the last fifty years, humanity's space activities have progressed from the first manmade satellite in 1957 to a Cold War space race for national prestige and security, and most recently to a wide array of activities that are used in everyday life. More than 70 entities (countries, commercial companies, and international organizations) currently operate more than 1,000 satellites in orbit around Earth providing a wide range of social and private benefits (Union of Concerned Scientists, 2012). These benefits include enhanced national and international security, more efficient use and management of natural resources, improved disaster warning and response, and reliable global communications and navigation. This increase in space activities by many different actors has brought about a number of pressing challenges.

Challenges from Expanding Use of Space

The first and foremost challenge is the growing amount of space debris - dead satellites, spent rocket stages, and other fragments associated with humanity's six decades of activity in space (Weeden, 2012a). The U.S. military currently tracks close to 22,000 pieces of human-generated debris in Earth orbit that are larger than 10 cm in size, each of which could destroy an active satellite in a collision (Union of Concerned Scientists, 2012). Research done by scientists and space agencies indicates there is also a population of another 500,000 pieces of space debris between 1 cm and 10 cm in size that is largely untracked, each of which could severely damage an active satellite in a collision (NASA, 2012).

Recent significant events have greatly exasperated the debris problem. In 2007, China conducted an anti-satellite test that resulted in the destruction of one of its own inactive weather satellites and the creation of more than 3,000 pieces of trackable space debris (Weeden, 2010b). In 2009, an American Iridium commercial communications satellite and a Russian Cosmos military communications satellite collided in orbit, destroying both and creating more than 2,000 pieces of trackable space debris (Weeden, 2010a). Additionally, there have been several unintentional fragmentations of dead satellites or rocket bodies since 2000 that have created thousands more pieces of space debris.

As space debris is generated by humanity's activities in space, it is concentrated in the most heavily used regions of Earth orbit where many active satellites also reside. These include the low Earth orbit (LEO) region below 2,000 kilometers in altitude and the geostationary Earth orbit (GEO) region approximately 36,000 kilometers above the Equator. Satellite operators in these regions are increasingly performing maneuvers to reduce the possibility of collision with other satellites or space debris. In 2012, satellite operators performed 75 of these avoidance maneuvers based on close approach warnings provided by the U.S. military (Miles, 2013).

The second major challenge is that of radio frequency interference (RFI). Due to a number of environmental and engineering factors, many satellites use the same or similar radio frequencies to communicate with ground controllers and transmit data. These radio communications can experience interference due to natural environmental effects such as space weather and solar storms, unintentional man-made interference such as broadcasting too close to another satellite, or intentional man-made interference such as deliberate jamming. RFI is a particularly challenging issue in the GEO region where hundreds of active satellites maintain mostly fixed positions relative to the surface of the Earth and are a critical part of the global communications infrastructure.[2]

The third major challenge involves national and international security. An increasing number of countries are using satellites for national security purposes. However, as more countries integrate space into their national military capabilities and rely on space-based information for national security, there is a growing chance that any interference with satellites could spark or escalate tensions and conflict in space or on Earth. The challenge of determining the exact cause of a satellite malfunction further complicates the situation: whether it was due to a space weather event, impact by space debris, unintentional interference, or deliberate aggression.

[2] Commercial GEO satellite operators continually cite unintentional RFI as their number one concern for day-to-day operations (see DalBello, 2012)

Emergence of Space Sustainability as a Policy Issue

Growing awareness of these challenges has given rise to the long-term sustainability of Earth orbit, commonly defined as the ability to use Earth orbit for benefits into the future, as a significant policy issue at the national and international level. Internationally, there are three major international initiatives dealing with various aspects of space sustainability. In 2008, the European Union agreed to a Code of Conduct for Outer Space Activities, which has since formed the basis for discussions of an International Code of Conduct (ICOC) among many spacefaring states (Chow, 2012a). In 2010, the Scientific and Technical Subcommittee (STSC) of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) formed the Long-Term Sustainability of Space Activities Working Group to develop voluntary best practice guidelines for all space actors to ensure the long-term sustainable use of outer space (Chow, 2012b). Further, in 2011 the United Nations Secretary General formed a Group of Governmental Experts (GGE) on Transparency and Confidence-Building Measures (TCBMs) in Outer Space Activities to provide recommendations for improving cooperation and reducing the risks of misunderstanding and miscommunication in space activities (Chow, 2012c).

At the national level, the long-term sustainability of space activities has also become a significant public policy issue within the United States. Although the United States is not the only country using outer space, it is by far the most reliant on space-based capabilities, particularly for national security, and has significant incentive to act in a leadership role on this issue. Both the 2010 National Space Policy (NSP, White House, 2010) and the Department of Defense's National Security Space Strategy (NSSS, Department of Defense, 2011) emphasize space sustainability as a critical goal. These NSP and NSSS outline specific actions to be taken by U.S. government entities to address challenges such as mitigating space debris, improving resilience and protection of space assets to natural and manmade threats, and enhancing international cooperation and stability.

The Role of Space Situational Awareness

SSA is at the heart of space sustainability and overcoming the challenges posed by our expanding use of space. SSA provides the knowledge about space activities and potential threats in space to mitigate the creation of orbital debris, detect and prevent collisions between active satellites and other space objects, resolve the sources of radio frequency interference, and provide transparency and confidence building measures (TCBMs) to help prevent conflict.

Although the Cold War concept of space surveillance has been rebranded to SSA, the methods and techniques for providing SSA have not adapted to meet the current space sustainability challenges. While several countries have a degree of SSA capabilities, the United States currently has the most comprehensive and by far the most advanced SSA capabilities in the world (Weeden, 2012b). Within the U.S. military, U.S. Strategic Command (USSTRATCOM) is responsible for operating the Space Surveillance Network (SSN), maintaining a catalog of space objects and providing a range of SSA services for users inside and outside the U.S. government, including conjunction assessments (CA) and warning services for satellite operators (Weeden, 2012b). The government began efforts to provide more comprehensive data and warning services to non-U.S.-government space actors in 2004 with the creation of the Commercial and Foreign Entities (CFE) program (Chow, 2011). These warning services were greatly expanded after the Iridium-Cosmos satellite collision. Prior to the collision, the U.S. military had been releasing publicly tracking data that was not accurate enough to be used for prediction of potential collisions. The U.S. military maintained a much more accurate private catalog that was used for a variety of purposes, including periodic screening of a limited number of high-value satellites for potential collisions with other space objects.

As a result of the 2009 collision, the U.S government decided to provide a close approach warning service for all satellite operators based on the more accurate private catalog to help prevent future collisions that could endanger all satellites, including those critical to U.S. national security. From a national security perspective, offering this service was considered to be a more attractive option than providing other satellite operators access to the high accuracy catalog. It would also forestall other actors from developing their own SSA capabilities that might diminish the U.S. advantage while also reducing the chances of further collisions. The U.S. military also began to request satellite operators provide additional information on the location of their own satellites to enhance the SSA services provided. These actions made U.S. military the central hub for global SSA activities while also allowing the U.S. to filter data to protect some of its national security activities in space. This decision also meant that in October 2009 USSTRATCOM was designated the lead agency for negotiating and signing agreements with commercial satellite operators and foreign governments to both provide data from the U.S. military as well as bringing in new sources of data to enhance their existing SSA capabilities (Chow, 2011).

Key Questions and Approach

The key question this project seeks to address is whether or not the current organizational structure with the U.S. military as the primary source of SSA data for all space actors is able to provide the SSA capabilities and services needed to support the existing international space sustainability initiatives and U.S. national policy goals. Secondly, this project attempts to determine what SSA data-sharing model and end state would best support national security, scientific research, safety of spaceflight, and commercial activities in space. Finally, it examines the steps the U.S. government can take in its leadership role on SSA to move towards the desired end state.

Although there are many actors involved in SSA and space activities in general, this project focuses on the U.S. because it is by far the most capable. It is possible for others to develop SSA capabilities that could eventually surpass the U.S., but given the expense of doing so it is more likely that others will develop niche capabilities that are complementary to existing U.S. SSA capabilities. And although it no longer enjoys the geopolitical might that it once had, the U.S. does hold a significant amount of sway in international decision-making, and many countries look to the U.S. for leadership on key issues such as SSA. Therefore, the authors argue that it is appropriate to focus on U.S. policy and organizational structures regarding SSA as the most efficient way of addressing the need for improving SSA in the short-term.

This project approaches the issue of SSA through the framework for sustainable governance of a common-pool resource developed by Elinor Ostrom.[3] Previous research conducted and sponsored by the Secure World Foundation (SWF) has explored the potential to apply Ostrom's framework to the Earth orbit CPR. Through a series of conference papers and journal publications, SWF researchers have found significant applicability of Ostrom's framework for sustainable governance to the challenges of Earth orbit (Weeden & Chow, 2012).

This capstone project extends SWF's work by focusing on one of Ostrom's principles, that of effective monitoring of the CPR by monitors who are part of or accountable to the resource appropriators. Monitoring is needed to ensure that all the resource appropriators are

[3] Further details of Ostrom's framework and its applicability to space governance can be found in Appendix B

complying with norms and rules of that CPR. Ostrom's research shows that optimal monitoring occurs when done by the resource appropriators themselves or when monitors are beholden to the appropriators (Ostrom, 1998). This structure eliminates the need to trust a third-party monitor, allows each resource appropriator to determine for itself that others are following the rules, and means appropriators know they are being watched by their peers as well. This framework may be accomplished either by a shared scheme of monitoring or one where the resource appropriators take turns in a monitoring role. In either case, it is important that the costs of monitoring be kept low and/or the benefits from monitoring high.

Recommendations for U.S. Policy

The report recommends that the U.S. government implement three specific policy actions to improve SSA. These can be implemented under the existing organizational structure for providing SSA data and services. The report also recommends a fourth policy action that modifies the existing organizational structure in order to more effectively implement the first three actions and improve the chances of success.

1. Provide more accurate positional data on space debris and other non-sensitive objects to all satellite operators.

The U.S. military currently makes low accuracy positional information for a subset of the space objects it tracks available to the public.[4] This data is not accurate enough to support many of the necessary SSA functions such as predicting close approaches and potential collisions. The

[4] There are several thousand space objects tracked by the U.S. military whose positions are not disclosed publicly for a number of reasons, including both lack of enough information to formally catalog the space objects and national security.

U.S. military also maintains a separate high accuracy catalog (HAC) of space objects, which it uses internally for a number of applications, including predicting close approaches between two space objects and atmospheric re-entry of space objects (Weeden, 2012b).

The U.S. military should provide more accurate positional data for space debris and other non-sensitive space objects to all satellite operators. Such an action would greatly improve the ability of satellite operators to make educated choices about their space operations and react to changing situations and threats. It would also relieve some of the burden currently placed on the U.S. military for performing a close approach warning service for all active satellites. Releasing data only on space debris and other non-sensitive objects, and only to satellite operators and not publicly will mitigate potential concerns that releasing such data will jeopardize national security.

2. Expand SSA "community of interest" to include all users of SSA data, including commercial and foreign actors

The U.S. military has developed a community of interest for SSA that enables users of SSA services to provide input on capabilities and data products they need to the SSA acquisition process. The current SSA "community of interest," according to the U.S. military, includes all U.S. government space users such as the Air Force, National Reconnaissance Office, Army, Navy, National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA). However, it noticeably does not include any commercial or foreign users of SSA services.

As the U.S. military continues to develop and improve its SSA capabilities, it must better take into account the needs of these other actors. The U.S. government, in an effort to fulfill its role as the world's SSA leader and to prevent others from developing their own capabilities, should expand this "community of interest" to include all users of its services and include their concerns and interest in the development of new systems and procedures. This measure will ensure that these other users will view the U.S. military as responsive and effective in the developments of any future services or technologies.

3. Formalize meaningful U.S. government participation in and adoption of best practices and standards for data sharing

For several years, various international bodies such as the International Organization for Standardization (ISO) have been developing standards for space activities. These standards include data formats, messages, and protocols for exchanging SSA information between space actors. The standards development activity is taking place in two main forums – the Consultative Committee for Space Data Systems (CCSDS) and the International Organization for Standardization (ISO). CCSDS is an organization founded by several of the world's major space agencies in 1982, while ISO was founded in 1945 and handles development of standards for a much wider range of issues and many more countries. While CCSDS is a recognized standards body by ISO, its discussions only include government agencies and not commercial or private sector stakeholders.

While there has been some limited participation from NASA in CCSDS, there has not been a coordinated and meaningful U.S. government presence in the ISO work. Further, there appears to be a disconnect between these international standards development activities and the acquisitions process that is developing new SSA systems and capabilities for the U.S. military. This disconnect could lead to a situation where the systems being procured by the U.S. military do not fully support international standards for SSA data sharing, making it more difficult to share data and improve SSA for years to come. Instead, the U.S. government should establish an interagency approach to meaningful participation in both the CCSDS and ISO standards activities, and ensure that any systems developed or acquired comply with international standards for SSA data messages and protocols.

4. Issue an executive order transferring responsibility for maintaining a central satellite catalog and providing conjunction assessment, collision avoidance, and anomaly resolution services for all satellite operators to a non-military U.S. government organization.

While Recommendation One (providing more accurate data publicly) would be easily achievable under the current SSA structure, implementing Recommendations Two and Three would be more difficult due to the competing demands within the U.S. military from their mission focus on national security. Because of the high risks involved with their mission the U.S. military is especially reticent to release data from any of their systems on the grounds that it might reveal capabilities or limitations that could be exploited by an adversary. The perceived unwillingness of the U.S. military to view other commercial and civil space actors as partners has engendered an atmosphere of mutual distrust.

Consequently, the U.S. government should transfer responsibility for basic SSA services, including maintaining a satellite catalog and performing conjunction assessment and collision warning for all satellite operators, to a non-military U.S. government agency. This agency would be responsible for providing these services to non-military entities both within the U.S. government and around the world. Its primary responsibility should be increasing safety and transparency of space activities.

The U.S. military must still retain the aspects of SSA that are directly related to national security. This includes building upon the satellite catalog maintained by the non-military agency with data obtained from classified sources and determining and characterizing threats to U.S. space assets. The U.S. military should also be the primary agency for sharing SSA data with U.S. allies and supporting military activities around the world.

Policy Rationale

The key dynamic behind the preceding policy recommendations is building trust. Trust is central to this problem because no one entity can provide the solution to the problem on its own. Developing good SSA requires a large, geographically distributed network of radars, telescopes, and other sensors to track space debris as well as data from satellite operators on the locations of their satellites and any planned maneuvers. This means that governments and commercial entities who build or operate tracking sensors must share data with each other and satellite operators to gain the necessary global coverage, timeliness, and fidelity.

Currently, there is a lack of trust between the various stakeholders in SSA that is hindering efforts to improve SSA to address the pressing challenges. This lack of trust stems from both deficiencies in the current system as well as organizational culture and inertia. The U.S. military does not trust others in its mission to protect U.S. national security and is wary of providing information that could reveal its capabilities or limitations. This attitude leads it to operate its services as "black boxes" with little to no information provided as to how the analysis was done or its accuracy.

Commercial and government satellite operators are unwilling to base the safety of their valuable assets on services and analyses that cannot be validated or verified. At the same time, many are hesitant to share data with the U.S. military because doing so requires signing a legal agreement with the U.S. military (in particular, the branch of the U.S. military that is responsible for delivering nuclear weapons. The symbolism in many cases is complicated at best, and in some cases presents a significant public relations challenge.

Many governments are also unwilling to trust the SSA data and analyses being provided by the U.S. military, hindering the ability of the global community to use SSA as the foundation for political agreements to enhance space sustainability and security. This includes the previously mentioned efforts to establish and enforce norms of behavior and develop transparency and confidence building measures.

Shortcomings of the current system

Because of this lack of trust, the U.S. government strategy of the military as the global lead for providing conjunction assessments has largely failed. While there have been some much-publicized benefits from the free close approach service, many doubts remain about its effectiveness in actually mitigating the threat. The U.S. military provides no statistics of how accurate its positional information on satellites is, nor the accuracy of its close approach warning service. Studies done by satellite operators indicate as much as a fifty percent false positive rate and fifty percent false negative rate for the close approach warnings (Morring, 2012). Other studies conducted by satellite operators indicate at least three percent, and in some cases as many as twenty percent, of the U.S. military's locations on operational satellites are wrong (de Selding, 2013).

As a result of these concerns, a growing number of satellite operators from both the commercial and government sectors are joining the Space Data Association (SDA), a non-governmental organization created by satellite operators. The purpose of the SDA is to pool positional data on active satellites operated by participating members and provide close approach warnings, assistance in planning collision avoidance maneuvers, and resolution of RFI. As of 2013, the SDA provides these services for more than twenty operators responsible for 320 active satellites in orbit (SDA, 2013). The creation of this organization runs counter to the U.S. military's goal of preventing the development of competing SSA analysis capabilities.

Just as the satellite operators are dissatisfied with the current arrangement, so too is the U.S. military. It is being asked to take on this new requirement to provide these services for all satellite operators without significant additional resources such as manpower and funding. The military is also being asked to provide these services with obsolete computer systems that are 150 percent over capacity and were not designed to share data with or accept data from sources outside the traditional military tracking network (Weeden, 2012b). It is this inability to ingest outside data, such as the positional information that satellite operators have on the location of their own satellites, which is the root cause of the false positives and false negatives in the close approach warnings.

The U.S. military is attempting to correct some of these computer system shortcomings by developing and procuring new systems that theoretically can provide the needed capabilities. However, these procurement efforts have largely failed. Since 2000, the U.S. military has initiated at least three major acquisition programs worth hundreds of millions of dollars and none of them have delivered any meaningful capability (Weeden, 2012b).

The military's emphasis on secrecy as a byproduct of security is a significant factor in these acquisition failures as well as the day-to-day shortcomings of the services provided. Since the beginning of the Space Age, satellites have played a vital role in U.S. national security and in particular the collection of intelligence from a variety of sources. The real-world secrecy requirements surrounding classified programs add significant cost and complexity to acquisition efforts.

The way forward

The policy recommendations in this report are specifically designed to address the lack of trust and shortcomings of the current SSA arrangement. As a first step, sharing the U.S. military's more accurate data on space debris and other non-sensitive space objects will enable satellite operators and other data analysis centers to perform some of their own detailed close approach analyses. This redundant capability would relieve some of the burden on the U.S. military as well as deflect some of the shortcomings in the SSA services it provides. Additionally, the community of SSA users may devise additional, as-of-yet unknown uses for this data, potentially crowdsourcing the development of future SSA analytical tools. Releasing the data would also build trust with other stakeholders which may in turn increase their willingness to share data with the U.S. military. It is also a no-cost option, as mechanisms for providing such data are already in place.

The second and third recommendations for broadening the community of interest and focusing on best practices and standards address both building trust and meeting the challenges in improving the U.S. military's SSA capabilities. If the U.S. is going to maintain its leadership role as the main provider of SSA capabilities, it needs to develop those capabilities so as to be able to provide the services and information that other space actors need. Currently, only U.S. government entities are involved in the process for identifying and developing new capabilities and systems. Involving other stakeholders, including commercial satellite operators and foreign governments, helps ensure that the U.S. will be able to satisfy their SSA needs and also helps build trust in the SSA capabilities being developed by the U.S. This level of cooperation is directly in line with the most current national space policy documents. At the same time, focusing on best practices and standards helps ensure that the U.S. can more easily share data with other space actors and integrate data from others into its own systems. This effort also enables other governments and commercial companies to provide SSA data to the U.S., further enhancing its coverage and capabilities in a cost effective manner.

It is also in the interests of the U.S. government to assign at least part of the SSA mission to a non-military governmental organization. The trust and transparency requirements make the U.S. military ill-fit to serve in this role. Assigning it to a non-military government organization provides several benefits. First, it assures the U.S. national security space community that national security information will still be protected. Second, it would appeal to commercial satellite operators by establishing a more accessible organization than the U.S. military with whom to interact. Third, it would increase data fidelity for the U.S. government and all other participating space actors by integrating formerly disparate data into a single source.

This non-military organization would be an integrator of data, rather than a collector. The U.S. military would still operate its existing networks of radars and other sensors, many of which perform missions other than SSA. However, the military would be responsible for passing unclassified versions of the tracking data to the new non-military organization, which would in turn be responsible for maintaining a catalog of space objects and providing a range of services to all space actors to support safety of spaceflight, space sustainability, and transparency.

The non-military organization would be able to also ingest data from other sources to perform its mission, including from commercial satellite operators and other governments. This data would be provided on a voluntary basis, enabling other data providers to exclude information on their own national security space objects if desired. Such exclusion would come with the explicit assumption that they are then liable for responsible operation of and any damage caused by those protected objects in accordance with international law and established norms of behavior. Shifting responsibility for basic SSA services to a non-military agency allows that agency to focus on building relationships and establishing services and trust with all users while simultaneously allowing the U.S. military to focus on the elements of SSA that are critical to national security. The U.S. military can focus on adding addition classified sources of data to the catalog maintained by the non-military organization and detecting threats to U.S. space systems.

All our policy recommendations are also crucial to implementing the 2010 NSP and 2011 NSSS. They would lead to improved information collection and sharing for space object collision avoidance enhance collection and reinforce America's leadership role in the enhancement of security, stability, and responsible behavior in space. The recommendations would also increase the openness and transparency of space activities to increase public awareness and help prevent mishaps, misperceptions, and mistrust.

Desired End State

While these policy actions should be implemented in the short-term and will improve the current situation, they will not bring about complete resolution of the problem. There will likely be additional steps that need to be taken by the U.S. and others to meet the safety, security, and sustainability goals for future space activities. At this point in time, it is difficult to specify what these future policy actions should be. However, based on the theoretical foundations of Ostrom's principles, previous research and analysis, and the interviews conducted for this project, the authors conclude that the end state should satisfy the following criteria:

1. All space actors have access to a basic level of data on the locations of space objects to support safety of spaceflight, conjunction assessment, and collision warning.
2. Enough data on space activities is *publicly* available to allow development, monitoring & enforcement of norms of responsible behavior and attribution of irresponsible behavior.
3. Multiple analysis hubs exist that can each provide independent assessment of space events, potentially using different sets of data.
4. Mechanisms exist for nation states to protect information on space activities vital to national security.

Analysis of Alternatives

In developing the policy proposals outlined in this report several alternative options were qualitatively evaluated as potential courses of action. These alternatives stem from the academic approach to dealing with a commons that is used by many and could lead to overexploitation. The "tragedy of the commons" as originally put forward by Garret Hardin (1968) argued that there are only two solutions to overexploitation of a commons: install a "Leviathan" authority to manage and oversee the resource management or privatize the commons. In Hardin's estimation, the true tragedy was that implementing either of these solutions would destroy the commons nature of the resource, thus greatly diminishing its value.

Creating a "Leviathan" for all space activities

One way of establishing a Leviathan authority would be for the U.S. military to serve as the guarantee of security and order in space. The most cogent argument for this path was put forwards by Everett Dolman (2002) in his book "Astropolitik" where he argued that the United States should withdraw from the current space governance regime, seize military control of LEO, and act as a benevolent hegemon in establishing a new governance regime of outer space based on the principles of capitalism and liberal democracy. Dolman suggested that the United States should act as a Leviathan to oversee and enforce the privatization of space in order to solve space sustainability challenges.

Dolman's solution relies on assumptions that are dated and no longer relevant. The most significant assumption is that the United States is the sole superpower in the world, with the resources, political will, and freedom of action to exert its will upon the international community. Although it may have seemed to be the case for a brief period following the fall of the Soviet Union, the decades since after have proven this assumption invalid. The American strategy of promoting liberal democracies around the world to help defeat the Soviet Union has resulted in a plethora of economic and political competitors, all taking advantage of the same benefits of globalization and rapid advances in technology that powered the rise of the United States. The result is a diffusion of technological, economic, and military power away from a single superpower to many countries and even non-state actors (Nye, 2013).

Another possible alternative for establishing a Leviathan for space would be to turn oversight of space activities to a multi-state governing body, such as the United Nations. Of course, this group would not necessarily have to be an existing body, but one constructed from an international community of interest. This option is viewed as impractical based on many of the same liabilities that have plagued other attempts at governing other commons, including the high seas. The U.S. has historically been reticent about ceding national control over its interests. Even among some of the most successful regimes, like the United Nations Convention on the Law of the Sea (UNCLOS), the U.S. has yet to ratify it. Given the importance of space to U.S. national interests it does not appear feasible to pursuit this path.

Privatization of Space

At first glance, the classical privatization solution to the overexploitation of the space commons appears to be unworkable because of the existing international treaties that form the foundations of current international space law. Article II of the Outer Space Treaty (OST) states that "outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means" (United Nations, 2008). This framework prohibits nation states from laying claim to specific portions of outer space, a prerequisite for privatization.

Although there are some aspects of privatization already in place over one particular region of Earth orbit, this regime is not a practical solution that can be applied to other regions. Currently, the International Telecommunications Union (ITU) uses exclusion mechanisms in the form of international and national legal mechanisms to regulate and allocate the spectrum used by GEO satellites, and in turn assign specific orbital slots for GEO satellites to specific countries (Weeden, 2012a). Although only partial property rights are granted, these exclusion mechanisms may be seen as giving property rights to satellite operators in GEO and have led to fairly efficient use of GEO and correspondingly less of a space debris problem relative to LEO. Unfortunately, this solution is only viable due to the unique physics of the GEO region and is not applicable to other regions.

Stay the Course

Finally, it is an option for the U.S. government to maintain the current set of policies. This study hypothesizes that the current trajectory for the U.S.'s involvement in global SSA is misguided. In the short-term the ramifications of not changing policy will not be readily apparent. However, the current path is suboptimal, and perhaps even unsustainable. In addition to current U.S. military SSA processes being antithetical to a subset of Ostrom's principles, it is clear that despite the rising acquisition costs and repeated schedule delays for the U.S. military to provide new IT systems and capabilities, these systems and capabilities are not being designed with input from the international community. The U.S. is not on a path to develop the kind of open-architecture, flexible computer system that will either have the potential to import and export SSA data or incorporate evolving algorithms that reflect best practices.

Conclusion

There are considerable challenges to be met in ensuring the ability to use space in the future for all of the current benefits it provides as well as all those benefits not yet realized. Central to meeting these challenges is improving SSA for all space actors to enable them to operate more safety and efficiently, and to improve trust and transparency among space actors.

This report has provided an overview of the shortcomings of the current system to provide SSA to most space actors, which is built on capabilities and services provided by the U.S. military. It argues that the U.S. government needs to implement four specific policy changes to enable it to provide the SSA capabilities and services needed to address current and future challenges. These actions include distributing more accurate SSA data, involving the broader community of stakeholders in the development of new capabilities, and better integrating best practices and standards into those capabilities. The report also argues that transferring some of the SSA mission and responsibilities to a non-military governmental organization will greatly assist in the ability of the U.S. to make these changes and improve its SSA capabilities and services.

The next step in implementing these policies is to first identify candidate agencies or organizations that are aligned with the SSA mission. A short list includes, but is not limited to, the Federal Aviation Administration (FAA), NASA, and the Department of Homeland Security (DHS). Subsequently, the Code of Federal Regulations (CFR) will need to be amended to allocate international SSA responsibilities accordingly.

Next, the U.S. government would need to establish a new program of record to develop the requirements necessary for an IT system that will be used by the non-military organization to provide SSA services. This program of record should factor in lessons learned from the acquisitions experience of the U.S. military.

The U.S. government will also need to establish a schedule that would facilitate the safe transition of SSA sharing responsibilities from the military to the new non-military organization. Key technical and security milestones should be identified and included as part of that transition plan. Finally, it will need to build an international community of interest with other space actors to support the development of the new organization. Technical standards and procedural processes should be agreed upon that ensure rapid, transparent, and flexible modes of information sharing, as proposed in this report.

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Appendix A - List of Acronyms and Abbreviations

CA - Conjunction Assessment

CCSDS – Consultative Committee for Space Data Standards

CFE – Commercial and Foreign Entities Program

CFR – Code of Federal Regulations

CPR - Common-Pool Resource

DHS- Department of Homeland Security

FAA – Federal Aviation Administration

GEO - Geosynchronous Earth Orbit

GGE - Group of Governmental Experts

HAC – High Accuracy Catalog

ICOC - International Code of Conduct

ILS – International Launch Services

ISO – International Organization for Standardization

ITU – International Telecommunications Union

JSpOC – Joint Space Operations Center

LEO - Low Earth Orbit

LMSS – Lockheed Martin Space Systems

MEO - Medium Earth Orbit

NASA - National Aeronautics and Space Administration

NOAA - National Oceanic and Atmospheric Administration

NSP – National Space Policy

NSSS - National Security Space Strategy

OST - Outer Space Treaty

RFI – Radio Frequency Interference

SDA - Space Data Association

SSA - Space Situational Awareness

SSN - Space Surveillance Network

STSC - Scientific and Technical Subcommittee (STSC)

SWF - Secure World Foundation

TCBMs - Transparency and Confidence-Building Measures

ULA - United Launch Alliance

UNCLOS – United Nations Convention on the Law of the Sea

UNCOPUOS - The United Nations Committee on the Peaceful Uses of Outer Space

USSTRATCOM – United States Strategic Command

Appendix B – Ostrom's Principles for Sustainable Governance of Common Pool Resources

Elinor Ostrom is a political scientist who won the Nobel Prize for Economics in 2008, for her work on sustainable governance of common-pool resources (CPRs). She argues - and supports with substantial empirical evidence - that many CPRs have been successfully governed without resorting either to a centralized government or a system of private property. In fact, there are numerous cases where resource users have effectively self-organized and sustainably managed a common-pool resource in spite of centralized authorities and without instituting any form of private property. Moreover, she has pointed out that both the "Leviathan" or private property management schemes are just as likely to fail as other efforts.

Ostrom developed an eight-principle framework from her extensive research on successful and unsuccessful attempts to govern common-pool resources. These eight principles outline the conditions necessary to sustainably manage commons resources without a centralized government or private property regime. In every otherwise dissimilar case where common-pool resources were successfully managed, these eight elements were present:

1. The CPR has clearly-defined boundaries (effective exclusion of external unentitled parties).
2. There is congruence between the resource environment and its governance structure or rules.
3. Decisions are made through collective-choice arrangements that allow most resource appropriators to participate.

4. Rules are enforced through effective monitoring by monitors who are part of or accountable to the appropriators.
5. Violations are punished with graduated sanctions.
6. Conflicts and issues are addressed with low-cost and easy-to-access conflict resolution mechanisms.
7. Higher-level authorities recognize the right of the resource appropriators to self-govern.
8. In the case of larger common-pool resources: rules are organized and enforced through multiple layers of nested enterprises.

Research conducted and sponsored by the Secure World Foundation (SWF) has explored the potential to apply Ostrom's framework to the Earth orbit CPR. Through a series of conference papers and journal publications, SWF researchers have found significant applicability of Ostrom's framework for sustainable governance to the challenges of Earth orbit (Weeden & Chow, 2012).

Appendix C – Stakeholder Perspectives

For this project, the authors conducted a series of interviews with key SSA stakeholders across the U.S. federal government and the private sector. The goal of these interviews was to solicit input from each of them on the most significant priorities for improving SSA, challenges and drawbacks to the current set of organizational structures, and any recommendations for important improvements or modifications. The interviews were conducted in an unclassified setting and under the condition of anonymity so that interviewees would have the opportunity to be as forthcoming as possible. The following sections offer a brief summary of the main issues, concerns, and recommendations from various sectors.

Executive Branch

As outlined in the 2010 National Space Policy, the executive branch of the United States government believes that the space environment and safe access to it must be preserved (White House, 2010). The U.S. also recognizes that despite having the best SSA capabilities in the world, the U.S. needs foreign participation to fully track and understand near-Earth space. To achieve this goal, the Department of State has organized cooperative agreements that enable the Joint Space Operations Center (JSpOC) to share SSA data with established international partners. However, a high volume of erroneous conjunction notices has diminished allies' trust in U.S. capabilities (Morring, 2012).[5] The system has led to an imbalance, with the U.S. wanting to receive more data from allies than to release to them. As a result, partners are looking to alternative data sources.[6]

[5] Phone interview with former government employee in the Executive Branch. 27 Sept. 2012 and 18 Mar 2013
[6] Ibid

Intelligence and Military

Given the critical importance of space assets to American intelligence-gathering and force-projection capabilities, the domestic national security community highly values SSA as a way to protect assets from both spectrum interference and physical conjunctions. Further, it enables an understanding of rivals' satellite locations and capabilities (United States Air Force, 2012). However, the Space Surveillance Network's (SSN's) capabilities have not evolved with changing needs.[7] While it was initially designed to as a tracking tool for both U.S. and Soviet satellites, it was not designed neither to be utilized to either protect against conjunctions (and not expected to protect against RFI), nor was it designed to do so in a highly timely fashion. As the total number of objects in space has grown along with U.S. need for satellites, the system is being overextended, thus resulting in errors.[8]

The U.S. military is also struggling to fund acquisitions programs for new systems to enhance its SSA capabilities. After spending $800 million on the Space-Based Space Surveillance (SBSS) system, a satellite equipped with an optical telescope for tracking other space objects, a follow-on system to replace it has been canceled (Ferster, 2013). Additionally, the flagship SSA program, the $1.8 billion S-Band Space Fence designed to be able to track hundreds of thousands of space objects as small as a few centimeters, is facing budget uncertainty that may jeopardize its future as well (Ferster, 2013).

Commercial Satellite Operators

Commercial satellite operation is the largest segment of the global space industry, representing 38% of the sector's revenues in 2011 (Space Foundation, 2012). Most companies in

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[7] Phone interview with former USAF and current commercial representative for SSA satellite manufacturer. Mar. 15 2013

[8] Phone interview with US Defense Representative. 2 April. 2013

this field provide data relay services, with very small minority providing remote sensing. The largest of these companies operate from the United States and the European Union with a multitude of others scattered around the world. In total, they maintain nearly four hundred active satellites and draw over $100 billion a year in revenues (Space Foundation, 2012).

As such, the industry has a vested interest in protecting its collective assets (DalBello, 2011). However, until recently, there was little incentive to take action beyond relying on U.S. government SSA data. The 2007 Chinese anti-satellite test followed by the 2009 conjunction between a commercial Iridium satellite and the derelict Russian Cosmos satellite shifted the community's perception towards being far more willing to take action (DalBello, 2011). In 2009, three of the largest commercial satellite firms (Inmarsat, Intelsat, and SES) formed the Space Data Association (SDA) to not only prevent future accidents but also avoid spectrum interference from passing satellites. Since then, 11 additional satellite operators have joined the group, plus both the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA).

Members of the SDA input all relevant orbital data about their spacecraft and notify the group when they are either deploying a new satellite or changing the orbit of an existing one. The group also draws data from the JSpOC regarding space debris and unclassified government satellites.[9] However, members of the SDA are dissatisfied with this data because they have determined that it is often incorrect, by failing to receive inputs from commercial companies and also by not fully being able to predict on a timely schedule where satellites were moving. The industry's goal is be able to fully capture and understand the entire environment, so as to mitigate any future chance of accident or interference.

[9] Interview with a senior commercial satellite industry executive. 1 Oct. 2012

Commercial Launch Operators

Commercial space launch providers are responsible to the placement of satellites either into a parking orbit or into their final orbit. They may conduct launches for either governments or private companies. There are approximately nine of them in the world: Arianespace, China Long March Corporation, International Launch Services (ILS), Lockheed Martin Space Systems (LMSS), Mitsubishi Heavy Industries, Orbital Sciences, Sea Launch, SpaceX, and the United Launch Alliance (ULA). Total sector revenues were approximately $4.8 billion in 2011 (Space Foundation, 2012)

Today these companies have very limited need for SSA and often do not even perform conjunction analyses prior to launch, with the understanding that it is the satellite operator's responsibility.[10] However, launch providers do contribute to space debris by leaving rocket second stages and other assorted detritus in orbit. These orbits are tracked by the JSpOC. In the future, launch operators providing human space flight services may have a substantial interest in SSA and will likely need to be included in the international community of interest.

Civil Spaceflight

Civil spaceflight operators are represented by the domestic space agencies of various nations around the world. The largest operators of such satellites are NASA and NOAA. Their satellites provide a myriad of scientific data, with crucial weather forecasting being the most public. SSA capabilities are critical to maintaining their satellites' operational continuity as well as providing critical safety to human spaceflight. These agencies cooperate with both the JSpOC and the SDA for SSA information.

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[10] Email interview with a senior launch industry executive. 25 Mar. 2013