Space Traffic Management Regime Needs and Organizational Options

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Abstract

With the increasing risks of collisions and electromagnetic interference, some suggest that there is a need for "space traffic management" (STM) in order to sustain safe operations in the space domain. Developing such a system to manage launch, on-orbit, and reentry space activities would embody important principles of the Outer Space Treaty's Article IX – cooperation, mutual assistance, and due regard – and honor the affirmative duty to consult. Performing any form of STM, however, would be technically daunting, and resolving the security and proprietary concerns would present significant obstacles to achieving success with any proposed scheme. Nonetheless, some argue that a comprehensive STM regime should be developed. These proponents recommend that the regime address information needs, notification systems, traffic management, and an implementing organization with appropriate oversight.

Relevant STM architecture options can vary. This paper addresses the need for new mechanisms, whether governmental, intergovernmental, or private, to address space congestion, debris, and electromagnetic interference concerns. Then, it will apply common-sense criteria to determine which organizational options have the greatest merit for the global spacefaring community. Three overarching approaches to reduce collisions and electromagnetic interference, and mitigate space debris challenges, will be examined and scored, and arguments for and against each will be presented.

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I. Congested Space Poses Risks to Operations

Throughout the Space Era, the space-faring community has been challenged. Problems. Failures. Crises. Tragedies. Spaceflight is complex, risky, and unforgiving. Fortunately, the history of Space has been that when problems arise, its leaders develop policies, organizations, and systems to solve them or to work around and avoid the problems in the future. Times and circumstances continue to change. As such, policies, organizations and systems evolve to respond to them.

In this vein, it is appropriate to discuss the multiplying numbers of objects left in space orbit during the last half-century. The numbers now precipitate flight safety and mission assurance concerns; so much so that some observers argue for "space traffic management" (STM), suggesting that controls imposed by such a regime are needed to mitigate risks of on-orbit collision and electromagnetic interference and protect the domain from growing clutter. Assuming a consensus can be reached how to define, develop, and implement some form of STM, a number of questions arise: What should such a system manage and when? What are its technical obstacles? What frameworks should be considered? What are the obstacles and considerations? What should be the government role? Can risk and regulation better managed and performed by the private sector? This paper will attempt to address these issues. First, however, we must recap the driving foundations for the desire to implement STM.

Demands for STM reached a zenith following the 2009 collision between the operational Iridium 33 and defunct Cosmos 2251 spacecraft, which generated over 3,000 trackable pieces of debris published to Space-Track.org.[1] This event had followed China's 2007 kinetic-kill anti-satellite (ASAT) test directed against one of its own satellites, the Fengyun 1C weather satellite, which generated over 3,400. Hundreds of thousands of pieces of smaller, untrackable debris also resulted from these events. Some estimate that the ASAT test created "a pervasive debris cloud of more than 150,000 objects greater than 1 centimeter in size [...] [M]any of the objects in this cloud – which accounts for more than 25 percent of all cataloged objects in low earth orbit – will stay in orbit for decades, and some for more than a century."[2]

The number of operational satellites now exceeds 1,300.[3] More are placed in orbit every month. Well over 400 spacecraft are operated in geosynchronous

1 Space-Track.org is the public-facing website through which the U.S. government makes its space situational awareness data available to those who register for an account.

2 Richard H. Buenneke, Remarks, European Space Policy Institute/GWU Space Policy Institute joint workshop on "Space and Security – Transatlantic Issues and Perspectives," Washington, DC, November 17, 2009, https://www.gwu.edu/~spi/assets/docs/111709Buenneke.pdf, accessed Sept. 11, 2014.

3 As of August 31, 2015, the Union of Concerned Scientists (UCS) assessed the operating number at 1,305, with 696 in low Earth orbit, 87 in medium Earth orbit, 41 in

Earth orbit (GEO) by governmental, international, commercial, and academic institutions. This number reflects the exponentially growing demand for space-enabled information services that is best delivered by systems in that unique orbital regime. The numbers also involve a tremendous investment in resources by their owner-operators. Over the decades, spacecraft placed in GEO have grown in complexity and capacity, and with that, their size and mass. The numbers of spacecraft placed in LEO also are growing rapidly because operators have begun to choose to leverage the tremendous capabilities now offered by small satellites, including CubeSats.[4] Small-satellite systems with advanced miniaturized payloads and buses are now ready to provide a wide variety of technical, schedule, and cost advantages and satisfy a wide mix of mission requirements, and they can use a wider mix of launch vehicles to achieve orbit. Some entrepreneurs now propose to orbit massive constellations of hundreds or thousands of satellites.[5] LEO spacecraft generate additional concerns because the relative collision speeds of objects in LEO are usually many times higher for those found in GEO. Even very small objects, traveling at speeds of about 6.9 to 7.8 kilometers per second (15,430 to 17,450 miles per hour), can inflict catastrophic damage, expelling large plumes of debris that may threaten other satellites for decades to come. Moreover, when LEO objects in different orbital planes collide, the event can take place at relative speeds of many more thousands of kilometers per hour.

The predicted increasing numbers of spacecraft have exacerbated concerns about growing domain congestion, especially important as small satellites are more difficult to track and catalog by even the best existing space situational awareness systems. With large investments at stake, operators seek to manage

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elliptical orbit, and 481 in geosynchronous Earth orbit. The authors use the UCS-assessed numbers for this paper. See "UCS Satellite Database," Union of Concerned Scientists, www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html, accessed Sept. 15, 2015.

4 A CubeSat spacecraft is usually used for research and usually has a volume of exactly one liter (10 cm cube), or some multiple of that volume (e.g., 20x10x10 cm cube or 30x10x10 cm or larger). Most employ commercial off-the-shelf components for the electronics. Leonard DavId., "Cubesats: Tiny Spacecraft, Huge Payoffs," *Space.com*, Sept. 8, 2004, www.space.com/308-cubesats-tiny-spacecraft-huge-payoffs.html, accessed Sept. 6, 2014. Jason Dorrier, "Tiny CubeSat Satellites Spur Revolution In Space," June 23, 2013, Singularity Hub, http://singularityhub.com/2013/06/23/tiny-cubesat-satellites-spur-revolution-in-space/, accessed Sept. 6, 2014. "CubeSat Design Specification Rev. 13," *The CubeSat Program*, Cal Poly San Luis Obispo, Feb. 20, 2014, http://cubesat.calpoly.edu/images/developers/cds_rev13_final.pdf, accessed Sept. 9, 2015.

5 For instance, a company called OneWeb plans to orbit a 600-satellite constellation to provide worldwide Internet access. Alan Boyle, "OneWeb Wins $500 Million in Backing for Internet Satellite Network", NBC News, June 15, 2015, www.nbcnews.com/science/space/oneweb-wins-500-million-backing-internet-satellite-network-n381691, accessed Sept. 9, 2015.

risks in order to assure long and productive on-orbit life. Given this, one might expect that operators would consider favorably any governmental or private offering that efficiently assists in the performance of such tasks. Of course, this will be the case only if the "cure" does not harm the patient – i.e., the solution does not impose dramatic new costs and restrictions that outweigh their intended benefit.

II. Space Traffic Management Defined

The International Academy of Astronautics (IAA), in its seminal study, *2006 Cosmic Study on Space Traffic Management,* offered the following definition for "STM":

Space traffic management means the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference.[6]

With this definition, one could think of STM as being grouped into three basic functions: situational awareness, control mechanisms, and traffic regulation. Situational awareness includes functions and services related to locating and tracking objects and monitoring the environment. Control mechanisms include functions and services by which operations can be directed and approved in order to promote safe and expeditious activities. Traffic regulation includes functions that are authorized and/or performed by an appropriate authority to assess, approve, and grant permission for spacecraft operations, and develop processes and ensure compliance with them. These functions can be performed at launch, while on-orbit, and upon re-entry, but are still subject to technical obstacles.

III. Surmounting the Insurmountable – Traffic Management Technical Obstacles

The technical aspects of performing any comprehensive form of STM are daunting. Indeed, just operating a spacecraft to achieve mission success is not easy, complicated by physics, engineering, acquisition operational, and sustainment issues. Though space systems have advanced over the decades, management of their activities involves good doses of "rocket science." Mitigating collision risks and electromagnetic interference (EMI) issues requires operators to work smartly as they perform complex operations.

6 *Cosmic Study on Space Traffic Management*, Corinne Constant-Jorgenson, Petr Lala, Kai-Uwe Schrögl, editors, International Academy of Astronautics (Paris, France) 2006, p. 10.

III.1. Space Situational Awareness (SSA)

SSA is essential to any STM system that might be fielded. Several SSA systems are being used by space operators to forecast and identify disruptive events so that responses can be developed. However, none of these SSA systems is capable of providing comprehensive awareness of the Earth's orbital space environment, which limits the efficacy of any STM regime that hopes to ameliorate the lion's share of orbital threats. While they do not protect against all threats, the current SSA systems do provide data that warn operators of conjunction and collision threats posed by larger objects and spacecraft. Beyond the space congestion and related safety issues, SSA also helps operators to understand and resolve on-orbit anomalies. Of further importance, quality SSA data can enable operators to distinguish unintended on-orbit anomalies from hostile attacks, and natural satellite re-entries from incoming ballistic missile warheads.

The U.S. Government, its allies, and most major commercial operators rely on the "gold standard" of SSA information distributed by the U.S. Strategic Command (USSTRATCOM) through its Joint Space Operations Center (JSpOC). The JSpOC integrates data from USSTRATCOM's Space Surveillance Network (SSN), a global network of optical telescopes and radar sensors, tracking about 23,000 orbiting objects. JSpOC analysts catalog a large portion of that number.[7]

Although the SSN is the world's best at providing SSA information, its sensors are unable to consistently track any objects smaller than ten centimeters in diameter, the size of a grapefruit, in LEO. In addition, environmental events, time lags, and uncoordinated satellite movements can disrupt and confuse tracking. Also, because there are a "large number of space objects and limited numbers of sensors available to track these objects, it is impossible to maintain persistent surveillance on all objects and therefore there is inherent uncertainty

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7 Aaron Mehta, "USAF Focuses on Space Debris, Other Threats," *Defense News*, May 24, 2014, citing General William Shelton, Commander, Air Force Space Command, in a keynote address given at the Space Symposium, Colorado Springs, Colorado on May 20, 2014, www.defensenews.com/article/20140524/DEFREG/305240019/USAF-Focuses-Space-Debris-Other-Threats, accessed Sept. 27, 2014. "The DoD's SSA capabilities have shortcomings. The main drawback is in the location and distribution of the tracking sites. Many of their tracking radar locations are optimized for their original missile warning functions and are thus located on the northern borders of the United States. This means that the system's coverage is focused mainly in the Northern Hemisphere. Thus there are large gaps in the tracking coverage for LEO space objects and sometimes significant time between tracks. There are efforts underway to alleviate some of these gaps, as in the recent decisions to move a radar and an optical telescope to Australia, but most of the gaps will remain." Brian Weeden, Prepared Statement, "Space Traffic Management: Preventing Real Life 'Gravity'," U.S. House of Representatives Committee on Science, Space and Technology, May 9, 2014, http://docs.house.gov/meetings/SY/SY16/20140509/102218/HHRG-113-SY16-Wstate-WeedenB-20140509.pdf, accessed Sept. 7, 2014.

and latency in the catalog."[8] In GEO, objects must generally exceed one meter in size to be tracked, and are best tracked with optical telescopes rather than the radar systems used for lower orbits. The tracking of objects in GEO presents the biggest challenge to USSTRATCOM's orbital analysts, especially "due to the small number of available deep-space tracking sensors. A satellite that maneuvers in this orbital regime may become 'lost,' which usually requires JSpOC analysts to devote additional time and resources to find the satellite, at the expense of sensor resources devoted to the rest of the catalog."[9]

Commercial and several government operators also obtain and share SSA information as members of the Space Data Association (SDA). Founded in 2009 by the world's three largest commercial satellite operators, Intelsat, Inmarsat and SES, the SDA provides "a mechanism for its members to share data on the locations of their satellites and any plans to reposition them that avoids revealing sensitive information yet contributes to SSA and the broader goal of 'space sustainability.'"[10] SDA claims its program provides "an automated space situational awareness (SSA) system designed to reduce the risks of on-orbit collisions and radio frequency interference. It is the satellite industry's first global operator-led network for sharing high-accuracy operational data to improve overall space situational awareness and satellite operations."[11] It is important to note that the data distributed by the SDA is built on a foundation of SSA information provided by the JSpOC; it augments the JSpOC data with individual tracking data offered by its members on their spacecraft. Since such information is continually updated, it tends to be very accurate and precise as to the systems its members operate. The SDA's contractor, Analytic Graphics, Inc. (AGI), ingests and processes operator-supplied orbital data; performs conjunction assessments; and generates automated warning alerts. It also supports avoidance maneuver planning, radiofrequency interference (RFI)

8 Abbot I. Abbot and Timothy P. Wallace, "Decision Support in Space Situational Awareness," *Lincoln Laboratory Journal*, Volume 16, Number 2, 2007, pp. 297-335, 297.

9 *Ibid.,* 298.

10 Marcia Smith, "Space Data Association and USSTRATCOM Reach Data Sharing Agreement," *Space Policy Online*, Aug. 11, 2014, www.spacepolicyonline.com/news/space-data-association-and-usstratcom-reach-data-sharing-agreement, accessed Sept. 6, 2014. On August 8, 2014, SDA announced in a press release that it had reached a data sharing agreement with USSTRATCOM, to enhance space situational awareness and provide a framework to exchange data, under the DoD SSA Data Sharing Program. According to SDA, it is the first non-satellite operator to sign an agreement with USSTRATCOM. See also "Satellite Data Association: SDA and US Department of Defense Sign Space Situational Awareness Agreement," *Business Wire*, Aug. 8, 2014, www.businesswire.com/news/home/20140808005645/en/Space-Data-Association-SDA-U.S.-Department-Defense#.VAwHcNLwvTt, accessed Sept. 6, 2014.

11 "The Space Data Association…How Close is Close (Analysis)," *Satnews Daily*, Jan. 24, 2011, www.satnews.com/cgi-bin/story.cgi?number=1681696938, accessed Sept. 11, 2011.

mitigation, and data sharing.[12] Despite the enhancements, comprehensive tracking and cataloging is still not provided for any but a tiny subset of the total numbers of operational satellites and man-made debris existing in Earth orbit.

More recently, an innovative private solution has been proposed to satisfy space operator SSA needs. On March 13, 2014, AGI announced the establishment of a Commercial Space Operations Center (ComSpOC™).[13] It claims the ComSpOC will offer subscribers fused satellite-tracking measurements from a growing globally-distributed network of commercial optical, radio frequency, radar and space-based sensors, which presently include 28 optical sites and one radar. AGI says it also has implemented closed-loop tracking with its sites; successfully tracked a recent space launch; and has the capacity to provide persistent tracking and characterization of space objects larger than five centimeters.[14] AGI claims to offer enhanced accuracy and readiness to satellite operators and intelligence analysts. This includes information on high-definition ephemeris, near-real-time maneuver detection, characterization of its entire space object catalog and of all non-cooperative maneuvers performed, satellite proximity monitoring, RFI characterization and geolocation, along with other services.[15] AGI's ComSpOC website brags that it now tracks over 5,000 space objects, 75% of active GEO satellites, and 100% of all active GEO satellites with communication and sensor footprints over the continental U.S. It claims to have verified an ability to do near real-time maneuver characterization and maintain continuous custody (tracking) of actively broadcasting GEO spacecraft. AGI also offers a "SpaceBook ®" as part of its service, providing data such as status, orbit mission and owner information of all tracked objects. In the future, AGI says this will serve as a subscription-based portal for ComSpOC data such as health, status, event and trending information of all tracked objects.[16] It remains to be seen how commercially viable the ComSpOC initiative will be, and whether it provides qualitative advantages over services provided by the JSpOC and SDA.

Many non-U.S. countries and commercial entities also perform SSA activities, notably the European Space Agency and France, Russia, China, India, Japan, and South Korea. The European Space Agency (ESA) is developing its own

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12 "Space Data Association Selects Analytic Graphics, Inc., to Design and Operate Its Space Data Center," *SDA News*, Apr. 12, 2010, www.space-data.org/sda/, accessed Jul. 18, 2010. See also Richard DalBello and Michael Mendelson, Keynote Address to *Space Law and Policy 2010*, Washington, DC, May 11, 2010.

13 "AGI's ComSpOC Takes the Guess Work Out of Ducking Speeding Space Objects," *Satnews Daily*, March 13, 2014, www.satnews.com/story.php?number=1111081326, accessed Jan. 12, 2015.

14 ComSpOC Commercial Space Operations Center, "Our Mission," http://comspoc.com/about/#ourMission, accessed Jan. 12, 2015.

15 Ibid.

16 Ibid.

SSA capacity under the European SSA Programme.[17] The Russians have initiated a separate SSA observation program, the International Scientific Optical Network (ISON). The Russians describes this effort as a "scientific project"[18] and it was initiated by the Keldysh Institute of Applied Mathematics and the Pulkovo Astronomical Observatory of the Russian Academy of Sciences.[19] The project now involves cooperation among disparate entities in Great Britain, ESA and Switzerland. It obtains data from a network of 25 optical telescopes located at 18 facilities in nine nations around the world.[20] China, Turkey, and their several partners in the Asia Pacific Space Cooperation Organization (APSCO)[21] have agreed to generate and share data through the Asia Pacific Optical Space Observation System (APOSOS).[22] India and the U.S. are beginning to coordinate together on data sharing and other space security matters.[23] In 2001, the Japanese fielded two telescopes at the Bisei Space Guard Center, which can track one-meter objects at GEO; in 2004, Japan fielded a mechanical phased-array radar at the Kamisaibara Space Guard Center, which can track one-meter objects in LEO at a 600 km range. Their optical and radar observations are integrated at the Japan Aerospace Exploration Agency's (JAXA) Tsukuba Space Center Tracking and Control Center. The Japanese have executed an agreement with USSTRATCOM to share this data with the JSpOC, and by "around the early 2020s" says that it hopes to construct SSA-related facilities and an operational framework to support its SSA needs, based on the Japan-U.S. partnership.[24] South Korea is developing its own SSA network. It calls this system of six geographically distributed

17 "ESA – ESA Spacecraft Operations – SSA Preparatory Programme." European Space Agency, 5 December 2008.

18 "ISON: International Scientific Optical Network – FAQ," http://isonteam.com/faq/, accessed 18 Jul. 2010.

19 Ibid.

20 Brian Weeden, Suzanne T. Metlay, and Ray A. Williamson. "Space Weather and International Civil Space Situational Awareness." PowerPoint briefing presented to NOAA Space Weather Week, 28 Apr. 2009.

21 See Convention of the Asia Pacific Space Cooperation Organization (APSCO), Bangl.-P.R.C.-Indon.-Iran-Mong.-Pak.-Peru-Thail.-Turk., Oct. 28, 2005, 2423 U.N.T.S. 43736 (entered into force Dec. 10, 2006).

22 Guo Xiaozhong, Nat'l Astronomical Observatories, Chinese Academy of Sciences, *Asia-Pacific ground-base* [sic] *Optical Satellite Observation System* (Oct. 2011), *available at* http://swfound.org/media/50867/Guo_APOSOS.pdf; See *also* Shen Ming, *Progress on APOSOS* (Nov. 8, 2012), *available at* http://swfound.org/media/95032/Shen-Progress_APOSOS-Nov2012.pdf.

23 U.S. Dep't of State, Joint Statement on the Fifth India-U.S. Strategic Dialogue (Jul. 31, 2014), *available at* www.state.gov/r/pa/prs/ps/2014/07/230046.htm.

24 Nobuhiro SAKAMOTO, "Overview of Space Situational Awareness in Japan, Office of National Space Policy, Japan, Feb. 26, 2015, www.jsforum.or.jp/debrisympo/2015/pdf/11%20150226_Sakamoto_rev.pdf, accessed Sept. 14, 2015.

telescopes the "Optical Wide-field patroL" (otherwise known as OWL), and plans to use it to monitor Korean satellites and space debris.[25]

Despite the progress and best efforts made in fielding SSA systems, USSTRATCOM, SDA, ComSpOC, the Russians, Chinese, and other entities cannot know where all orbiting spacecraft and debris are at all times. They are only tracking the larger objects. Hundreds of millions of man-made objects and debris also are found in Earth orbit – estimated to include up to 330,000,000 objects of one millimeter to one centimeter in size and, more importantly, the 560,000 objects in the one-to-ten-centimeter range, sizes that easily can destroy or catastrophically damage satellites.[26] The numbers of man-made objects thought to exist in Earth orbit dwarf the relatively small number of approximately 1,300 operational spacecraft found in Earth orbit.

Given the risks posed by smaller objects, and concerns about threats that might be posed by adversaries, the U.S. Air Force is shoring up USSTRATCOM's tracking capacities. Its Space Based Space Surveillance (SBSS) Satellite was launched into orbit in September 2010, and the Geosynchronous SSA Program (GSSAP) system was launched in late-July 2014. The two-satellite GSSAP constellation will operate with electro-optical sensors in a near-geosynchronous orbit to provide tracking and characterization of objects resident in GEO.[27] These two space-based sensor systems are expected to add many more objects to the USSTRATCOM space object catalog. In addition,

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25 Jang-Hyun Park et al., *Korean Space Situational Awareness Program: OWL Network* (paper presented at AMOS Technologies Conference, Sept. 11-14, 2012), *available at* www.amostech.com/TechnicalPapers/2012/POSTER/PARK.pdf.

26 The numbers are from 2006, citing Dr. Heiner Klinkrad, European Space Agency Space Debris Office and one should expect the numbers to be much larger today. Union of Concerned Scientists, "What's in Space?", *Ensuring Space Security: Fact Sheet No. 2*, www.ucsusa.org/assets/documents/nwgs/satellites.pdf, accessed Sept. 18, 2014, citing H. Klinkrad, *Space debris: Models and risk analysis* (2006) Berlin: Springer Praxis, 96. According to the NASA Orbital Debris Program Office in 2013, radar data indicates that the number of pieces of space debris at the 1-centimeter level is approximately 500,000. At the 1-millimeter level, the population is estimated to be on the order of hundreds of millions. J.-C. Liou, "Engineering and Technology Challenges for Active Debris Removal," Progress in Propulsion Physics 4 (2013) 735-748, p. 737, www.eucass-proceedings.eu/articles/eucass/pdf/2013/01/eucass4p735.pdf, accessed Sept. 18, 2014.

27 Mike Gruss, "Military Space Quarterly – Shelton Discloses Previously Classified Surveillance Satellite Effort," *Space News*, Feb. 21, 2014, http://spacenews.com/article/military-space/39578military-space-quarterly-shelton-discloses-previously-classified, accessed Sept. 18, 2014; Aaron Mehta, "USAF to launch a previously classified satellite system this year," *Air Force Times*, Feb. 21, 2014, www.airforcetimes.com/article/20140221/NEWS04/302210013/USAF-launch-previously-classified-satellite-system-year, accessed Sept. 18, 2014; "Delta IV finally launches with semi-secret GSSAP Satellites & ANGELS NanoSat," *Spaceflight 101*, Jul. 28, 2014, www.spaceflight101.com/delta-iv---gssap-launch-updates.html, accessed Sept. 18, 2014.

USSTRATCOM will use the enhanced computing capabilities offered by a new JSpOC Mission System (JMS) to handle greatly expanded analytic tasks which numbers will increase dramatically when the new "Space Fence" radar tracking system is fielded. This acquisition, awarded to Lockheed Martin, will replace the Air Force Space Surveillance System (AFSSS).[28] The AFSSS operated from 1961 until September 1, 2013, and eventually tracked up to 20,000 objects. The new Space Fence will use three ground radars "operating in the S band, which has shorter, more accurate frequencies than AFSSS used" and is expected to expand the total number of trackable objects to well over 100,000.[29] With 23,000 trackable objects detected on-orbit, the JSpOC presently produces about 1,400 conjunction summary messages[30] and issues about 30 conjunction warnings to operators for their maneuverable spacecraft on a daily basis.[31] One can expect the conjunction numbers to dramatically increase as the number of tracked objects grows over 100,000.

The dramatically expanded numbers of tracked objects found by the new Space Fence will exacerbate analytical challenges for all users of USSTRATCOM's SSA data. Further, and perhaps important, some fear the increased numbers could pose a conundrum for operators – *analysis paralysis*, the state of over-analyzing (or over-thinking). With *analysis paralysis*, a decision-maker is overwhelmed by too much information, and too many options – so many that he or she cannot make a reasoned decision. The decision-maker concludes that an optimal or "perfect" solution cannot be found, and fears making any decision that could lead to erroneous results. This, in effect, paralyzes the operator and its management team. Unless decision-making tools can effectively account for the increased numbers, there is a danger that analysis paralysis will confound and overwhelm space operators, so much

28 The AFSSS was originally known as the U.S. Navy Space Surveillance Systems and was called the "Space Fence." Its command passed to the Air Force's 20th Space Control Squadron on Oct. 1, 2004.

29 Kevin McCaney, "Air Force awards deal for Space Fence to track orbital debris," *Defense Systems*, June 3, 2014, http://defensesystems.com/articles/2014/06/03/air-force-space-fence-lockheed.aspx, accessed Sept. 7, 2014.

30 Lieutenant General John W. Raymond, Commander, Joint Functional Component Command for Space, Prepared Statement, House Committee on Science, Space and Technology on Space Track Management, May 9, 2014, p. 4, http://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-113-SY16-WState-JRaymond-20140509.pdf, accessed Sept. 7, 2014. "The JSpOC actively tracks all objects of "softball size" (10 centimeters) or larger on orbit, using the U.S. Space Surveillance Network as its primary detection suite of sensors, …mitigating the danger of these systems colliding with the more than 23,000 trackable objects orbiting in space." Maj. Larry van der Oord, "614th Air and Space Operations Center welcomes new commander," *Inside Vandenberg*, posted June 9, 2014, and updated June 12, 2014, www.vandenberg.af.mil/news/story.asp?id=123413786, accessed Sept. 27, 2014.

31 Liou, *supra* note 26, p. 735.

that they are unable to perform and act on any cost-benefit analysis of the risk against a decision to maneuver.[32] To achieve some modicum of success, any chosen STM system will need to incorporate tools and procedures that mitigate the effects of these analytical challenges.

III.2. Control Mechanisms

Protecting satellites from on-orbit collisions depends on interplay between two separate activities: conjunction assessment and collision avoidance. In order to responsibly operate space systems, operators must act to minimize identified risks. They must perform operations supported by competent SSA capabilities. Conjunction assessment, an SSA function, involves determining the close approaches between two objects, assessing the probability of collision, and providing warning to spacecraft owner-operators. Collision avoidance involves performing a cost-benefit analysis of the risk posed by approach and deciding whether or not to perform a maneuver to decrease the risk to an acceptable level. The process of making a decision responsive to the risks, directing and implementing changes, and then monitoring internal and external feedback mechanisms, describes a control mechanism.

International capacities to perform precise conjunction assessments among known objects continue to increase, and the numbers catalogued will increase once the new Space Fence is fielded. Though there is risk of analysis paralysis, thus far the increased capacity and operator coordination has enhanced the ability of operators to take steps to reduce risks of on-orbit collisions, at least among the spacecraft that operators have the ability to control and maneuver. The increased capacity has spurred operators to push forward to improve their own best practices so as to avoid collisions. The largest spacefaring States and commercial operators believe that they can benefit tremendously by orchestrating coordinated solutions to reduce chances of collision among satellites and with on-orbit debris. For example, the 2010 United States (U.S.) National Space Policy confirms U.S. policymakers' interests in confronting debris issues and improving environmental and operational stability of the domain via international cooperation.[33] To this end, the U.S. State Department has spent several years on the World's Stage suggesting it may be time for a non-binding "Code of Conduct" for space operators, to be used as a means of encouraging greater international best practices in the domain.

As another example of international coordination, the Inter-Agency Space Debris Coordination Committee (IADC), a United Nations (UN) advisory

32 Comparing the relatively miniscule numbers of operational maneuverable satellites to the vast numbers of untracked, non-maneuverable objects believed to be on-orbit, or at least those that pose a collision risk and attendant risk of damage to the operational systems, also gives a bit of a lie to any thought that a fully comprehensive *space traffic management* regime can be achieved.

33 National Space Policy of the United States of America, June 29, 2010.

body composed of representatives of national space agencies, facilitates information exchange on space debris research, mitigation options, and developing best practices. Participating States consider the IADC's recommendations as "voluntary" but have used them when developing their own domestic standards, regulations, and laws relating to debris mitigation.[34]
In addition to the IADC activities, the International Organization for Standardization (ISO), a non-governmental federation of national standards bodies, established an Orbital Debris Coordination Working Group in 2003. The ISO working group has initiated several standards projects addressing space debris mitigation, disposal of satellites operating at geosynchronous altitude, and prevention of the break-up of unmanned spacecraft.[35]
The measures and procedures encouraged by the IADC and ISO initiatives have helped slow the growth in orbital congestion. Unfortunately, "these procedures have not been adequate to prevent growth in the debris population from random collisions [...] A more focused collision avoidance capability may help, but without adherence to current guidelines and an active debris removal program, future spacecraft operators will face an increasing orbital debris population that will increasingly limit spacecraft lifetimes."[36] The technical and operational challenges to mitigate debris issues are formidable. Post-mission disposal (PMD) rates have not matched hoped-for results. "Today, based on early data analysis, it is estimated [that] around 10% of the spacecraft and rocket bodies reaching their end of life between 600-1400 km performed a re/deorbitation manoeuvre (cit. om.)."[37] This rate has implications. The long-term trend of the numbers of objects left in orbit changes depending on the PMD compliance rate. "For a PMD compliance of 90%, the population remains more or less constant over the 200 years; for a PMD compliance of 60%, the effective number of objects in the population evolves with a slight exponential trend; while for a PMD compliance of 30%,

34 For example, the French Space Operations Act (FSOA), described as "uniquely French contribution to global space jurisprudence," is being used to implement IADC and ISO recommended guidelines. ESA says it will comply with the FSOA, even though it claims it has no legal obligation to do so. Peter B. de Selding, "French Debris-mitigation Law Could Pose Issue for Arianespace" (Apr. 10, 2014) http://spacenews.com/40171french-debris-mitigation-law-could-pose-issue-for-arianespace/ (accessed Sept. 23, 2015).
35 S. Tranchard, "ISO standards for a safer, cleaner space," ISO, Oct. 9, 2013, www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1784.
36 D. Kessler, N. Johnson, J.-C. Liou, and M. Matney, "The Kessler Syndrome: Implications to Future Space Operations," 33d Annual AAS Guidance and Control Conference, Breckenridge, Colorado, February 2010, AAS 10-016, http://webpages.charter.net/dkessler/files/Kessler%20Syndrome-AAS%20Paper.pdf.
37 J.C. Dolado-Perez, B. Revelin, and R. Di-Costanzo, "Sensitivity Analysis of the Long Term Evolution of the Space Debris Population in LEO," 65th International Astronautical Congress, Toronto, Canada, October 2014.

the number of objects in the population clearly evolves in an exponential manner."[38]

Compounding the slow progress on PMD rates, theoretical space traffic management control mechanisms are confounded by the physics of operating, directing, and monitoring the activities of systems on-orbit. Operator-to-spacecraft communications essential to the control can be hindered or disrupted by often-unexpected natural or man-made events. Television and movie depictions notwithstanding, speed-of-light physical realities deny ground-based operators any type of instantaneous control of spacecraft, or the detection or analysis of on-orbit issues. The distances involved in the satellite operator's communications chain, ranging from about 500 to 35,000 kilometers once operational orbits are achieved, limit the immediacy of data transfer between sender and receiver, different systems, and even among components within the spacecraft or in supporting ground systems. There are time lags associated with sensing, observing and analyzing events; orienting systems to ascertain the dangers and potential for damage; determining a course of action and deciding to act; and then responding to the threat and communicating with and controlling a satellite to avoid it. And, as we have discussed, oftentimes there are not enough sensors to fully monitor relevant on-orbit events. This accentuates time lag challenges.

Another vexing control issue confronting satellite operators is that even if they know precisely where all the threatening objects are and their ephemerides (and as we have discussed, they cannot), they may not have sufficient time, propellant or maneuvering capability to direct spacecraft maneuvers to avoid them. The issue is exacerbated in LEO because many spacecraft placed in that orbit are essentially non-maneuverable, including all or nearly all CubeSats that are being orbited. If a spacecraft can perform a collision avoidance maneuver, however, its operators must push their predictive analysis to a maximum, and "thread the needle" among known threats as they select maneuver options among a variety of possible collision and near-collision scenarios. Operators also must be prepared for scenarios involving two live, maneuverable satellites where both satellites can perform maneuvers to avoid a threatened collision. Unless these maneuvers are coordinated, they could end up increasing the risks of collision, making the situation worse. Such scenarios are described as "non-cooperative satellite monitoring," situations in which operators act unilaterally, intentionally or unintentionally, without information on the spacecraft station-keeping and maneuver plans of other systems.[39] This is a longstanding issue, well known to operators.

In addition to the time-lag issues discussed above, attempts to implement control mechanisms as part of any comprehensive STM scheme also are

38 Ibid.

39 Abbot et al, "Decision Support…," *supra* note 8.

confounded by conflicting operator mission interests. Operators want to maximize mission life, but commanding a spacecraft to perform a collision avoidance maneuver could reduce mission life. Changing a satellite's orbital plane, or increasing or decreasing orbital periods, to reduce collision risks could exhaust much-needed propellant valued for other long-term operations to include attitude control, station-keeping, and operations. For these reasons, even when operators are apprised of a collision risk, they may choose to accept that risk. There are no mechanisms to compel the operator to perform a satellite movement.

III.3. Traffic Regulation and Enforcement

At first blush, any State agreeing that its space activities should be regulated by any STM system would appear to be acting consistent with the obligations imposed by the Outer Space Treaty.[40] Under Article VI, States bear international *responsibility* for their activities in outer space, whether conducted by governmental agencies or private citizens.[41] Parties must authorize and continuously supervise all space activities undertaken by their citizens.[42] Article IX of the

40 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, T.I.A.S. No. 6347, 610 U.N.T.S. 205.

41 Article VI reads:
"States Parties to the Treaty shall bear international responsibility for national activities in outer space, including the Moon and other celestial bodies, whether such activities are carried on by governmental agencies or by non-governmental entities, and for assuring that national activities are carried out in conformity with the provisions set forth in the present Treaty. The activities of non-governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty. When activities are carried on in outer space, including the Moon and other celestial bodies, by an international organization, responsibility for compliance with this Treaty shall be borne both by the international organization and by the States Parties to the Treaty participating in such organization."

42 According to Rand Simberg: "Some parties to the treaty, particularly the Soviet Union, wanted space activities to be the sole preserve of governments. But negotiators from the United States managed to achieve a compromise in Article VI of the treaty that, as [Vladimir] Kopal writes, "paved the way for the private sector to conduct space activities side by side with States and international intergovernmental organizations"… By permitting non-governmental activities in space, albeit under government supervision, this section of the treaty allowed for the creation of the commercial telecommunications, remote-sensing, and spacecraft launching industries, which were then in their infancy and today are thriving…At the time the treaty was negotiated, the issues of economic development in space seemed remote, and so diplomats set them aside as potential obstacles to finding agreement on what they saw as more pressing issues." Rand Simberg, "Property Rights in Space," *The New Atlantis*, Number 37, Fall 2012, pp. 20-31, www.thenewatlantis.com/publications /property-rights-in-space, accessed Sept. 23, 2014.

Outer Space Treaty also sets out important guiding principles for activities conducted by space-faring nations, to include cooperation, mutual assistance, and due regard.[43] In addition, Article IX also binds signatory States to undertake "appropriate international consultations" before proceeding with any "activity or experiment planned by it or its nationals in outer space" that the State "has reason to believe [...] would cause potentially harmful interference." Article IX further provides signatory States with a right to request consultation concerning "an activity or experiment planned by another State in outer space" for which the State requesting consultation has a "reason to believe [the planned activity or experiment] [...] would cause potentially harmful interference with activities in the peaceful exploration and use of outer space [...]."
Article IX does not specify the nature of the procedures or even the interested additional parties needed to conduct appropriate international consultations. One might expect, however, that a State is obligated by the Treaty to contact the States or parties whose outer space activities would experience or cause potentially harmful interference. Logically, the obligation requires these States or parties be provided with information sufficient to take appropriate action to prevent the potentially harmful interference, or mitigate its effects. Thus, the procedure and substantive nature of "appropriate international consultations" depend on the nature of the planned activity or experiment.[44]
With risks of collision and electromagnetic interference increasing, operators have pressured each other to operate systems more responsibly. With nearly 60 years of experience, generational technological improvements, and evolved operator best practices, the confluence of the Article IX principles of cooperation, mutual assistance, and due regard, and the consultation obligation, appear to require that spacefaring States:

- Access SSA capabilities to determine if their actions might create "potentially harmful interference." This, in turn, would require each to obtain and use SSA capabilities to prevent the interference.
- Share SSA data with other spacefaring states if there is a reason to believe potential harm would result from not sharing.
- Perform cooperative monitoring of space activities.

43 Outer Space Treaty, Article IX states, in pertinent part, that States Parties: …shall be guided by the principle of *cooperation* and *mutual assistance*, and shall conduct all their activities in outer space, including the Moon and celestial bodies, with *due regard* to the corresponding interests of all other States Parties to the Treaty. (Emphasis added).

44 Michael C. Mineiro, "Principles of Peaceful Purpose and the Obligation to Undertake Appropriate International Consultations in Accordance with Article IX of the Outer Space Treaty," 5th Eilene Galloway Symposium on Critical Issues in Space Law, Washington, DC, Dec. 2, 2010, p. 2.

- Act to reduce debris generation and mitigate risks posed by their space objects.[45]

These practices would appear to comprise important, foundational prerequisites for regulating traffic in an international STM scheme. Nonetheless, the rules that would be necessary for a truly comprehensive STM regime are far from complete. As noted by the IAA, current international space law rules do not fully address a number of important issues, and they should be considered and accounted for before the international community attempts to develop any management system:

- The Registration Convention does not require pre-launch notification but only requires registration following the launching. Provisions for pre-launch notifications only exist on a multilateral basis in the non-legally binding Hague Code of Conduct against Ballistic Missile Proliferation (HCOC).
- There is no prioritization of certain space activities, no "right-of-way-rules," nor is any kind of utilization of space ruled out (except when it is against the peaceful uses).
- There is no prioritization of maneuvers, no traffic separation ("one-way-traffic").
- There are no "zoning" rules (restriction of certain activities in certain areas).
- There are no communication rules (advance notification and communication if orbits of other operators are passed).
- There is no legal distinction made between valuable active spacecraft and valueless space debris.
- There are no legally binding rules requiring the mitigation of space debris and the disposal of spent space objects, or preventing of pollution of the atmosphere or troposphere.
- Space law lacks enforcement mechanisms. There are no "police" in outer space, nor is there an elaborate dispute settlement system, although the Liability Convention includes a system for settlement of claims.
- Private space activities in some cases may escape (i.e., not be subject to) space law, which is still State-centered.
- The legal delimitation between air space and outer space is missing.[46]

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45 See generally, James D. Rendleman and Sarah M. Mountin, "Evolving spacecraft operator duty of care," *Space Safety is No Accident*, T. Sgobba, I. Rongier (eds.), Springer International Publishing: Switzerland (2015), pp. 389-404.

46 *Cosmic Study*, *supra* note 6, p. 10. The authors do not subscribe to all these observations, however. For instance, they do not believe that a spatial delimitation between air and space is necessary. Rather, they subscribe to a functionalist view of space activities.

Any STM regime should respond to these shortcomings of international space law. In addition, and perhaps more intractable, any STM system developed must respond to national security concerns of spacefaring States. These States want to protect attributes, vulnerabilities, and maneuver capabilities of their national security satellites. Similarly, commercial proprietary and economic interests may need to be protected. Protection of systems against physical and information security risks must be balanced against the operational, safety and stability benefits achieved through STM. Identifying the most important information to protect can establish the groundwork for what kind of data can and should be exchanged. Information assurance concerns relating to the exchange of data to other networks and databases, including one ostensibly established to securely inject information in support of STM functions, would also be a high-interest item, as participants in such a database would want to reduce the risk of loss to a determined hacker, or prevent it altogether.

This balancing act is taking place with USSTRATCOM's SSA Sharing Program, where data sharing and services have been allowed by U.S. law and national policy, consistent with military operational constraints and needs. To date, USSTRATCOM has entered into SSA sharing agreements with 49 commercial firms, two intergovernmental organizations, and nine countries.[47] The USSTRATCOM SSA Sharing Program efforts have been extraordinary in reaching out to the international spacefaring community, while protecting U.S. national security interests and the interests of partner governments and commercial entities.

A similar balancing has taken place among commercial operators, who desire to limit exchanges of information that could give competitors insight into sensitive proprietary information relating to the capabilities, health, and life of their satellites and overall program. The SDA provides an inspired solution to the sharing challenge, employing a third-party sharing mechanism to protect the data and coordinate maneuvers and RFI mitigation.

Of course, unreasonable controls can impose costs greater than the value of the information they seek to protect, without meaningfully enhancing the security of that information. For example, many satellite systems' attributes, vulnerabilities, and capabilities can be determined by a knowledgeable or informed adversary, or by an informed third party. The combination of relatively low prices for telescopes and tracking software, along with the growing amounts of data globally available, make tracking medium-to-large satellites more feasible for an increasingly large number of observers. That has, in part, inspired AGI's ComSpOC initiative. Some suggest that even sensitive national security satellites may no longer be able to rely upon the vast distance and

47 USSTRATCOM Public Affairs, "U.S. Strategic Command signs space data-sharing agreement with Israel," Aug. 12, 2015, https://www.stratcom.mil/news/2015/570/US_Strategic_Command_signs_space_data-sharing_agreement_with_Israel/, last viewed Sept. 11, 2015.

darkness of outer space to "hide" there in the open.[48] According to this argument, sharing more data, less constrained by today's strict security or economic controls, may help achieve more vital STM objectives, that is, to achieve effective collision avoidance among all active satellites, mitigate EMI and RFI, and improve planning and coordination among operators. The proponents also suggest that releases might serve as transparency and confidence-building measures that could in turn lead to enhanced stability among adversaries.

Ultimately, to achieve success, those cooperating must find utility arising out of their efforts. Any STM framework selected must be politically realistic – that is, it must be a framework likely to be adopted by major spacefaring States and operators. The interest to assure safe operations is tipping the balance toward sharing more data, but only in accord with carefully scripted rules or regulations to constrain releases of only the most sensitive data. Providing more complete information on national security systems may be carefully considered by policy makers, and perhaps encouraged, as part of SSA sharing activities and any chosen STM scheme. Commercial operators are already performing similar assessments, as many do via SSA sharing agreements with USSTRATCOM or within the Space Data Association. Determining what and how much data should and can be shared will require examination and balancing of the costs associated with protecting and securing facts, databases, and operations.

IV. EMI and RFI Risk Management Regime Is Functioning, Albeit Imperfectly

SSA tools and spacecraft control functions have matured to control the EMI and RFI problems that have plagued operators for several generations. The International Telecommunication Union (ITU) plays an important role in supporting these activities and helps to prevent and resolve these issues, and will continue to do so in any future STM scheme.[49] The ITU has developed an extensive body of regulation of the electromagnetic spectrum, including rules concerning satellite stations' use of that spectrum – and, for GEO satellites, their longitudinal "slot" within the GEO belt. Member States domestically implement the ITU rules and this helps to minimize harmful interference

48 See Brian Weeden, "Going Blind: Why America is on the Verge of Losing its Situational Awareness in Space and What Can be Done About It," Secure World Foundation, Sept. 10, 2012, pp. 38-40.

49 The ITU counts as its members the 193 United Nations Member States, along with over 700 non-governmental members in the communications industry. The ITU's governing documents, i.e., its Constitution, Convention, and Radio Regulations, are international treaties binding on all Member States.

by their telecommunications operators.[50] The ITU even has procedures for resolving disputes over allegations of harmful interference, although it does not have the power to enforce them against a recalcitrant Member State.[51]

To complement the ITU's EMI/RFI prevention and resolution processes, the SDA also offers its members RFI resolution services. According to its brochure for prospective members, "The SDA provides tools for its members to: share information and seek assistance in investigating RFI events; automatically generate data to more quickly configure geolocation systems and perform interference source analysis; and search historical data for RFI event information."[52] When members sign up for RFI resolution services and enter in transponder data for their spacecraft, SDA boasts that its tools will "perform automatic comparison with other satellites for distribution of RFI Alert notifications and recommendation of geolocation solution sets."[53] Assistance resolving EMI and RFI is among the services the JSpOC provides to USSTRATCOM's SSA sharing agreement partners, including SDA itself.[54]

Despite the progress and ITU Radio Regulations that provide for a form of control mechanisms, satellites in the GEO belt still suffer from significant inadvertent EMI and RFI, and some intermittent intentional jamming. These phenomena have been the bane of the spacecraft operator's existence for many years. For example, Intelsat's Galaxy 15 satellite, nicknamed "Zombie-Sat,"[55] suffered a glitch, was temporarily disabled, and began to drift; all the while, its receiver and transmitter equipment continued to function. As the Galaxy 15 drifted, there was a concern that its continuing receive and rebroadcast capability could precipitate multi-path interference for nearby satellites. As a result, IntelSat coordinated Galaxy 15's movement with other space system operators to mitigate risks posed and until it regained control. Looking ahead, operators of GEO communications satellites have expressed concerns that OneWeb's plans to launch a new LEO constellation of 700 satellites could inflict significant EMI on their existing satellite stations.[56] These

50 In the United States, for example, this responsibility falls primarily on the Federal Communications Commission (FCC).

51 See, e.g., Peter de Selding, *France Seeks ITU Help To Halt Satellite Signal Jamming by Iran*, SpaceNews, Jan. 8, 2010, *at* www.spacenews.com/article/france-seeks-itu-help-halt-satellite-signal-jamming-iran.

52 SDA, "Space Data Association, Prospective Member Briefing" 2 (Jul. 18, 2013), *at* www.space-data.org/sda/wp-content/uploads/downloads/2013/08/SDA-Prospective-Member-Briefing-18Jul2013.pdf (accessed Sept. 22, 2015).

53 *Ibid.* at 7.

54 "Satellite Data Association [...].," *Business Wire, supra* note 10.

55 See, for example, Ben Schott, "Zombie-Sat," Shott's Vocab: A Miscellany of Modern Words & Phrases, *New York Times*, June 1, 2010, http://schott.blogs.nytimes.com/2010/06/01/zombie-sat/, accessed Sept. 18, 2014.

56 Peter B. de Selding, "OneWeb Fails (At Least for Now) To Soothe Satellite Interference Fears," Space News (Sept. 18, 2015), accessed Sept. 22, 2015.

incidents and concerns about future satellite constellation architectures demonstrate that sophisticated coordination and rigorous operator discipline are vitally important to mitigate interference problems and should be requisite attributes of any contemplated STM framework.

V. Evaluating Frameworks to Perform Space Traffic Management

There are no uniform standards for what should be included as part of STM, or more importantly, how it should be executed.[57] The frameworks can vary, and each will have their own advantages, disadvantages and chances of adoption. Space operator interests in avoiding spacecraft collisions and reducing EMI and RFI are compelling, but those interests must be balanced against the likelihood that programs can be adopted, and national security interests protected.

There are a number of architecture combinations available for organizing global STM capabilities to make available the information necessary to support satellite collision avoidance operations and preserve successful access to the space domain. The architecture combinations considered must involve the confluence of U.S. and other countries' national security, commercial, and civil SSA systems, leveraging the potential benefits of each. Of course, USSTRATCOM provides the most comprehensive SSA capabilities to global space operators. Integrating its capabilities may be desired in most circumstances. Accordingly, this paper addresses the following three options to integrating and improving these capabilities:

1. Evolve the status quo, employing the current DoD SSA Sharing Program as a foundation for STM.
2. STM intergovernmental organization.
3. Commercial operators provide their own STM.

The options each have their own advantages, disadvantages and chances of adoption. The assignment and evaluation of technical and non-technical criteria is always valuable in evaluating any solution. Accordingly, essential criteria for evaluating future STM improvement options have been identified: (1) How well does the proposed option manage risks to space operations?

57 Professor Paul Stephen Dempsey and Dr. Michael Mineiro suggest that there are four possible alternative actions the international community could take to address this issue: (1) maintenance of the status quo (the "do nothing" alternative); (2) uniform regulation on a case-by-case basis through bilateral or regional agreement; (3) establishment of a new international organization with jurisdiction over these issues; or (4) the exercise by the International Civil Aviation Organization (ICAO, a specialized agency of the United Nations charged with coordinating and regulating international air travel or a comparable alternative international organization currently in existence of authority to standardize orbital traffic management. Paul Stephen Dempsey & Michael C. Mineiro, "Space Traffic Management: A Vacuum in Need of Law," International Institute of Space Law Colloquium, Glasgow, 2008, IAC-08-E3.2.3, p. 3.

(2) How efficient is the proposed option? (3) How well does the option accommodate proprietary and security concerns?
We will now grade each STM option using the above criteria with a score on a scale from negative one to positive three:

- No improvement (0)
- Some improvement (+1)
- Good improvement (+2)
- This is the answer! (+3)

Option 1: Evolve the status quo, employing the current DoD SSA Sharing Program as foundation for STM.

As noted, the current DoD SSA program publishes historical and current satellite data to Space-Track.org. It also provides decay and re-entry data and has a support request procedure, all at no cost. To obtain collision avoidance services a satellite operator/owner must execute a written agreement with USSTRATCOM. The system currently provides notification of close approaches three days in advance through direct emails to the operators.
Users such as Intelsat and AGI have complained about shortfalls in this system, however. These include concerns that the program provides less than optimal notification. Operators prefer more than a minimum of three days to plan efficiently and make fuel-efficient maneuvers. They also desire much more collaboration as maneuvers are planned. Users also complain that the position information provided is not the most accurate data available. More precise and accurate information allows planning for maneuvers further into the future, saving valuable fuel and ensuring accuracy. Operators want more timely and accurate data concerning threatening spacecraft as well. Inter-operator coordination can be time-consuming and information and services may not be available when needed. For LEO, the long-term accuracy of element sets is a continuing challenge. As the space environment approaches solar maximum, the variability of orbits due to atmospheric expansion may make orbital forecasting even less accurate for more than a few days into the future.
The United States nearly always leads international initiatives when deploying complex systems. It does so because of its wealth and technology integration, but also because the framework allows it to exercise significant control over a program's resources, schedules, technologies, and operations. Historically, at least during the last half of the 20th Century, the United States accepted these costs because it nearly always undertook the major risks of each venture. Given the allocation of risk, marginal or minimal contributors to efforts are not usually given veto power over the mission decisions.
Opponents could argue that there would be security risks if the United States unilaterally controlled STM and somehow withheld its benefits. Similar arguments were made by proponents of Europe's Galileo precision navigation and timing satellite program, arguing it should be funded because the United

States could not be trusted to provide services with its USSTRATCOM-operated program.[58] The objections to so-called "unilateral" U.S. control might be muted if participants were invited to serve as part of the staff and crews of whatever the STM system's mission control station might be.

While the U.S. Government has concluded that it should invest the resources to develop and operate USSTRATCOM's significant SSA systems and services, it remains to be seen whether USSTRATCOM will continue as the key agency providing STM. The U.S. Government will still have to decide which Federal agency should "own" the STM program as it evolves. This would require careful evaluations of the purpose, resources, and institutional competencies of different departments and agencies. Should STM be the purview of the military, of a civil aviation authority such as the Federal Aviation Administration (FAA), of a civilian space agency such as NASA, or of a new organization or interagency body created specifically for the purpose?[59] Also importantly, the U.S. Government seeks to protect the national security data inherent in its SSN, satellites, and their supporting systems, and garners some comfort in that. Despite the perceived drawbacks, and protests about secrecy, USSTRATCOM is moving forward to improve its systems, and has been successful in integrating its data and services at an accelerating pace with global operators and other SSA providers.

Since this option is the current program, it can be scored as follows:

- Manages risks: 1
- Efficiency: 2
- Proprietary and security concerns: 2
- Total score: 5

Option 2: STM intergovernmental organization.

Professor Dempsey and Dr. Mineiro propose that the International Civil Aviation Organization (ICAO) be granted the authority to regulate suborbital and orbital traffic management, at the least standardizing navigation for space vehicles traversing airspace. The Convention on International Civil Aviation, also known as the Chicago Convention, established ICAO.[60] The Chicago Convention provides rules for airspace, aircraft registration and

58 European Space Agency, "Why Europe Needs Galileo," June 27, 2014, *at* www.esa.int/Our_Activities/Navigation/The_future_-_Galileo/Why_Europe_needs_Galileo (last viewed Sept. 12, 2015).

59 One senior U.S. military official has argued for shifting STM activities to a civilian government entity. Mike Gruss, "Strategic Command Envisions Civil Space Traffic Management" (June 16, 2015), *at* http://spacenews.com/strategic-command-envisions-civil-space-traffic-management/ (accessed Sept. 17, 2015).

60 Convention on International Civil Aviation, art. 3(c), Dec. 7, 1944, 61 Stat. 1180, 15 U.N.T.S. 295 (entered into force Apr. 4, 1947) [hereinafter Chicago Convention].

safety, and details air travel rights of the signatories.[61] Under Dempsey and Mineiro's proposal, ICAO's authority over space activities could be established either by amending the Convention, or by ICAO's exercising its existing jurisdiction under the Convention over suborbital and orbital vehicles to the extent they impact the safety, regularity, and efficiency of commercial air navigation. They further suggest that such a system could integrate orbital vehicle navigation, maneuver and communications activities into a single unified system and regulate space activities to minimize chances of on-orbit collisions and EMI.[62] Developing such a system could, in turn, fully embody the dream and objectives of three principles of Article IX and affirmative duty to consult.

According to Ryan Zelnio, a coordination model of cooperation "is inviting in that it is easy for people to agree, as it allows each country to maintain its total independence and manage its own contributions. The disadvantage of coordination is that countries often push programs that greatly overlap efforts pursued by other countries, causing much duplication of efforts."[63] Coordinating groups exist in the international community, such as that provided by the IADC, ISO, and ITU. These groups have achieved considerable success in improving international dialogue on scientific efforts.

Granting STM powers to an ICAO-like organization could provide opportunities to improve international cooperation on STM. Nevertheless, Dempsey and Mineiro suggest that creating a new international organization to perform STM functions would require significant political effort, and economic expense. They express concerns that this resistance might need an accident to provide the political impetus for supporting international standardization.[64]

Under the ICAO approach, each nation or region would be expected to enter into bilateral and multilateral agreements to achieve STM objectives related to launch and reentry activities, on-orbit collision avoidance protocols, and, if the ITU mechanisms are insufficient, EMI/RFI mitigation. Active debris removal activities, if they ever have technical merit, could be addressed. Each participating spacefaring nation or group of nations could be expected to operate their own STM program, or support a multi-lateral program. Such a

61 See generally, *Convention on International Aviation* Doc 7300, found at the International Civil Aviation Organization website – www.icao.int/publications/pages/doc7300.aspx, accessed September 23, 2014.

62 Dempsey & Mineiro, "Space Traffic Management [...]" *supra* note 57, p. 3. Efforts to reduce EMI via STM mechanisms would also need to be coordinated through the International Telecommunication Union (ITU), which already regulates access to GEO orbital slots and to the frequency bands used by space-based radiocommunication stations. See, *e.g.*, Radio Regulations of the International Telecommunication Union (2012), app. 4, annex 2.

63 Ryan Zelnio, "A model for the international development of the Moon," *The Space Review*, December 5, 2005.

64 Dempsey & Mineiro, "Space Traffic Management [...].", *supra* note 57, p. 3.

system of systems could be designed to leverage the best of network-centric operations theory, empowering STM with information sharing among the partners. The ICAO framework would not require USSTRATCOM to make major changes to its current systems and it would allow direct data integration from other spacefaring States and commercial operators. One would expect that exchanges would be more limited on information provided national security systems,[65] but perhaps established on an experimental basis until standards, reliability, and confidence among partners have been fully established.[66] National security spacecraft could be exempted from having to follow specific STM requirements, subject to a requirement to act with due regard for the safety of other space objects.

The ICAO organization option can be scored as follows:

- Manages risks: 2
- Efficiency: 1
- Proprietary and security concerns: 1
- Total score: 4

Option 3: Commercial operators provide their own STM.

The final approach for providing STM is for operators to contract out the capability to one or more international commercial concerns or nonprofit entities. The AGI ComSpOC and SDA initiatives are emblematic of this option. These entities provide close-approach warnings to a number of commercial satellite operators. There are limitations, but leveraging operator-produced orbital data allows them to provide participating satellite operators with accurate orbital predictions and collision warnings on conjunctions between participating satellite systems.

Fortunately, the private sector offers a number of attractive models for STM. Market participants frequently choose to comply without any statutory mandates or government direction. They perceive the compliance costs of private regulation as a necessity for survival in the marketplace rather than as a burden. Since the price of privately regulated goods reflects the full cost of regulation, private regulators are very sensitive to the burdens they impose.[67] In turn, private regulators minimize the costs of running their private regulatory organizations, and in doing so, decrease the costs of their regulatory activities where possible. Thus, whereas indirect costs of private regulation are often minimal, privately regulated entities usually understand the fees and the

65 Just as State aircraft are exempt from the Chicago Convention under Article 3, national security space assets could be exempted from international coordination requirements, provided their operators exercise due regard for the safety of other satellites in accordance with Article IX of the Outer Space Treaty.

66 Chicago Convention, Art. 3.

67 Yesim Yilmaz, "Private Regulation: A Real Alternative for Regulatory Reform," *CATO Policy Analysis No. 303*, April 20, 1998, p. 1.

compliance costs in advance. As such, they better assess the expected costs and benefits.

Regulation of space activities and movement into and through the domain need not be performed by a governmental or international agency. Indeed, much regulation throughout the global economy is privately performed – produced and enforced by the marketplace, independent parties, or trade associations. Recent activities of SDA point to possibilities of an independent and comprehensive private regulatory scheme, at least for the commercial satellite industry. Regulations provide users and consumers information and help them make informed decisions. Unfortunately, regulation is also an overpowering and intoxicating tool that bureaucrats and policymakers can employ to achieve a variety of objectives, either good or bad. Regulation can also be used to achieve political objectives. For example, some proponents for STM believe that if it can be implemented with international agencies, it will be an opportunity to demonstrate global governance can be effective and achieve a greater good on the grand stage of international relations.

In establishing any STM regime, incorporating privately performed regulation, instead of a more traditional and onerous domestic or international governmental scheme, could provide a significant opportunity to select a more flexible, responsive, and evolutionary system. This, in turn, could drastically reduce operator regulatory compliance costs. Since such private regulation has been shown to work, it deserves close consideration as an option to perform STM.

The downside of the commercial arrangement is that such an entity initially would have few comprehensive resources of its own (such as large-scale radars and telescopes)[68] and would be compelled to rely upon government-provided data on debris and non-participating satellite operators. AGI solves some of this issue by contracting for its own sensor network.

One might think the Air Force's SSN system could be transferred to an independently-control entity. That is unrealistic because transferring control involves the systems that contribute to U.S. missile warning capabilities. It would require a revolutionary change in strategic thinking on how the United States treats systems that provide warning of attack by weapons of mass destruction. Ultimately, few national security systems are likely to depend on a commercial option. On the other hand, a commercial option could serve the needs of the majority of commercial space operators.

Private organizations often oversee participants' actions by processes such as standard-setting. Operating in this setting usually takes much less time and consumes fewer resources than coercive governmental regulation. The major challenge presented by governmental regulation is the costs imposed on the

68 The sensors SDA uses, for example, are owned and operated by its members, not by SDA itself.

regulated and regulators. Today, there is no comprehensive accounting system to fully assess the costs and benefits of what would be space regulatory actions. In contrast, privately managed and developed STM activities have the potential to reduce the burdens of regulations on operators while still keeping space systems safe and prosperous. Merely writing down more rules, or suffering through micromanagement by national or international agencies, cannot achieve this necessary goal.

The integrated framework is scored as follows:

- Manages risks: 3
- Efficiency: 3
- Proprietary and security concerns: 0
- Total score: 6

VII. Concluding Thoughts

Developing a space traffic management system to manage launch, on-orbit, and reentry space activities would embody important principles of the Outer Space Treaty's Article IX – cooperation, mutual assistance, and due regard – and the affirmative duty to consult. But performing any form of STM would be technically daunting. What is more, the national security and proprietary concerns would be difficult to navigate. Such issues would constrain the alternatives for whatever framework is chosen. A privately managed STM framework might provide a more flexible, responsive, and evolutionary process, and this in turn could reduce space operator compliance costs.