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Space Traffic Management 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." 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 the affirmative duty to consult. This paper highlights the global space sustainment interests and evolving rules used during space operations. It then evaluates the space traffic management definition and examines questions about its possible legal underpinnings, technical obstacles, what should the system manage, security and economic considerations, frameworks, and the role of government(s) and the private sector. Performing any form of space traffic management would be technically daunting, and the security and proprietary concerns would be significant. The paper also comments on whether a privately performed space traffic management framework might provide a more flexible, responsive, and evolutionary process, and whether this in turn could reduce space operator compliance costs.

Analysts wring their hands as they note the growing numbers of objects that have been placed and left in space orbit over the last half-century. The numbers have precipitated safety of flight concerns. In response, concerned observers cry out for "space traffic management," arguing that such a regime is vitally needed to deal with the growing risks of on-orbit collisions and protect the domain from the growing clutter.

Assuming that a global consensus can be reached on the premise that some form of space traffic management should be developed and implemented, a number of questions and criticisms arise: What is space traffic management? What should the legal underpinnings of such a system be? What are the technical obstacles? What should the system manage and when? What are the security considerations? What frameworks should be considered? What should be the government role? Can risk and regulation better managed and performed by the private sector?

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This paper will address these questions and considerations. First, however, we must recap the foundations for the desire to implement space traffic management.

I. A tipped balance -- Crowded space poses a growing risk to safe operations

Demands for space traffic management reached an apex following recent large debris-generating events, such as the 2009 collision between the operational Iridium 33 and defunct Cosmos 2251 spacecraft which generated over 3,000 pieces of debris published to Space-Track.org, and a Chinese 2007 anti-satellite (ASAT) test against the Fengyun 1C, generating over 3,400. Hundreds of thousands of pieces of smaller, un-trackable debris were also produced. The Chinese ASAT test created "a pervasive debris cloud of more than 150,000 objects greater than 1 centimeter in size. U.S. experts estimate that many 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."[1]

The number of operational satellites now exceeds 1,100.[2] Not all are maneuverable, however. And more are placed in orbit every month. Well over 300 spacecraft are operated in geosynchronous Earth orbit (GEO) by governmental, international, and commercial institutions. This number reflects the exponentially growing demand for space-enabled communication and information services that can be delivered by systems in that unique orbital regime. Responding to the demand, the numbers also reflect a tremendous investment in resources by spacefaring entities. The growing numbers of satellites are matched by each spacecraft's growing complexity and capacity, and with that, their size and mass—the trend in GEO is to field massive satellites. And massive payloads have historically demanded corresponding massive program budgets. With that, operators pay tremendous attention to assure their safe operations in order to better manage programmatic risks. Many operators would consider favorably any government or private system that efficiently assists in the performance of such tasks.

As to systems placed in low Earth orbit (LEO), "Earth observation has become one of the principal missions for these spacecraft, which prefer sun-

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1 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/111709 Buenneke.pdf, accessed September 11, 2014.

2 On February 1, 2014, the Union of Concerned Scientists assessed the operating number at 1167. With 605 in low Earth orbit, 77 in medium Earth orbit, 38 in elliptical orbit, and 477 in geosynchronous Earth orbit. "UCS Satellite Database," Union of Concerned Scientists, http://www.ucsusa.org/nuclear_weapons_and_global_security/solutions/space-weapons/ucs-satellite-database.html, and http://www.ucsusa.org/assets/documents/nwgs /changes-to-the-database-2-1-14.pdf , accessed September 18, 2014.

synchronous orbits, usually between 450 and 1,000 [kilometers]."[3] Orbital analysts tell us that the relative intercept closing collision speeds of objects in LEO are usually many times higher for those found in GEO. Even 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 on an operating spacecraft. And when LEO objects in different orbital planes intersect, the collision can take place at relative speeds of many more thousands of kilometers per hour. The differences in risks associated with the two orbital regimes are stark and demonstrated by using "car" analogies. Neighboring GEO satellites travel in the same direction in orbit around the Earth, staying in their lanes as cars traveling down a highway might. LEO satellites, in contrast, can be characterized as cars driving blindly through a corn field, at top speeds, in all directions at once.

The number of LEO satellites is expected to grow in coming years as government, industry, and academic owner/operators seek to rein in the costs of their programs. It is expensive to place spacecraft into orbit. Small-satellite program managers can reap a variety of technical, schedule, and cost advantages by leveraging a wider mix of launch vehicles. And the March of Time has brought forward advanced small-satellite technologies. New, small-satellite buses can be employed to host new miniaturized payloads that can satisfy a wide mix of mission requirements.

Miniaturization innovations provide mission planners and spacecraft developers with opportunities to achieve affordability goals. Small satellite technologies also enable acquirers to deliver needed capabilities faster within rapidly changing technology refresh cycles. This enables the use of rapid building block or spiral development acquisition approaches, and they have generated considerable excitement in the space system acquisition community. The innovations associated with small satellites have attracted considerable investment, and this has fostered rapid increases in the numbers of satellites deployed in LEO during the last several years. This includes hundreds of new, simple CubeSats.[4] These increasing numbers have

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3 *Cosmic Study on Space Traffic Management*, Corinne Constant-Jorgenson, Petr Lala, Kai-Ewe Schrogl, editors, International Academy of Astronautics (Paris, France) 2006, p. 26.

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. California Polytechnic State University at San Luis Obispo (Cal Poly) and Stanford University helped developed the CubeSat specifications to help universities worldwide to perform small-scale science and exploration. While the bulk of development and launches comes from academia, several companies build CubeSats. Leonard David, "Cubesats: Tiny Spacecraft, Huge Payoffs," *Space.com*, September 08, 2004, http://www.space.com/308-cubesats-tiny-spacecraft-huge-payoffs.html, accessed September 6, 2014. Jason Dorrier, "Tiny CubeSat Satellites Spur Revolution In Space," June 23, 2013, Singularity Hub, http://singularityhub.com/2013/06/23/tiny-

exacerbated concerns about growing domain congestion. As noted by Lieutenant General John "Jay" Raymond, commander of United States Strategic Command (USSTRATCOM) Joint Functional Component Command for Space (JFCC SPACE):

> A continuing trend of multi-payload launches with an ever decreasing satellite size will add to on-orbit congestion. In 2012, 72 new satellites were placed in orbit; in one 7-day period in 2013, 78 new satellites were placed in orbit. The trend includes deployment of cubesats -- cube-shaped satellites, 10 centimeters on a side, that are highly capable for their size. In February 2014, the International Space Station (ISS) deployed 33 CubeSats. The Falcon-9 ISS cargo resupply mission is programmed to deploy 5 additional CubeSats, including a Cubesat that deploys 104 chipsats, which are smaller than a credit card. Detecting and tracking multiple objects of chipsat size over 250 miles above the earth is beyond the current capabilities of fielded systems. [5]

With the growing numbers of on-orbit satellite conjunctions and the attendant growth in collision risks, policy maker interests have tipped toward improving global collaboration to mitigate and reduce them. This collaboration has built support for improved space system operator best practices and standards designed to improve launch safety and limit the generation of debris. The

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cubesat-satellites-spur-revolution-in-space/, accessed September 6, 2014. "CubeSat Design Specification Rev. 13," *The CubeSat Program*, Cal Poly San Luis Obispo, February 20, 2014, http://cubesat.calpoly.edu/images/developers/cds_rev13_final.pdf, accessed September 6, 2014.

5 John W. Raymond, Prepared Statement, House Committee on Science, Space and Technology on Space Track Management, May 9, 2014, pp. 4-5, http://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-113-SY16-WState-JRaymond-20140509.pdf, accessed September 7, 2014. The "ChipSats" Lieutenant General Raymond describes should not be confused with the Cosmic Hot Intersteller Plasma Spectrometer Satellite (also, ChipSat), a now-decommissioned satellite launched on January 12, 2003. Rather, he refers to the KickSat 3U CubeSat mission, launched onboard the April 18, 2014 Falcon-9 CRS-3 mission. The KickSat mission was designed to dispense 104 Sprite satellites, 3.2 x 3.2 cm femtosatelites, and also called "ChipSats." The 104 Sprite satellites were to have been released on 4 May 2014. That did not occur. The "automatic timer that was to release the satellites was reset by the onboard "watchdog" microcontroller on 30 April 2014, probably due to a high dose of radiation (it appears the reset happened some time in the morning of April 30). One consequence of the watchdog reset on KickSat is that the spacecraft's master clock was reset, thus also setting the deployment countdown for KickSat back to 16 days. That would have put the deployment some time in the morning of May 16. However, KickSat itself re-entered, as predicted, on 14 May 2014." "KickSat Nanosatellite Mission," *eoPortal.org*, https://directory.eoportal.org/web/eoportal/satellite-missions/k/kicksat, accessed September 11, 2014.

efforts have been a major topic of interest for the United Nations (UN) Inter-Agency Space Debris Coordination Committee (IADC), an advisory body composed of representatives of national space agencies. In addition, the International Organization for Standardization (ISO), a non-governmental federation of 163 national standards bodies, consisting of members, corresponding members, and subscriber members, established its own Orbital Debris Coordination Working Group in 2003. This working group has been developing standards to mitigate debris, properly dispose of satellites operating in GEO, and prevent the break-up of unmanned spacecraft.[6]

Consistent with spacecraft technology improvements, the international capacities to perform precise conjunction assessments have significantly increased. This has enhanced the ability of operators to take steps to reduce chances of future on-orbit collisions, at least among spacecraft that can be maneuvered. This increase is pushing common space operator practices forward with an objective to avoid collisions.

Most operators want to improve on-orbit spacecraft safety of flight. And policy leaders have endorsed efforts to prevent collisions in space that could result in additional debris. 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.

The issuance of the 2010 United States (U.S.) National Space Policy by the Obama Administration confirmed U.S. policymaker interest in international cooperation as a means to confront debris issues and improve environmental and operational stability of the domain.[7] The U.S. State Department has also spent several years proselytizing on behalf of a new, non-binding "Code of Conduct" for space operators, as a means of encouraging greater international best practices in the domain.

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6 According to the ISO, its "ISO 24113 aims to ensure that spacecraft and launch vehicle orbital stages (the engine sections used to propel the spacecraft that are discarded after use) are designed, operated and disposed of in a way that prevents them from generating debris throughout their orbital lifetime. The standard is one of a family that helps avoid the release of objects during normal operation, helps prevent accidental break-ups and helps ensure that launch vehicle orbital stages leave the low and geostationary earth orbits where they pose most risk…. A number of other standards are under development such as ISO 16158, which focuses on avoiding collisions using the Conjunction Data Message… Other topics also in development include the standardization of space debris and natural environment models (ISO 14200) and the design and operation manual for spacecraft operated in the debris environment (ISO 18146)." Sandrine Tranchard, "ISO standards for a safer, cleaner space," *ISO*, October 9, 2013, http://www.iso.org /iso/home/news_index/news_archive/news.htm?refid=Ref1784, accessed September 18, 2014.

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

Under the U.S. Department of Defense (DoD)'s Space Situational Awareness (SSA) Sharing Program, USSTRATCOM offers non-U.S. Government-affiliated entities access to information collected by the Space Surveillance Network (SSN), a global network of optical telescopes and radars.[8] The information is provided to them by JFCC SPACE's Joint Space Operation Center (JSpOC) through the website, Space-Track.org. The website provides registrants access to Two-Line Element (TLE) sets that describe the orbital position of objects. The TLEs are generated using a model where drag caused by the Earth's atmosphere, the gravitational attraction of the Sun and Moon, asymmetric shape of the Earth, and other factors are averaged out along the entire orbit to give an average position of a satellite at any one moment in time.[9] The website also provides registrants satellite catalog messages, project tip messages, satellite decay messages, predicted decay forecasts, satellite box scores, and satellite reports.[10] In addition, it provides information on the current and historical orbital positions of man-made objects while also providing some analysis on future potential collisions.

II. What is Space Traffic Management?

An agreed-to, authoritative definition for "space traffic management" has not been firmly established. The International Academy of Astronautics (IAA), in its seminal study, *2006 Cosmic Study on Space Traffic Management,* offered the following:

> 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.[11]

The IAA study's authors argued that their space traffic management definition supports the universal freedom to use outer space as laid down in the *Outer Space Treaty of 1967*.[12] They also argued that for the purpose of achieving a common good, which also should be in their self-interest, spacefaring States and operators must follow specific rules.[13]

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8 Weeden, "Billiards in space," *The Space Review*, February 23, 2009, http://www.thespacereview.com/article/1314/1, accessed September 18, 2014.
9 *Ibid*.
10 One can register with Space-Track.org at https://www.space-track.org/auth/login.
11 *Cosmic Study*, *supra* note 5, p. 10.
12 *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.
13 *Cosmic Study*, *supra* note 5, pp. 11-12.

One could think of space traffic management being grouped into three basic functions: situational awareness, traffic regulation and enforcement, and traffic control. Situational awareness includes functions and services related to locating and tracking objects and monitoring the environment. Traffic regulation and enforcement includes functions that are authorized and/or performed by an appropriate authority to assess, approve, and grant permission for spacecraft operations, to ensure that approved processes are adhered to, to guarantee safety of systems, personnel and the general public, and to ensure compliance. Traffic control includes functions and services by which operations can be directed and approved in order to promote safe and expeditious activities. These functions can be performed at launch, on-orbit, and upon re-entry.

III. What should be the legal underpinnings to space traffic management?

Establishing or agreeing to be regulated by a space traffic management system would appear consistent with the obligations imposed by the *Outer Space Treaty*. Under Article VI, States bear international *responsibility* for their activities in outer space, whether conducted by governmental agencies or private citizens.[14] Signatories must authorize and continuously supervise all space activities undertaken by their citizens. This requirement is unique to space activities, forged from a compromise between the United States and the former Soviet Union. The Soviets insisted that only governments should be permitted to go into outer space, whereas the United States insisted on a regulatory system that accommodated access to the domain by private entrepreneurs.[15]

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14 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.

15 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

Article IX of the *Outer Space Treaty* also sets out important guiding principles for activities conducted by space-faring nations. It 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).

In addition to guiding principles of cooperation, mutual assistance, and due regard, 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.[16] Since Article IX is guided by principles of "cooperation and mutual assistance" with "due regard to the corresponding interests of all other States Parties to the Treaty," interpreting the international consultation obligation provision as requiring a State to fulfill the aforementioned procedural and substantive obligations should require good-faith interpretation of the Treaty.

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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, http://www.thenewatlantis.com/publications/property-rights-in-space, accessed September 23, 2014.

16 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, December 2, 2010, p. 2.

"Imposing any less of an obligation would emasculate the international consultation clause of Article IX, a result that is unreasonable."[17]
Accordingly, the confluence of the Article IX principles of cooperation, mutual assistance, and due regard, and the consultation obligation, appear to require that spacefaring States:

- Develop and maintain 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.
- Act to reduce debris generation and mitigate risks posed by their space objects.[18]

One can see that exercising these practices would comprise the important elements of an international space traffic management scheme.
Regardless of the space traffic management definition, the rules of treaty and customary international law essential to any comprehensive space traffic management 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 manoeuvres, 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).

17 Michael Mineiro, "FY-1C and USA-197 ASAT Intercepts: An Assessment of Legal Obligations under Article 9 of the Outer Space Treaty" 34(2) Journal of Space Law 321 (2008) at 339.

18 See generally, James Rendleman and Sarah Mountin, "Evolving spacecraft operator duty of care," 7th International Association for the Advancement of Space Safety, Friedrichshafen, Germany, 20-22 October 2014.

- There is no legal distinction made between valuable active spacecraft and valueless space debris.
- There are no legally binding rules with regard to the mitigation of space debris and the disposal of spent space objects as well as the prevention of pollution of the atmosphere/troposphere.
- Space law lacks enforcement mechanisms. There is no "police" in outer space and there is no elaborate dispute settlement system, although the Liability Convention includes a system for settlement of claims.
- Private space activities can in some cases may escape (i.e., not be subject to) space law, which is still State centred, and, as already pointed out, the legal delimitation of air space and outer space is missing.

> A space traffic management regime has to fulfil these shortcomings of international space law.[19]

There are no uniform standards for what should be included as part of space traffic management, and more importantly, how it should be executed. As suggested by Professor Paul Stephen Dempsey and Dr. Michael Mineiro, 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.[20]

Dempsey and Mineiro suggest that creating a new international organization would require significant political effort, and economic expense. They assert that maintaining the status quo is a position that can be held until suborbital and orbital activities become common enough that the current ad hoc system can no longer provide safe *aerospace* traffic management. They argue this may be a reactive approach, however, waiting for an accident to provide the political impetus for supporting international standardization.[21]

Bilateral or regional agreements could function on a limited basis, depending on the nature of the agreements and the parties. For example, such

19 *Cosmic Study*, *supra* note 5, p. 10.

20 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.

21 *Ibid*.

agreements could establish coordination among two foreign airspace traffic management systems.[22]

Dempsey and Mineiro argue that the simplest and most cost-effective approach could be for ICAO to exercise authority would be to empower it to standardize suborbital and orbital traffic management, at the least standardize navigation for space vehicles traversing airspace. The Convention on International Civil Aviation, also known as the Chicago Convention, established ICAO. The Convention provides rules for airspace, aircraft registration and safety, and details air travel rights of the signatories.[23] Under Dempsey and Mineiro's proposal, ICAO's authority over space activities could be established either by amending the Convention, or by ICAO 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. [24] Developing such a system could, in turn, fully embody the dream and objectives of three principles of Article IX and affirmative duty to consult.

IV. What are the technical obstacles?

The technical aspects of performing a comprehensive form of space traffic management are daunting. Indeed, just operating a spacecraft to achieve mission success is complicated by physics, engineering, and operational issues. Though space systems have advanced over the decades, the activity still involves good doses of "rocket science." Mitigating collision risks requires operators to work smartly to perform complex operations.

Spacecraft depend on operators to communicate with and control satellites without hindrance, or disruptions caused by natural, man-made, or unexpected events. Of course, physical realities deny ground-based operators any type of instantaneous control. There are also time lags associated with: observing, detecting 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. The distances involved in the satellite operator's communications chain, ranging from about 500 to 35,000 kilometers once operational orbits are achieved, further complicate control tasks. The distances involved (light travels just 299.8 millimeters, just 5 millimeters under one U.S.

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22 *Ibid.*

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

24 *Dempsey and Mineiro, "Space Traffic Management…," supra* note 22.

imperial foot, in a nanosecond) and time associated with on-orbit and ground processing make any talk that an operator can direct instantaneous satellite maneuvers or any other change a bit laughable. Travel times limit the speed of data transfer between sender and receiver, different systems, even components in the same computer. And, as we will discuss below, oftentimes there are not enough sensors to fully monitor relevant on-orbit events. This accentuates operational time lag challenges.

Satellites in the GEO belt suffer from significant electromagnetic and radiofrequency interference (EMI and RFI, respectively) between satellites in addition to being what some argue is one of the most physically congested regions[25] in space. Inadvertent EMI and RFI, and some intermittent intentional jamming, have been the bane of the spacecraft operator's existence for many years. The International Telecommunications Union (ITU), a United Nations affiliate, regulates satellite and other wireless communications frequencies and satellite orbital slots. It has difficulty in obtaining compliance with its rules by bad actors, however. The ITU was characterized as a "gentlemen's club by Francois Rancy, director of France's National Frequencies Agency (ANF). He observed, "It depends on the goodwill of its members. There is no mechanism for forcing an administration into compliance with the rules."[26]

Beyond jamming incidents, some spacecraft, such as Intelsat's Galaxy 15, malfunction and stop responding to ground commands altogether, and then present RFI problems for other satellites. For example, the Galaxy 15 satellite, nicknamed "ZombieSat,"[27] suffered a glitch, was temporarily disabled, and then 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 re-broadcast 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. This incident demonstrates that sophisticated coordination and rigorous operator discipline are vitally important to mitigate interference problems and should be requisite attributes of any contemplated space traffic management framework.

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[25] While the GEO belt is congested, the sun-synchronous LEO poses the greatest concerns for conjunctions and the potential for collisions. As an example, see the discussion about problems associated with the loss of the European Envisat in a near-polar orbit at 782.4 kilometers in altitude. Peter B. de Selding, "Envisat to Pose Big Orbital Debris Threat for 150 Years, Experts Say, *Space News*, July 26, 2010, p. 1.

[26] Peter B. de Selding, "France Seeks ITU Help To Halt Satellite Signal Jamming by Iran," *Space News*, January 8, 2010

[27] 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 September 18, 2014.

Operators can enhance this coordination by employing SSA tools. SSA systems enable an operator to ascertain and attribute disruptive events so that appropriate responses can be developed and implemented. There are a number of SSA options available to global operators.

The U.S. Government, its allies, and most major commercial operators rely on SSA information distributed by the JSpOC. Large commercial operators also obtain and share SSA information as members of the Space Data Association (SDA). SDA was formed in 2009 by the world's three largest commercial satellite companies: Inmarsat, Intelsat, and SES. "SDA created 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.'"[28] Under this commercial initiative, SDA collects, standardizes, and shares SSA orbital and radio frequency information with its members. According to SDA, 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."[29] Building on a commercial software backbone, SDA provides its members networked access to its data. The SDA's contractor, Analytic Graphics, Inc., ingests and processes operator-supplied orbital data; performs conjunction assessments; and generates automated warning alerts. It also supports avoidance maneuver planning, RFI mitigation and data sharing.[30]

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[28] Marcia Smith, "Space Data Association and USSTRATCOM Reach Data Sharing Agreement," *Space Policy Online*, August 11, 2014, http://www.spacepolicyonline.com/news/space-data-association-and-usstratcom-reach-data-sharing-agreement, accessed September 6, 2014. On August 08, 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*, August 8, 2014, http://www.businesswire.com/news/home/20140808005645/en/Space-Data-Association-SDA-U.S.-Department-Defense#.VAwHcNLwvTt, accessed September 6, 2014.

[29] "The Space Data Association…How Close is Close (Analysis)," *Satnews Daily*, January 24, 2011, http://www.satnews.com/cgi-bin/story.cgi?number=1681696938, accessed September 11, 2011.

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

Neither USSTRATCOM, SDA nor any other entity knows where all orbiting spacecraft and debris are at all times. Presently, USSTRATCOM's sensors track about 23,000 orbiting objects, and its analysts catalog a large portion of that number.[31] Its radar sensors have difficulty tracking objects smaller than the size of a grapefruit or 10 centimeters in LEO, and space environmental events and uncoordinated satellite movements can disrupt and confuse that tracking. "Because of the 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 and latency in the catalog."[32] In GEO, objects must generally exceed 1 meter in size to be tracked, and are best tracked with optical telescopes rather than the radar system used for lower orbits. Tracking objects in GEO presents the biggest challenge to orbital analysts, "due to the small number of available deep-space tracking sensors. A satellite that maneuvers in this orbital regime without detection may become lost, which will require the analyst to devote additional time and resources to find the satellite, at the expense of sensor resources devoted to the rest of the catalog."[33]

Exacerbating these challenges are hundreds of millions of objects in Earth orbit—up to 330,000,000 objects of 1 millimeter to 1 centimeter size and 560,000 objects in the 1 to 10 centimeter range.[34] Given the risks posed by

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31 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, http://www.defensenews.com/article/20140524/DEFREG/305240019/USAF-Focuses-Space-Debris-Other-Threats, accessed September 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 September 7, 2014.

32 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.

33 *Ibid*, 298.

34 The numbers are from 2006, citing Dr. Heiner Klinkrad, European Space Agency Space Debris Office. Union of Concerned Scientists, "What's in Space?", *Ensuring Space Security: Fact Sheet No. 2*, http://www.ucsusa.org/assets/documents/nwgs/satellites.pdf, , accessed September 18, 2014, citing H. Klinkrad, *Space debris: Models and risk analysis* (2006) Berlin: Springer Praxis, 96. According to the NASA Orbital Debris Program

these smaller objects, the U.S. Government is shoring up its tracking capacities. The U.S. Air Force's 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.[35] These two space-based sensor systems are expected to add many more objects to the USSTRATCOM space object catalog and exacerbate analytical challenges. The enhanced computing capabilities provided by the new JSpOC Mission System (JMS) will be used to respond to the greatly expanded analytic tasks. Complementing the space-based sensors will be the "Space Fence" radar tracking system. This program, recently awarded to Lockheed Martin, will replace the Air Force Space Surveillance System (AFSSS).[36] The AFSSS, operated from 1961 until September 1, 2013, eventually tracked up to 20,000 objects. The new Space Fence will expand the number of trackable objects to 100,000 or more by using three ground radars "operating in the S band, which has shorter, more accurate frequencies than AFSSS used." When operational the radars are expected to cover enough continuous area to effectively create a "fence" through which orbiting objects will pass.[37] However, the dramatically expanded numbers of tracked objects poses 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

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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, http://www.eucass-proceedings.eu/articles/eucass/pdf/2013/01/eucass4p735.pdf, accessed September 18, 2014.

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

36 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 20th Space Control Squadron on October 1, 2004.

37 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 September 7, 2014.

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 program and its management team.

Protecting satellites from on orbit collisions requires two separate concepts: conjunction assessment and collision avoidance. Conjunction assessment 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 to perform a maneuver to decrease the risk to an acceptable level.

Presently, the SSN collects 400,000 daily observations or more on resident space objects. Of these observations, 90 to 95 percent are correlated with known objects, whereas the remainder are set aside by orbital analysts for further correlation and analysis to keep USSTRATCOM's catalog of tracked objects up-to-date. With 23,000 trackable objects detected on-orbit, the JSpOC produces about 1,400 conjunction summary messages[38] and issues about 30 conjunction warnings to operators for their maneuverable spacecraft on a daily basis.[39] One can expect these numbers to increase as the number of tracked objects grows well over 100,000. Unless decision-making tools can effectively account for the increased numbers, one can expect that analysis paralysis could confound and overwhelm some operators, so much that they are unable to perform and act on a cost-benefit analysis of the risk against a decision to maneuver.[40]

Beyond situational awareness, another vexing issue confronting satellite operators is that even if they know precisely where all the threatening objects are

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38 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 September 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, http://www.vandenberg.af.mil/news/story.asp?id=123413786, accessed September 27, 2014.

39 Liou, *supra* note 36, p. 735.

40 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.

and their ephemerides, they may not have sufficient time, propellant or maneuvering capability to avoid them. Operators must anticipate a wide variety of collision and near-collision scenarios. For example, two live, maneuverable satellites could both perform maneuvers to avoid a threatened collision. Unless these maneuvers are coordinated, they could, at best, waste valuable propellant or end up making the situation worse. Such scenarios have been described as "noncooperative satellite monitoring," a situation in which operators act unilaterally, intentionally or unintentionally, without information on the spacecraft station-keeping and maneuver plans of other systems.[41] This is not a new issue nor one that operators are unaware. The longstanding growth in the numbers of spacecraft has made cooperating to mitigate problems more urgent.

Despite global sensor coverage and the ability to track smaller objects more consistently than any other entity, USSTRATCOM analysts benefit, that is, their jobs are made easier and their analysis more accurate, if they can obtain spacecraft operator information and maneuver plans well in advance. Indeed, the USSTRATCOM SSA Sharing Program's authorizing statute was amended in 2009 to authorize just this.[42] Under the revised program, the DoD is now authorized to receive SSA information from satellite operators and non-Federal entities.[43]

In addition to the command and control time-lag issues discussed above, attempts to implement any comprehensive space traffic management scheme are confounded by other physical complexities. Commanding a spacecraft to perform a collision avoidance maneuver could adversely affect a mission. Changing a satellite's orbital plane to achieve this result can expend much needed propellant resources. For example, once a spacecraft is in LEO, a significant amount of delta-v, that is, change in velocity, is required to change a spacecraft's direction. Thus, to change a satellite's orbital plane by just one degree requires a delta-v maneuver of approximately 122 meters per second (400 feet per second). This not only comes at the expense of spacecraft on-orbit propulsion maneuvering capability, but also affects the spacecraft's ability to control attitude, station-keep, and perform rendezvous operations and other maneuvers.

The challenge of commanding satellites to change velocity vectors and orbital planes was noted by the IAA:

> Space traffic has some fundamental characteristics, which distinguishes it from other human activities on land, sea and air environments. In those traditional environments, the motion of most objects can be

41 Abbot et al, "Decision Support…," *supra* note 34.
42 10 U.S.C. § 2274.
43 Susan Helms, Major General (USAF), "Space Situational Awareness." presentation to the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) meeting, June 3, 2010.

> speeded up or slowed down and its direction changed. In outer space, the ability to change velocity is the exception, rather than the rule. Even more important, objects on Earth can be at rest for indefinite time spans, but an object can last in outer space only if it is in orbital motion which is usually very fast compared to our everyday experience.
>
> …[The] main characteristics of orbital motion lead to the following observations:
>
> - The orbit of any space object is in principle determined by conditions at the end of the launching phase and by the gravity field of the Earth. Any substantial change of such orbit requires additional energy.
>
> - Even with propulsion systems on board the space object, it would be costly (in terms of propellant consumption) to change the orbital plane and this fact should be taken into account in planning the new missions or correcting the orbit of existing systems.[44]

V. What are the security (and economic) considerations?

As it began its new expanded SSA Sharing Program, USSTRATCOM told the world that it would work to forge, strengthen and expand cooperative partnerships with other governments, implement data-sharing relationships with partners, and expand the sharing of operator contact information.[45] Thus far, these data sharing arrangements have been made as allowed by U.S. law and national policy, and services and information provided under the program consistent with military operational constraints and needs. As promised, USSTRATCOM has strengthened and expanded its cooperative partnerships with governments and operator partners by entering into SSA sharing agreements with 42 commercial firms and 7 nations.[46] The USSTRATCOM SSA Sharing Program efforts have been extraordinary in reaching out to the international spacefaring community, but that success was not achieved without some angst. Still, as highlighted below, U.S. national security interests were protected, as have the interests of partner governments and commercial entities.

Any system developed to perform space traffic management must consider the realistic and unrealistic secrecy interests about national security systems and commercial proprietary matters and balance them against operational, safety

[44] *Cosmic Study, supra* note 5, pp. 28-29.

[45] Susan Helms, *supra* note 45.

[46] John W. Raymond, Prepared Statement, *supra* note 40, p. 6. When Lieutenant General Raymond testified, the numbers were 41 commercial firms and 5 nations. At the time of this writing, the numbers are 42 commercial entities and 7 nations.

and stability benefits. Facilitating exchange of data concerning satellite locations and ephemerides, if needed to achieve successful space traffic management, will generate some tension against desires to safeguard a country's national security or corporate proprietary interests. If such exchanges are hoped for, a balancing of interests must be conducted.

Identifying the most important information to protect can establish the groundwork for what kind of data can and should be exchanged. Major spacefaring nations want to protect attributes, vulnerabilities, and maneuver capabilities of their national security satellites. These capabilities would likely need to be treated as sacrosanct and non-releasable. Releases of such information would not be allowed except under strict security controls; consistent with these controls and supporting agreements, allies and friends would be encouraged not to share controlled information with others.

Similarly, commercial operators 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. 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 space traffic management functions, would also be a high interest item. And participants in such a database would want to reduce the risk of loss to a determined hacker, or prevent it altogether. National security risk management concerns also would precipitate imposition of constraints on commercial entities.

Proprietary and national security constraints must be balanced and realistic. The costs of imposing unreasonable controls may be outweighed by the costs of protecting information. On this point, many satellite systems attributes, vulnerabilities, and capabilities can be determined by a knowledgeable or informed adversary, or by an informed third party. In fact, a satellite's mission can usually be ascertained by measuring and evaluating its orbital characteristics (e.g., most communications satellites are in GEO to facilitate global coverage). Some even argue that 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 plausible and possible for an increasingly large number of observers.[47] Given today's state of the art, these same proponents argue that actual orbital data on systems is fairly well known, including the locations of national security satellites, albeit no sensor network can ever provide perfect or up-to-date information on all satellites. So, in the end, strictly protecting data may be a Sisyphean task. These same proponents suggest stepping forward to acknowledge this may help the

47 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, September 10, 2012, pp. 38-40.

global spacefaring community span the gaps necessary to share data that heretofore has been protected.[48] Under their arguments, sharing more data, less constrained by today's strict security or economic controls, may help achieve more important objectives, that is, to achieve effective collision avoidance among all active satellites, mitigate EMI and RFI, and improve planning and coordination among operators. The releases might also enable transparency and confidence-building measures that could in turn lead to enhanced stability among adversaries.

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 should be carefully considered by policy makers, and perhaps encouraged, as part of any SSA sharing activities and space traffic management scheme. Similar assessments are already being performed by commercial operators. Determining what and how much data should and can be shared will require some examination and balancing of the costs associated with protecting and securing discoverable facts, databases, and operations.

Other complexities appear to constrain international and even commercial collaborative sharing relationships. There are often strong economic, political, cultural, and military pressures to go it alone. Each nation wants to demonstrate its own international leadership and technical prowess. While cooperation provides a spacefaring State the basis to draw on additional resources when its own are not adequate, success is often secured at tremendous expense. Resources could be wasted in failed or even successful attempts to collaborate. Ultimately, to achieve success, those cooperating must find utility arising out of their efforts.

VI. What framework should be considered to perform space traffic management?[49]

There are a number of international cooperative frameworks that could be employed to perform space traffic management activities. The frameworks each have their own advantages, disadvantages and chances of adoption. Space operator interests in avoiding spacecraft collisions and reducing EMI and RFI are compelling, but that interest must be balanced against realities that programs can be adopted, and national security interests protected. The assignment and evaluation of technical and non-technical criteria is always valuable in evaluating any solution. Accordingly, the criteria for evaluating future SSA improvement options have been identified: Does the framework increase or decrease the probability of spacecraft collision (and/or reduce

48 *Ibid*.

49 See also, Robert E. Ryals and James D. Rendleman, "SSA Sharing Architecture Options," AIAA Space 2010.

EMI and RFI)? Is the framework politically realistic, i.e., is the framework likely to be adopted by major spacefaring States and operators? Does the framework properly balance national security and proprietary interests?[50]
In general, there are four basic types of international cooperative frameworks: augmentation, coordination, interdependence, and integration.[51]

- ***Augmentation*** – *Cooperating countries provide important elements of the project of the prime country but are not on the prime's program critical path.*[52] The United States nearly always employs the augmentation framework. Selecting an augmentation framework is believed to be consistent with its perceived leadership imperatives and, more importantly, reflects the country's tremendous investments in space activities. The suspicions between competing national systems may render this framework of limited value. In addition, the disadvantage is that the bulk of the costs fall on the prime country. Of course, using the augmentation framework allows the prime country to exercise significant centralized 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 mission. It, therefore, wants to control the risks and their costs. Given the allocation of risk, marginal or minimal contributors to efforts are not usually given veto power over the mission decisions.

Some academics question whether the *augmentation* framework really enables true cooperation. D.A. Broniatowski, G. Ryan Faith, and Vincent G. Sabathier argue:

> …[T]here are diplomatic drawbacks to insisting on sole control of the critical path. By restricting international partners to noncritical-path items, a nation is sending a signal indicating a lack of trust and confidence in the partner's capabilities and unwillingness to rely on that partner. Rather than committing to work through problems, the nation is hedging bets in case the partner "fails." This sort of partnering is, in effect, not truly cooperative, because the requirement that one nation possess all of the critical-path capabilities is an

50 *Ibid*.
51 RYAN ZELNIO, "A MODEL FOR THE INTERNATIONAL DEVELOPMENT OF THE MOON," *THE SPACE REVIEW*, *DECEMBER 5, 2005*.
52 *IBID*.

implicit statement that such a nation can complete the system under its own power and therefore does not need its partners.[53]

Opponents could argue that there would be security risks if the United States unilaterally controlled space traffic management 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. 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 space traffic management system's mission control station might be.

Implementing the augmentation framework program would require exchanging models used for predictions as well as creating an engine that would translate orbit data and datum planes easily between systems. Establishing exchange agreements between the U.S. and commercial operators that are already primary vendors to the U.S. Government would be more easily achieved under this approach. Incorporating data from other national systems still appears very difficult, and performing effective configuration control activities would be a key to success.

While the U.S. Government has concluded that it should invest the resources to develop and operate USSTRATCOM's significant SSA systems, it remains to be seen whether it will step forward to serve as the prime country to operate a global space traffic management system. The legal underpinnings, the scope of what the system might be, the technical obstacles, and security and economic obstacles might be too costly, and benefits gained too tangential.

- ***Coordination** – Each country operates a separate program independent of others but coordinates on technical and scientific matters.* According to Ryan Zelnio, "This 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."[54] Coordinating groups exist in the international community, such as that provided by the ISO. These groups have achieved success in improving international dialogue on scientific efforts.

Operating parallel national space traffic management programs, with international coordination, has significant merit. The system of systems could

53 D. A. Broniatowski, G. Ryan Faith, and Vincent G. Sabathier, "The Case for Managed International Cooperation in Space Exploration," *Center for Strategic and International Studies*, Washington DC, 2006.

54 RYAN ZELNIO, "A MODEL FOR THE INTERNATIONAL DEVELOPMENT…," *SUPRA* NOTE 53.

be designed to leverage the best of network-centric operations theory, enabled by information sharing among partners. This framework would not require USSTRATCOM to make major changes to its current systems as it would allow direct data integration from other spacefaring States and commercial operators. Integrating data directly from government or commercial operators could improve tracking accuracy and custody at minimal cost, assuming standards and rules are in place. USSTRATCOM is already hosting sharing discussions with SSA providers and satellite owners or operators to establish data exchange standards and to conduct one-on-one negotiations for the sharing of data. The exchange of information necessary for enhanced maneuver planning might be achieved, which is important to commercial operators who profit from efficient mission planning. One would expect that exchanges would be more limited on national security systems, but perhaps established on an experimental basis until standards, reliability, and confidence among partners have been fully established.

- ***Interdependence*** *– Cooperation occurs on the critical path as well as on functional systems, with each participant still controlling their component part of the project.*[55] An interdependence framework however, suffers from a number of objections. Any contributor's lack of cooperation or funding would affect the balance of the program and its participants. Operators dependent upon space traffic management services and information could not afford interference or failure, especially in time of crisis. The United States would likely be unwilling to cede control of its SSN assets to third parties, especially since some assets contribute to its missile warning systems. Further, the United States, and some European spacefaring States, may be unwilling to share data on their most sensitive national security satellite systems.

Leadership, security and configuration control problems would probably plague an interdependence framework. For example, the Galileo precision navigation and timing satellite constellation program suffers from using an interdependence framework. Its partner nations have, from time to time, unilaterally withheld contributions, causing program schedules to "slip to the right," that is, causing delays to the overall schedule. Similarly, the United States and Russia cooperation on the International Space Station (ISS) suffers from the use of the framework. Since they serve as its prime resource contributors, this has satisfied each nation's desire to exercise leadership over the enterprise and protects equities. Unfortunately however, the framework has proven to be extremely costly. Neither has been able to keep the other from slipping their schedules and contributions and causing significant delays and cost increases, whether for good reasons or bad. For example, the

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55 *IBID*.

NASA's contributions were delayed during a safety stand-down that followed the destruction of the Space Shuttle *Columbia*. In contrast, the ISS suffers as part of mischief and miscalculations taking place as the two States jockey over the intrigues in Ukraine. On this point, Jacqui Goddard reports:

> Russia is planning to move part of its cosmonaut training programme to occupied Crimea, potentially forcing the US and Europe into a diplomatic tight spot over the future of the International Space Station (ISS). The state-owned news agency Itar-Tass has announced that splashdown survival training could soon be shifted from Moscow's outskirts to the Crimean city of Sevastopol. Any such move would pose a dilemma for [NASA] and the European Space Agency, which rely on the Russian government to ferry their astronauts to and from the ISS.[56]

- ***Integration** – Full cooperation with a pooling of resources on shared and joint research and development.* "This framework spreads the financial costs, and can utilize the industries of multiple nations while maintaining a single entity to control the critical path."[57] The European Space Agency (ESA) and Intelsat successfully employ the integration framework, perhaps with the latter doing the better job of it, in part because of its commercial not political nature. Perhaps space traffic management tasks could be contracted out to an international commercial concern. The previously mentioned SDA already provides close approach warnings to a number of commercial and government operators.

The primary negative aspect of the *integration* framework is that it usually requires acceptance of maximum levels of technology transfers between the parties. This is often difficult and complex. Proprietary and national security policy interests might make such sharing very unlikely.
A downside of an integration framework fielded with a commercial backbone is that such an arrangement might not have sensor resources of its own, such as radars and telescopes.[58] It might still need to rely upon government-

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56 Jacqui Goddard, "Russia to train astronauts in Crimea," *The Times: Europe*, September 12, 2014, http://www.thetimes.co.uk/tto/news/world/europe/article4203957.ece, accessed September 15, 2014.

57 ZELNIO, *SUPRA* NOTE 53.

58 Then again, perhaps commercial operators may be willing to invest in such systems. As reported by Mike Gruss, *Space News*: "Two companies with key roles in improving the U.S. Air Force's space surveillance system are setting up similar, privately owned capabilities to tap what they see as an emerging market to sell orbital data to government and commercial customers.
Lockheed Martin Space Systems, working with Australia's Electro Optic Systems, announced Aug. 25 it is planning a new space object-tracking site in western Australia

provided sensor systems and the participation of significant numbers of satellite operators. Transferring national-security sensor systems to contractor control may be problematic. It would require a revolutionary change in strategic thinking on how the United States and others treat sensor systems that provide warning of missile attack.

VII. What is the government's role? Can risk and regulation be better managed and performed by the private sector?

It is a mistake to assume that space traffic management necessarily involves any government, or international governmental system. 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 regulation scheme, at least for the commercial satellite industry.

In establishing any space traffic management 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 space traffic management.

Regulation of space activities and movement into and through the domain need not be performed by a governmental or international agency. The original meaning of "regulate"--as in the United States Constitutional authorization to "regulate . . . interstate commerce"--was to "make regular."[59] In this sense, 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 space traffic management 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.

Of course, regulatory entities and regulations are often seen as desirable because they can inform, educate, reduce uncertainty, and help protect one

and hopes to sell the data to the U.S. and Australian governments." Mike Gruss, "AGI, Lockheed Tout Commercial Space Surveillance Systems," *Space News*, September 1, 2014, http://www.spacenews.com/article/military-space/41727agi-lockheed-tout-commercial-space-surveillance-systems, accessed September 15, 2014.

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

from dubious activities. 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 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 space traffic management 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.

Whatever regulatory system is chosen should deliver incentives so that space operators and States will "voluntarily modify their behavior" to achieve the goals of the regulation. Space traffic management regulation, however implemented, should be designed to reduce uncertainty, reduce costs, and increase the safety and quality of space operations. Even if they deliver those benefits, we still need to compare the benefits of regulation with the costs they impose. These include:

- On-budget costs, or the costs of running and maintaining the proposed regulatory agencies.
- Compliance costs, or the burden those individuals, businesses, and the government have to bear in order to comply with regulations. Indeed, regulatory spending tends to be only a tiny fraction of total regulatory costs. Compliance costs include the necessary expenditures for meeting regulatory requirements and the resources spent on filing the paperwork required by specific regulations.
- Hidden costs, or the indirect costs of regulation, which include lost opportunities and benefits that could have been attained if available government and private resources had not been devoted to excessive regulatory activity. The hidden costs of regulatory activity would include the loss of forgone services and benefits from alternative uses of the wealth used to implement the regulations. These costs can reduce wealth without any real contribution to health, safety, or mission success. One of the most unfortunate consequences of government regulations is the reduction of output. Regulations increase costs. As a result, productivity losses and decreased investment reduce total output and hamper growth.

Fortunately, the private sector offers a number of attractive models for space traffic management. 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.[60] 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 compliance costs in advance. As such, they better assess the expected costs and benefits.

VIII. 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 space traffic management 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. Privately performed space traffic management framework might provide a more flexible, responsive, and evolutionary processes, and this in turn could reduce space operator compliance costs.

60 *Ibid.*