



Shaping the Future of Aerospace

Space Traffic Management (STM): Balancing Safety, Innovation, and Growth

A Framework for a Comprehensive Space Traffic Management System

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Statement of Attribution

This paper was drafted over the course of the past year, reviewed in September 2017 and approved by the AIAA Board of Trustees in November 2017. The AIAA Space Traffic Working Group consisted of members of AIAA and the Association of Space Explorers (ASE) who, collectively, have a breadth of experience in space technology, policy, and operations.

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Executive Summary

With alarming and recent increase, space has become more crowded with earth orbiting space craft and debris, bottlenecks have emerged in highly desirable regions of operation, and Government cataloging, analyzing, and warning systems are becoming overwhelmed and inadequate to the conditions at hand. The clear implication of all of these factors is that safe and uninterrupted operations in earth orbit may be at risk. This is strong motivation for the development and deployment of a mature Space Traffic Management (STM) system. The suggested topics in this paper in no way comprise the necessary solution in its entirety and there is a strong need for much additional discussion. This paper serves as a framework, for deliberation and action by a broad community of practice that must become a community of participation in a coherent plan of attack. The framework is a vehicle to initiate a structured dialog, preserve continuity of thought, and provide a catalyst for change with the best interests of a multi-faceted space community in mind.

The essential outcome of an effective Space Traffic Management (STM) system is safer operations in space now and in the future. Keys include avoiding unnecessary and unabated pollution of the space environment with new debris and improving cataloging and tracking custody of more and smaller objects for better collision avoidance and achieving more confidence in smaller and safer close-miss distances to increase the credibility of alerts and reduce the distraction of warnings that aren't likely to materialize. Focused conversations around collision avoidance and data sharing, debris mitigation, a code of behavior, more extensive and transparent voluntary coordination while a central authority is established, and a communication strategy are needed. The resulting improvements that can be established will lead to more transparency of action, more timely understanding and management for real risks, and more proactive cooperation, while laying a foundation for a more robust STM in the future under a coherent purview by a central agency with authority, resources, and immunity to act.

Space exploration at its outset was primarily the business of Governments and accordingly, national and scientific interests drove policies, procedures, and behaviors. As with the emergence of commercial and private interests in the aviation sector many years ago, industry and private enterprise are poised to assume a dominant role in the space domain. The need to manage safety of space operations for present day space platform owners and the public, and the need to preserve the space environment for generations to come, requires a 'back to basics' approach, leaning heavily on the familiar successes of the aviation model, with relevant adaptations. It is time to develop a coherent, coordinated, open, and strategic approach to Space Traffic Management (STM), structured to handle the large number of objects in orbit today and anticipated in the near future.

Since our first ventures into space, from the lunar landings of the Apollo Program, through the Cold War, and throughout the Space Shuttle and the International Space Station eras, we have systematically expanded our space operations knowledge, applied lessons learned, and advanced our operational capabilities by mastering each new space related challenge. Driven by a host of well-funded companies' intent on placing large satellite constellations in space, we have reached the Third Phase of Space Exploration: Commercialization.¹

While the present space surveillance system created by NASA, the Department of Defense (DoD), and the Intelligence Community (IC) has been adequate to meet needs so far, the demands of this Third Phase will require a more innovative, scalable, open, and cost-effective system to support the increased tempo and density of activity. In addition to a broadened approach, emerging technologies including increased autonomy, machine learning, and big data analytics will be essential in the design and operation of a comprehensive space object and event tracking management system, necessary to help humans understand and respond to the complex and fast-moving world of space traffic.

¹ <http://archives.esf.org/hosting-experts/scientific-review-groups/humanities-hum/news/ext-news-singleview/article/space-exploration-30-about-to-begin-357.html>

The safety of all space operations today and the assurance of a usable space environment for generations to come depends on how well we can design and perform effective Space Traffic Management (STM). The Federal Aviation Administration (FAA) has been tasked with leading a collaborative effort with other US government agencies to address these challenges. While the problem is international in scope, paradigms established in the US will help inform and create a starting point for dialog with the global community regarding the institution of an approach satisfying the needs of all space-faring nations.

Solving all of the problems associated with our situation today may not be possible, but the following framework is suggested by the AIAA to begin to address some of the more pressing issues related to STM:

Collision Avoidance and Data Sharing: As congestion increases in orbital bands and objects transition from one band to another, the ability to successfully predict potential collisions and take action to avoid them is critical. Predicting these events requires adequate data, advanced algorithms, identification, and tracking techniques. Several key technologies and capabilities need to be developed and standardized. For example, based on predictive capability, various avoidance methodologies must be defined, standardized, and developed. In addition, smaller pieces of debris may not be measurable even with updated technologies. Therefore, protection from micro-sized debris must also be incorporated into spacecraft design. STM is not the magic solution for controlling the behavior of dead objects. However, tracking (i.e. detecting and uniquely identifying) more of them and predicting conjunctions more accurately, further in advance, could help maneuverable objects avoid the consequences of a new, larger dead-debris field and even reduce the likelihood that the arrival of live objects will become dead ones in an expanding region of collision risk.

Given the amount of debris remaining to be discovered, tracked, and characterized, all countries and organizations should be encouraged to contribute observational data using community-accepted (e.g. International Organization for Standardization or ISO standard) methodology and parameters that can be used to create a high confidence catalog of all objects in earth orbit. Pooling and normalizing civil and commercial data into a “Data Lake”² without diminishing the accuracy or removing the traceability (audit) of its collection, will enable broad access to accurate data for operational and research purposes related to tracking, analyses, conjunction monitoring, and sharing. A critical element of data sharing must be cooperation between military and civil agencies. A process for taking into account classified objects and classified missions must be developed to account for the conjunction probability of a live (maneuverable) satellite with any object (dead, alive, disclosed, or hidden) that reduces risk while preserving important secrets.

Debris Mitigation: A combination of factors can help reduce the debris problem including 1) better science to understand debris behavior, 2) quantification of the amount and the priority of debris removal necessary to reduce risk, 3) the maturity of the proposed solutions concerning reliability and effectiveness and 4) more affordable solutions that can be brought to bear. An important dimension of dealing with the debris problem for the future is to not make it worse in the present. Near term actions can slow the creation of new debris, improve the tracking of more objects, and improve conjunction assessments. The DoD cannot by itself keep up. This will require an enabling business model to increase commercial and academic participation in monitoring, tracking, and characterizing objects and growing our body of knowledge faster and more completely.

Behavior Guidelines/Code of Conduct: Establishing common standards for behavior, based firmly upon empirical data and evidence, will help satellite operators avoid misunderstandings, conform to safety constraints, plan for reasonable operating envelopes, and anticipate and practice procedures for dealing with normal and emergency situations. Potentially, this could be developed under the auspices of ISO³ activities and the Union of Concerned Scientists (UCS)⁴.

2 *Jah* <https://sites.utexas.edu/moriba>

3 <https://www.iso.org/committee/46614.html>

4 <http://www.ucsusa.org/nuclear-weapons/space-weapons/satellite-database#.WX3Rantt4II>

Organizational Oversight: Establishment of a body or organization responsible for monitoring, oversight, coordination, and enforcement (including incident management) will greatly benefit design and operation of a successful and sustainable space traffic management system. This body must incorporate the concerns of the affected parties while balancing the need for effective control as policies and procedures are developed.

Comprehensive Communication Strategy: Ultimately, a space traffic management program could involve a large number of agencies, companies, universities, and technologies. The efficient and secure sharing of information amongst this group will be vital for managing traffic in a congested space. As such, a communication strategy that includes policies and procedures for who to contact, when to initiate, how to format, how to assess and assign urgency, and expected responses will be required. In addition, communications have to be secure and reliable.

Introduction:

Since the birth of aviation, the aerospace sector quickly evolved from having a few isolated adventurers daring the skies, to the present day, with thousands of military and commercial aircraft operating simultaneously across the globe. Despite the seeming vastness of the skies, as more people and machines came online, bottlenecks emerged, and unmanaged traffic introduced new dangers. As the aviation community grew, the need for a framework to reduce the risk to flight operations and the general public became apparent. Maintaining safety in an increasingly complex environment, while aiding the growth and development of aviation, required a multi-faceted approach to managing, not eliminating, traffic.

The first step required was to understand both the point of origin, the path to be followed, and the destination (predictive situational awareness) of aloft vehicles with quantifiable accuracy and precision. From this requirement came the principal of “custody” as related to vehicle tracking frequency. Tracking requirements, whether continuous or periodic, based on object behavior, enabled the development of evidence-based behavioral norms and rules, which lead to standards, codes of conduct, and licensing that reduced human-induced error and surprise. Second, guidelines, oversight, and inspections certified through licensing ensured increased airworthiness of aircraft and control systems, incorporating diligently derived and applied lessons learned. Authority and custody for tracking objects was established. Evidence-based behavioral norms and rules emerged and became institutional practices. Finally, a real-time communication strategy was established and managed by a central entity, leading to agile and comprehensive coordination across a full spectrum of stakeholders vested in the progress and dependent upon the success of aviation.

Today, crowding, bottlenecks, and increasing numbers of objects orbiting the planet signal the need to develop a mature space traffic management (STM) system. As with early air traffic, reduction in barriers to space travel like technical accessibility and economics have now caused sufficient congestion and risk in space travel to where an analogous organization and structure to air traffic management is now required to manage space traffic. Many new entrants into the launch and operations business have expressed the intent to launch satellites, both large and small, as well as humans, into Earth orbit. The Indian Space Research Organization (ISRO)’s recent single booster launch of 104 satellites⁵ is just one recent example of action following intention. As more entities express interest in deploying “clusters” of small satellites (like Boeing, who plans to orbit up to 2956 satellites⁶) more must be done to anticipate growth and deal with this increasing orbital traffic. Growth in launch services will soon be joined by several companies performing satellite servicing or inspection, which requires closer operations and smaller miss distance tolerances as rendezvous and proximity operations and near-continuous maneuvering mature.

⁵ <http://www.reuters.com/article/us-space-launch-satellites-india-idUSKBN15UOEI>

⁶ <http://spacenews.com/fcc-gets-five-new-applications-for-non-geostationary-satellite-constellations/>

Commercialization of Earth orbit has begun.

Currently, antiquated methodologies and procedures exist to prevent conjunctions between an increasing number of intentionally placed satellites and as many as 500,000 pieces of space debris, much of it undetectable and/or un-trackable today by earth-based sensors. Given that congestion is on the rise, and any object in orbit on the order of millimeters or larger (satellite or debris) could pose life-time risk to operating satellites, the use of outdated technologies and tracking methods is especially troubling. Furthermore, at this time, approximately ninety-five percent of debris is untracked on a regular basis (i.e. 23000 are tracked but 500000 are hypothesized to exist). In addition, predicting the path and de-conflicting potential conjunctions for 100+ slow ascending/descending satellites through orbits occupied by objects like the International Space Station (ISS) is no trivial matter. Current observational frequencies (i.e. how often a given object is physically interrogated) for sensors to develop an up-to-date track for space objects can be on the order of days. This creates large uncertainties in orbital data which are managed by expanding the size of conjunction “buffers” around space objects, which in turn results in more potential conjunction warnings.

Current assessment and warning capabilities provided by the Department of Defense (DoD) have been overwhelmed by the increase in orbital activity, causing a growing distraction from their primary mission of ensuring national security. As orbital traffic increases, ***an independent, non-DoD-based capability that can provide Space Situational Awareness (SSA), timely communications, and central coordination is essential***, to ensure coherent and safe management of our near Earth environment.

Framing the Issue:

As with the evolution of the aviation sector many years ago, industry and private enterprise are poised to assume a dominant place in the space domain. Management of safety for space platform owners and the public, and the preservation of the space environment for the future, requires a ‘back to basics’ approach, leaning heavily on the familiar successes of the aviation model, with relevant adaptations. It is time to develop a coherent, coordinated, open, and strategic approach to STM, structured to handle the burgeoning number of objects anticipated in the near future.

Conceptually, key elements of aviation safety strategy can be applied to the burgeoning congestion of the space environment, with one noticeable exception: debris in the atmosphere dissipates quickly (burns, vaporizes, falls to earth, etc.) before it becomes a persistent threat to other flying objects: debris in space typically persists for lifetimes unless and until an effective a debris purging capability can be implemented (and affordable, effective clean-up techniques seem to be a long ways away).

Consequently approaches to avoiding unnecessary and unabated pollution of the space environment with new debris and improving cataloging and tracking custody of more and smaller objects for better collision avoidance and achieving more confidence in smaller and safer close-miss distances to increase the credibility of alerts and reduce the distraction of warnings that aren’t likely to materialize must be identified.

There are several initial steps that must be taken to create the infrastructure for a comprehensive, reliable STM system:

Collision Avoidance and Data Sharing: The top priority and metric for success of the STM Program will be collision avoidance. Coupled with successful avoidance is the reduction of unnecessary warnings (false alarms), which can be achieved only when there is greater confidence in object state vectors, prediction, and narrower miss distances. Thanks to advances in astrodynamics (the science that studies the motion of objects in space), orbital trajectories are more predictable than the flight path of an aircraft. Despite the ability to understand trajectories, however, predicting collisions remains complicated; over half a million pieces of debris are hypothesized to be

moving at extreme speeds in unknown orbits, ranging from low Earth to beyond the geosynchronous belt. Add in objects that are changing orbits in real time, such as satellite servicers or slow ascent objects, and the problem becomes even more severe. Because a predictive SSA capability must minimize the risk to all space platforms in this complex environment, accurate and timely tracking data on the largest possible quantity of orbital debris is necessary to inform analytical techniques. In addition, as the database of objects orbiting the Earth grows, it is necessary to develop the ability to assign a Unique Space Object Identification (USOI) to all trackable objects; the lack of a rigorous object characterization and classification scheme is a strong contributor to our inability to track more objects in space and communicate clearly. The key to a successful STM system hinges on its capabilities to detect, track, identify, and predict the behavior of orbiting objects in a timely fashion. Only by knowing where all of these individual objects are and how they move and behave can evidence-based norms of behavior be developed.

Several technical steps are required to develop a comprehensive, effective collision avoidance program:

1. Accurate observational methodologies and modeling techniques are imperative to understanding, tracking, and predicting the orbits of all satellites and significant debris. Currently, scientific taxonomy does not exist to accurately describe and uniquely identify orbiting objects. Unfortunately, all of these objects are modeled as simple spheres, reducing the accuracy and utility of orbital trajectory determination used to predict potential collisions. Simple geometric approximations of objects in a densely populated orbital environment are not adequate to support collision avoidance strategies; modeling techniques must be improved beyond simple spherical geometries.
2. More sophisticated modeling techniques must be accompanied by additional observational data (telescopes, radars, lasers). A database of all available sensors, as well as the identification of new sensor systems required to create more accurate databases for Resident Space Objects (RSOs) should be created.
3. Increasing numbers of sensors surveilling space objects, and pooling of observational data is necessary to increase the frequency and numbers of observations needed to monitor the growing population of satellites and debris in earth orbit. Decreasing dependency on DoD sources without excluding releasable information can make sharing easier and broaden non-DoD participation in official space object tracking, without introducing unmanageable additional risk. This will require a central entity to collect all observational data, ensure its accuracy, and create the “Data Lake” suggested by Dr. Jah⁷. With more accurate and timely orbital information and better propagation models, spurious conjunction warnings can be reduced.
4. Once advanced modeling techniques are combined with sufficient observational data (data lake), adequate state vectors and information trajectories can be used to develop propagation predictions for orbiting objects. Well-developed propagation models can be used to predict potential conjunctions, even before new spacecraft are launched. For preflight analyses, simple orbital information (RA, Dec, inclination, etc.) can be used to identify obvious conflicts. This would prevent placing satellites into occupied orbits. Shortly before launch, more detailed and current data could be used to identify specific conjunctions to coordinate both launches and orbital insertions. Once in orbit, more sophisticated methods will be required. The challenge is building adequate propagation models to provide actionable data in advance to support decision making (e.g. for satellite orbit insertion or collision avoidance maneuvers). Consequently, the baseline assumptions and error margins of the prediction models have to be well understood and documented throughout the community. Standardization and agreement on assumptions, uncertainties in data, and confidence levels in analytical methodologies are crucial to building assurance in any conjunction warning system or decision making algorithms.

⁷ <http://www.satellitetoday.com/technology/2017/05/31/academic-research-can-help-solve-space-junk/>

5. In order for a STM system to remain relevant and useful for adequate space situational awareness, the catalog of debris objects needs to be continually updated with all sources of information, (e.g. sensor systems, analytical methods, responsible individuals or companies, etc.). An agreed to list of the type and scope of data on each object necessary for a functional catalog should be established.
6. A collision avoidance function should issue alerts and warnings with sufficient lead time, and realistic measures of uncertainty, for operators to further analyze the information and perform a maneuver if needed, within an appropriate reaction time window. The probability of any collision is never based upon knowing the truth, because the truth is never known until after the event happens or not. This is to underscore that the probability of any collision is determined by the analyst's belief in their current and predicted knowledge of the resident space object population. Collision probabilities will become lower with increased knowledge (reduced uncertainty) of current and predicted locations of resident space objects. In other words, a community-wide pool of both independent and disparate sources of information available to analysts is the single-most important capability that will effectively reduce collision warnings and enable increased actionable knowledge to support decision-making processes. Moreover, additional metrics are needed above and beyond reports of collision probabilities. A collision probability is a scalar value that in no way provides insight into the type, quality, or quantity of information sources used in deriving it. This is part of the problem. A collision probability of $1e-2$ in the absence of any other information could trigger a maneuver, but what if that number was achieved with only a single sensor? Most decision-makers would want at least two independent sources of information to either confirm or refute a given belief or hypothesis. This gets to the heart of orbital safety: deriving and defining metrics that provide actionable knowledge where actionable implies realistic measures of confidence.
7. There will always be a certain amount of smaller sized debris that cannot be tracked. To harken back to the aviation analogy, small 'bird strikes' of micrometeoroids are inevitable for any spacecraft, but more analysis is required to understand the orbital population and distribution of unwarned damaging objects that cannot be avoided. A better understanding of what constitutes lethal debris along with models that provide insights into risk exposure, can aid space craft developers to better protect high value assets through design options such as shielding. As an extreme example, satellites without appropriate shielding against micrometeoroids for their environment run the risk of mission loss, not to mention also becoming a new debris object.

Data sharing must include cooperation between military and civil agencies. Some classified objects and most classified missions can perhaps remain undisclosed in the future but the conjunction probability of a live (maneuverable) satellite with any object (dead, alive, disclosed, or hidden) must be shared so that if the best solution is to maneuver the acknowledged object to reduce risk and preserve National security, the acknowledged object has a reasonable window of opportunity to succeed and its operator has a reasonable degree of certainty that the unplanned consumption of fuel was warranted. And similarly, should there be civil or commercial objects that a persistent non-military collection enterprise supporting STM sees more accurately or more timely way than a military counterpart, that information must be shared with operators of sensitive military objects. Given the right trust environment, collaborating on assessments, models, and methods can be a distinctive advantage to safety and security.

Debris Mitigation: There is no shortage of novel ideas on the drawing board for debris removal in space. What is lacking is 1) better science to understand debris behavior, 2) quantification of the amount and the priority of debris removal necessary to reduce risk, 3) the maturity of the proposed solutions concerning reliability and effectiveness, and 4) the affordability of the solutions that can be brought to bear. Several studies have shown that while the larger sized pieces will create more spectacular conjunctions and cascading consequences (Kessler Syndrome) if they occur, the knee in the curve of where active debris removal begins to reduce risk is beyond the reach of our current technology or purse strings. Commodity priced solutions necessary to address the volume

and scope just aren't ready yet. When the technology enables prototypical success, there may still be a long road to travel before sufficiently scaled solutions fall within limits of practical affordability.

This is not to say nothing can be done about debris in the meantime.

An important dimension of dealing with the debris problem for the future is to not make it worse in the present. Near term actions can slow the creation of new debris and reduce the amount of untracked, uncharacterized objects. As the expansive wave of planned launches materializes, third party data collection can be introduced showing the amount and location of debris created during each launch and insertion. Launch agencies (companies and countries, government and commercial) can be encouraged or required to self-report the debris they create and where it will persist in orbit. Offering reduced launch fees (license and registration) and more affordable insurance could inspire more responsible behavior. As could requiring larger amounts of insurance coverage where debris risk is not sufficiently addressed prior to mission start.

Similar efforts to reward on orbit and de-orbit practices that are demonstrably contributing to the long-term space environment sustainability, can also be designed and encouraged. With a more thorough understanding of the debris already in orbit, how it behaves (classes and taxonomies), and where and when it is likely to surface as a threat, we can improve conjunction assessments and enable narrower safe miss distances. This can also enable better mission planning, fewer false alarms, safer execution of maneuvers.

Leaving responsibility for expanded coverage of more debris, more launches, and more conjunction possibilities solely in the hands of the DoD and its exquisite defense and intelligence collection and warning systems, will quickly overwhelm capacity. This massive expansion can only be dealt with by creating an enabling business model to leverage commercial and academic capabilities that can stare, track, and characterize objects more persistently and affordably. Putting more minds to work on the problem will grow our body of knowledge to predict behavior (classes of objects, ontologies, propagation models, and perturbations of forces like weather, radiation, and gravity) faster and more completely.

Behavior Guidelines (Code of Conduct): A code of conduct defining rules, regulations, treaties, and agreements required to develop a uniform, effective, and safe STM system should be created. Such codes exist in the maritime and aviation domains. Without a common code of behavior, the space community risks operational confusion, potentially leading to increased numbers of collisions, resultant debris, and the loss of utility of entire orbital bands. Developing a code of conduct is a significant undertaking, requiring the participation of all stakeholders. Various components of an effective Code of Conduct include:

1. The Code of Conduct for satellite operators must be tied to timely and actionable orbital information on all objects. The community will need to establish what information is vital to document each object, in order to predict behavior early enough to take actions to avoid collisions.
2. Clear policies and licensing that goes beyond frequencies and GEO slot assignments are essential. For example, policies and procedures that meter sequencing and integration into other orbits would be beneficial.
3. Technical and operational safety standards for highly dynamic activities such as rendezvous, proximity operations, and satellite servicing should be developed to provide a basis for predictable behavior. The recent DARPA program, CONFERS, is an example of such an effort.
4. Documentation establishing what information needs to be shared and exchanged for STM purposes (including incident management) should be agreed on and widely disseminated. In addition, identification and elucidation of the consequences for failure to follow guidelines established is imperative to creating an effective Code of Conduct.

Oversight Organization or Body: The key to a sustainable, stable, and successful STM approach is the identification of a responsible body or organization for monitoring, oversight, and enforcement. Doing so would provide a clear centralized location for coordination with industry and other entities, rather than having different functional elements of a space tracking management system spread across different organizations. For the near term, as a structured solution to this challenge is developed, responsibility should fall to the Federal Aviation Authority (FAA), so that the DoD may focus its attention on national security issues in space. In order for the FAA to be successful in this regard, they will require:

1. **Legislative Authority:** Congress needs to act immediately to make the FAA the lead government agency to perform these functions for Civil and Commercial satellites. Military agencies must be collaborative partners in assisting the development and transfer of STM capabilities to the FAA.
2. **Adequate Funding:** The development of a reliable STM system will require suitable and sustainable funding. Marginal or inadequate funding will delay development raising the risk of a significant accident.
3. **Immunity for Liability of Actions:** The FAA should not be legally liable for any outcomes or events resulting from the execution of their assigned duties.
4. **Program Plan:** A detailed program plan must be developed that outlines a vision for STM and operationalizes an approach that includes not only the development of activities, schedules, and funds, but also the interagency agreements needed to move STM forward.
5. **Coordination with International/Industry Partners:** The development of any STM program should not be conducted in a vacuum. The United Nations and other foreign governments, along with the global space industry, should be made aware of the efforts of the US and FAA and invited to comment and make suggestions on ways to improve upon their proposals.
6. **Arrangements to attain sensor information:** The STM program hinges on the ability to see RSOs using a multitude of sensors. As such, the FAA should have a robust program to attain sensor information (if not data) from both government and commercial sources. This would include cooperative requests for additional sensor taskings in the event of a pending collision and/or a post-collision incident.
7. **International Coordination:** At the same time that the U.S. community works to develop an initial framework for STM, appropriate discussions with the international space community must be included in the effort to support an eventual transition to an international program.

Communication Strategy: Ultimately, a globally successful and effective STM program will encompass a large number of agencies, companies, and other entities all of whom will need to be able to communicate with each other in an efficient and secure manner. At a minimum, a communications plan should include:

1. When, what, and how satellite operators who are planning maneuvers should be sharing information about their intentions. For example, the required information may not simply include when the maneuver is planned, but also the associated uncertainty (i.e. execution error, deterministic and stochastic). As previously mentioned, standards are required to ensure the right information flows at the right time to the right parties, with a set of mutually agreed upon expectations.
2. Policies and procedures identifying all participants in the STM program, how they can be contacted, under what circumstances communications should take place, and what result should be expected from any communication.

3. The application of information technology and cyber security practices to ensure data and communications remain secure and uninterrupted.
4. A rudimentary warning procedure for all entities, in the event of a pending/actual on-orbit collision.

Conclusion:

It is not necessary to start from scratch to develop a robust, comprehensive STM system. The DoD space community already has experience with existing regulations and reviews governing launch, on-orbit operations, and end of mission policies. NASA and the Air Force, for example, have guidelines in place designed to limit debris generation through design considerations, and the Air Force has regulations that require the attainment of debris mitigation metrics by any launch program. The Air Force (and other DoD components) and STRATCOM have been launching, tracking, and operating spacecraft for decades. In addition, the industry, academic, and international communities have in large part cooperative experiences for conjunction analysis with the DoD. Existing practices for geosynchronous orbit, Earth observation, and operating frequencies have decades of operational exposure. An expansion of these practices, to include proper procedures for changing orbital altitude and inclination, and the establishment of cooperative network of cost effective systems for monitoring on orbit activity is a logical next step. If appropriately integrated, industry and academic capabilities available today (outside of the DoD and Intelligence Community), can be used to improve metric analysis, frequency awareness, and conjunction assessment in a more timely manner. Non-governmental assets have evolved and bring both improved capability and cost margins, and the owners of these capabilities should be approached as partners in a future space traffic management network.

It is time for the space community- government, industry and academic- to join forces to address the myriad of issues related to establishing a space traffic management system. Using the framework outlined in this document, tasks and action plans can be defined and assigned to those best positioned to lead. The community at large recognizes the urgency and timeliness of tackling this problem—continuing in the current operational mode is not sustainable for the DoD, nor is the current mode an appropriate one for the increasingly challenging complexities of the space environment and the myriad of entities who leverage it. Without more robust guidance, oversight, liability management, and accountability by an entity capable of making STM a primary focus, use of space and the sustainability of the space environment will face increasing risk. This framework provides the starting point of a much-needed conversation on the future of space traffic management.