ADVANCING A STRATEGIC APPROACH TO GLOBAL SPACE TRAFFIC COORDINATION

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A message from MITRE and NAPA Leadership

On December 1, 2021, Vice President Kamala Harris convened the first National Space Council (NSpC) meeting of the Biden Administration and presented the United States (U.S.) Space Priorities Framework. Among the priorities identified for this governance board was the intention of its members to "bolster space situational awareness sharing and space traffic coordination."[1]

The timing for this priority could not be more critical.

Global space traffic coordination (GSTC) is one of the most pressing issues facing the space domain, and the world is not prepared. With nearly every industry relying on space-based services, the risk of degradation or disruption of those services resulting from collision and catastrophe is growing, with extreme implications for our Earth-based security, economy, and societal progress.

This sentiment has been echoed by other participants in the space industry. For instance, the National Academy of Public Administration's report, "Space Traffic Management," published in August 2020, commented on the importance of addressing these challenges: "with the risk of orbital collisions and close conjunctions growing astronomically, we face a crisis that must be urgently addressed in order to facilitate orbital safety and enhance commercial and research advances."[2]

More leadership is needed.

The U.S. can play a much larger role in shaping the GSTC domain. By working with other nation-states, the private and non-profit sectors, and international entities (e.g., the United Nations), the U.S. can champion a strategic direction for the global community; develop and share global standards and norms; innovate and build the technology needed to mitigate risks and solve problems; and execute the functions necessary for global safety, security, and progress.

This paper builds on this idea by proposing a strategic direction for GSTC. It identifies a set of long- and short-term performance outcomes and indicators that reflect the most pressing challenges facing the domain and serves as a roadmap for decision making and resource allocation. The paper also helps government leaders by identifying what the GSTC community should value, informing its choices about policy, regulation, norms, accountability, roles, responsibilities, and authorities in the near future.

As the NSpC implements the current policies of the Biden Administration for space traffic coordination, this paper seeks to guide, inform, and support the advancement of this priority.

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Executive Summary: A Call for Urgent Action

Space is a common pool resource for the world. The use of orbits around the Earth is vital to many capabilities that drive global civilian and commercial activities, including telecommunications and access to the internet, navigation, weather forecasting and prediction modeling, as well as scientific research. However, as space becomes increasingly popular, the shared use of this resource becomes threatened.

Building on the recommendations identified in the National Academy of Public Administration's (the Academy) report, "Space Traffic Management," this paper lays out a strategic direction for the United States (U.S.) to advance global space traffic coordination (GSTC) and preserve space as a common pool resource for future generations. The purpose of this strategic direction is to guide all GSTC activities and contribute to ongoing conversations about federal priorities, resources, and investments.

In this spirit, the authors propose that all GSTC activities should be guided by three long-term performance outcomes for the domain:

1. Preserving operating regions of space
2. Advancing the space economy
3. Maximizing the probability of mission success

These outcomes reflect what should be the shared interests for all space actors. They are interdependent and mutually reinforcing. Because of the diverse interests of space actors, these outcomes may be interpreted or valued differently. These outcomes reflect what should be the shared interests for all space actors. They are interdependent and mutually reinforcing. Because of the diverse interests of space actors, these outcomes may be interpreted or valued differently. It will be important for the U.S. to work alongside its partners—other nation-states, international governing entities, state and local governments, as well as private and nonprofit entities—to come to a shared understanding of the outcomes and, by extension, adapt to evolving global market trends with policy and regulation, standards, and norms that influence and incentivize desired behaviors. The convening role, such as that recommended for the Office of Space Commerce (OSC) in the Academy's report, can be applied more broadly to urgently perform activities that establish a stable foundation for GSTC to operate upon.

THE PURPOSE OF THIS STRATEGIC DIRECTION IS TO GUIDE ALL GSTC ACTIVITIES AND CONTRIBUTE TO ONGOING CONVERSATIONS ABOUT FEDERAL PRIORITIES, RESOURCES, AND INVESTMENTS.

As leaders navigate the accelerating pace of change to space-based activities, they will need to take additional factors into consideration that should frame their choices and inform their decision making. To advance the long-term outcomes, this paper uses a performance logic model to sequence near-term progress, related performance indicators, a prioritized list of supporting activities, and suggested domain values.

This paper is organized in four sections: Section I highlights the overall approach; Section II, the long-term strategic approach; Section III, considerations for the next three to five years; and Section IV, considerations for next steps.

Section I: About This Paper

The authors took a phased approach to the development of the recommendations in this paper.

Initially, the authors reviewed nearly 140 articles from open source materials, including academic literature, industry papers, government documents, and news and commentary. This was complemented by a series of interviews with nearly 30 current and former government leaders, industry practitioners, and subject matter experts. The interviews explored the challenges facing the global space traffic coordination (GSTC) domain and considered what success for the U.S., in the context of a global system, could look like.

The authors then derived themes from the literature and interviews to inform a series of working sessions with select subject matter experts and to develop a set of long- and short-term performance outcomes and indicators for GSTC. These outcomes were laid out and sequenced in a performance logic model that represents a proposed strategic direction that U.S. government leaders can use to drive future engagement with international and domestic actors in shaping the GSTC domain.

The working session members also identified a set of values to support government leaders in maturing the GSTC domain. Proposed changes in the organizational system that supports GSTC can be weighed against these values to inform their choices and actions.

A Long-term Strategic Approach to GSTC

The space domain is becoming increasingly crowded, with grave implications for the global use of space as a common resource. From a security perspective, direct-ascent anti-satellite tests by China in 2007 and the most recent test by Russia in November 2021 have generated sizable debris fields; Russia's test alone generated over 1,500 new trackable debris objects in low Earth orbit.[4] Similarly, on the commercial side, the number of satellites and the relative size of the global space economy are expected to more than triple in the next decade, mostly from the launch and deployment of large constellations of commercial spacecraft.[5] Similarly, on the commercial side, the number of satellites and the relative size of the global space economy are expected to more than triple in the next decade, mostly from the launch and deployment of large constellations of commercial spacecraft. Indeed, this accelerated growth in activity poses potential global risks to, among other things, overall access to and capacity of useable orbits; communications; positioning, navigation, and timing (PNT) capabilities; and continuity of Earth observation.

Acknowledging these risks, both the Trump and Biden administrations, as well as Congress, have recognized the need for robust space traffic management (STM) capabilities, referred to in this paper as GSTC, to manage this congestion. These efforts included:

- The National Space Council (NSpC) under the Trump administration issued Space Policy Directive (SPD)-3 to coordinate a federal response to GSTC by directing the Department of Commerce (DoC) to lead select civilian GSTC functions.[6]
- Congress, in turn, responded to (SPD)-3 through the Consolidated Appropriations Act of 2020[7] and directed the National Academy of Public Administration (the Academy) to provide recommendations on which federal government agency should lead civilian GSTC functions. The Academy made several recommendations on the role of DoC in leading the community as a convener.[8]
- The White House released the National Space Policy in December 2020, reaffirming the Academy's recommendation that DoC lead U.S. government stakeholders in partnerships with the private sector in support of space situational awareness (SSA) and civil and commercial space safety. Congress provided additional funding to the Office of Space Commerce (OSC) through the Consolidated Appropriations Act of 2021, which initiated an STM pilot program to develop an Open Architecture Data Repository (OADR).
- The NSpC under the Biden administration published the U.S. Space Priorities Framework, acknowledging GSTC as a continued priority[9]

However, more leadership from the U.S. is needed to advance GSTC and promote space as a common pool resource.

This paper builds on the Academy's analysis and recommendations by advancing a strategic direction for the federal government that broadens the U.S.'s impact across the GSTC domain. This strategic direction is intended to contribute to ongoing conversations about priorities, resources, and investments, and, in this spirit, includes a set of long- and short-term outcomes and corresponding performance indicators, as well as a prioritized list of activities. In other words, what does the U.S. need to advance GSTC, what does success look like, and how should today's government leaders think about changes to the GSTC domain in the near future?

Who are the actors involved?

Operating on the old adage that people participate in the change they help to create, U.S. leadership on a strategic direction for GSTC, then, will require commitment from a variety of actors.

The GSTC community is made up of actors with varying interests, roles, responsibilities, functions, and authorities, each of them influencing and executing GSTC activities in different ways.[10] These actors fall within the categories of U.S. government, international, non-governmental, and commercial entities. Table 1 identifies the broad categories of actors involved in GSTC, examples of those actors within each category, and a high-level description of their respective roles.

TABLE 1. STAKEHOLDERS INVOLVED IN GSTC

	Actors	Role
U.S. Government	Federal Executive Branch: NSpC; various Cabinet-level departments and agencies	· Executive oversight; policy development · Satellite operators · Owners of important processes including: spectrum allocation, licensing, research and development · May promulgate regulations that impact GSTC system
	Federal Legislative	· Agency authorizations · Legislative oversight · Appropriations and funding
	State and Local Legislative	· Enact state and local legislation that impacts commercial space industry · Determine how to compete in the global launch facility market
International	Intergovernmental Organizations	· Broker international agreements/treaties · Coordinates standards and helps establish international norms · Hosts forums for international discussions and facilitates international cooperation
	Foreign Governments	· 11 countries capable of launch, over 100 have satellites in space, and many more utilize space-based services
Non-Governmental	Nonprofit/ Non-Governmental Organization Sector	· Advocate for space policy · Share information
	Academia	· Research and development · Partners to solve engineering and technology challenges
Commercial	Global Space Industry and Its Users	· Satellite and payload operators · Impacted by regulation, processes, rules, and norms · Active decision makers that affect and are affected by the system · Provide and utilize a variety of services that include: SSA, launch, data analytics, monitoring, hardware, space tourism

For actors within the U.S., including state and local governments or private and nonprofit sectors, this may simply involve additional input into the strategic direction for GSTC. However, internationally, because individual nation-states possess sovereignty and therefore control over their respective space activities, commitment will likely require more than simple input. Indeed, attempting to align these international efforts with domestic policy may require new models for participatory decision making.

In its report, recognizing this plethora of actors and functions related to GSTC, the Academy recommended that DoC operate as a convener to execute its civilian GSTC functions internationally and domestically at an operational level. This would involve DoC bringing these actors together in a single assembly to provide inputs on the development of policy, regulation, standards and norms, etc. The authors further recommend using this convener model nationally and internationally on a strategic level, like that of the NSpC, to expand that charge by working collaboratively on a strategic direction for GSTC. Under U.S. leadership, all actors should be responsible for working together to achieve a shared definition of success.

What does the GSTC community need to accomplish in the long-term?

The proposed strategic direction offers a starting point for U.S. government leaders to engage with other actors on the nation's outcomes for GSTC in the context of global efforts. A refined strategy embraced by the breadth of actors would frame key choices about priorities, resources, and investments.

The authors propose that all GSTC activities should drive toward the three target outcomes listed below. These outcomes are interdependent.

1. Preserving operating regions of space
2. Advancing the space economy
3. Maximizing the probability of mission success

Preserving operating regions of space

The preservation of operating regions of space is defined using the basic principles embedded in the Outer Space Treaty,[11] and more recently the Artemis Accords.[12]

Actors within the GSTC community should ensure the preservation of operating regions[13] for future generations by actively managing risks and shaping consequences that would limit future access and use. This means that:

- An operator necessarily occupies an orbit for a defined timeline—there can be no ownership of, or claim on, orbits in perpetuity.
- Operators should strive to "leave no trace," a concept developed by U.S. federal agencies in the 1970s.[14] Leave no trace, in the context of GSTC, assumes that the operator leaves the region undiminished at the end of their mission.
- Operators must plan carefully for future missions and coordinate in good faith during operations. Operators should take actions in accordance with the Inter-Agency Space Debris Coordination Committee (IADC) Guidelines founded on the following principles:
  - Preventing on-orbit breakups
  - Removing spacecraft and orbital stages that have reached the end of their mission operations from the useful densely populated orbit regions
  - Limiting the objects released during normal operations[15]

Advancing the space economy

The space economy is composed of space-based and space-reliant services, both providing immense public benefit. Disruption of these services would cause immense harm on Earth, jeopardizing lives and the Earth-based economy. Nearly every digital service provided in the U.S. relies on the missions executed by space assets, including telecommunications, PNT, weather forecasting, and critical infrastructure (agriculture, banking, transportation).

Additionally, the space economy holds promise for the future, executed today through efforts like scientific investigation and space-based manufacturing.

Crowding in operating regions put economic pursuits at greater risk. Actions taken to manage this risk as well as maintain a level playing field for competition will stimulate investment in the global space economy.

Maximizing the probability of mission success

Maximizing the probability of mission success focuses on the protection, continued function, and resilience of critical capabilities and assets for all categories of space activity: commercial, civilian, defense, and scientific. For commercial activity, this outcome supports the commercial and public services reflected in outcome two, advancing the space economy, to bolster investor confidence and facilitate competition. Similarly, civilian and scientific space activities that enable government-driven missions must be safeguarded: weather monitoring, communication, PNT, imagery, and ongoing research.

To pursue economic endeavors in space, commercial operators also need to have a degree of confidence that a given mission will be fulfilled successfully, including post-mission disposal. This means that all phases of the mission must be executed in the most safe and secure environment possible.

What does the GSTC community need to accomplish in the shorter term to achieve the long-term outcomes?

Shorter term outcomes, and the relationship among them, are captured in the performance logic model displayed in Figure 1.[16] The logic model depicted here was developed by the authors from right to left, working backward from the long-term outcomes to identify the near-term progress that the GSTC community needs to make. The arrows describe the relationships among these near-term outcomes and show how progress can be achieved over time. The model does not address technical or acquisition programs and milestones, such as development and initial operational capability of the OADR. Rather, the OADR development and other stakeholder development activities will be expected to support all elements of the logic model.

Stakeholders can use the logic model and related indicators to help determine whether course corrections are needed and to guide investment decisions.

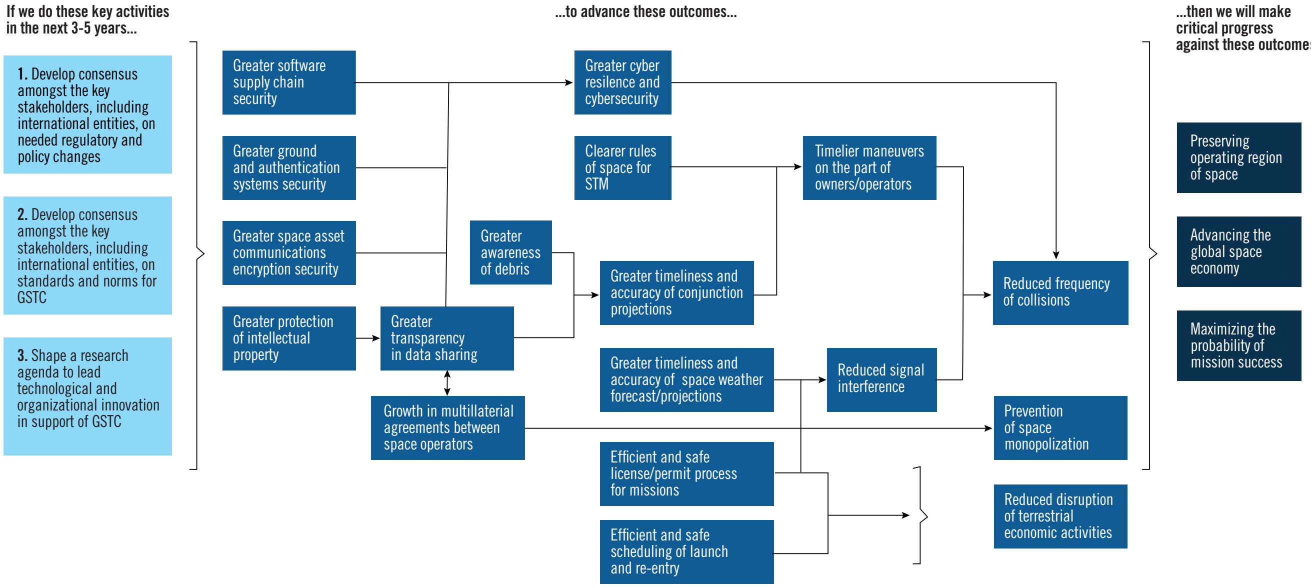

FIGURE 1: GTSC LOGIC MODEL[17]

How would we know that the GSTC community is achieving its desired long-term outcomes?

Performance indicators are a way to describe, quantitatively or qualitatively, a condition achieved or action completed. Progress in GSTC, as gauged by the use of performance indicators, should influence ongoing international discussions and decisions (e.g., international agreements and technical norms and standards), as well as domestic considerations for policy and regulatory development, decision-making processes, organizational alignment, research requirements, and technological innovations.

To characterize the state of the GSTC domain, the authors propose seven indicators (listed in Table 2 and described in detail following the table) for consideration by U.S. federal leaders in its engagement with the domestic and international communities.

By recommending these indicators, the authors encourage a multidimensional view of how the domain is evolving with regard to all of the long-term outcomes for the system: preserving operating regions in space, advancing the space economy, and maximizing the probability of mission success. The authors believe the outcomes and the indicators need to be assessed in context, relative to one other, to obtain a balanced view of the system and, ultimately, to achieve the three outcomes jointly. Where indicators cannot be readily quantified, the ideas they represent, when coupled with appropriate leadership behaviors, still have merit: they remind user audiences of what is not known or well-quantified, to help to qualify discussions and decisions with the quantitative indicators they do have.

Most of these indicators are not currently tracked, although some could draw on existing data sources.

Many will be challenging to measure. All of the indicators would need to be formally defined, with specified data sources and calculation methods that are well-documented and repeatable. Most will need to be normalized (e.g., relative to the growth in space activity) to provide context for considering changes in individual numbers (e.g., risk will increase with the growth in space activity). The level of precision possible for each quantified indicator will vary, and those limitations should be well understood to qualify the use of the indicators in decision making. All of the indicators should be public-facing, calculated and updated with an appropriate frequency to enable transparency, timely decision making, and course corrections as needed. Such an approach will encourage confidence in the system and in the space economy, informed by a common understanding of risk facing all future operations, and promote shared commitment to keeping all operations safe. The indicators could also be compounded into an index representing the overall risk in space.

TABLE 2. INDICATORS OF PROGRESS TOWARD THE OUTCOMES

		Outcome		
Preferred direction of change[18]	**Indicator** (change over time in)	**Preserving operating regions of space**	**Advancing the space economy**	**Promoting mission assurance**
▼	1. Projected collision risk over the lifecycle of a proposed operation	X	X	X
▼	2. Spatial density post- v. pre-mission	X	X	X
▲	3. Accuracy of lifecycle estimates for assets in orbit		X	X
▲	4. Number and type of operators in orbit		X	
▲	5. Conjunction warning accuracy		X	X
▼	6. Frequency and magnitude of incidents	X	X	X
▲	7. Estimated size of the U.S. space economy, in absolute 2019 dollars, as a percentage of U.S. gross domestic product (GDP) (calculated in 2019 dollars), and as a percentage of the total estimated global space economy		X	

1. **Change over time in the projected collision risk over the lifecycle of a proposed operation.**

   This indicator represents the risk to operations posed by degradation of space.

   The operating assumption behind the preservation of regions of space is linked to operational capacity, factoring in known debris and existing operations. As regions of space become densely packed or degraded, the risk of collisions or other damaging circumstances grows, for current and future operations. Degradation of one region can limit the use of adjacent orbits and altitudes through misallocation and debris generation, resulting in limited or eliminated ingress and egress options. This causes harm to operators by stranding assets while denying others the future opportunity to use a region of space.

   Monitoring this indicator helps leaders determine the speed at which operating regions of space are being degraded, which in turn would limit economic growth and constrain other uses of space. The indicator also provides context for considering the growing risk to operations already under way. Additionally, leaders can use this indicator to assess the overall success of civilian GSTC to adapt to operator requirements and behavior over time. This indicator can build off of guidance issued by the Federal Communications Commission in April 2020 that revised disclosure rules and incorporated numeric thresholds for lifetime collision risk[19]

2. **Spatial density post- versus pre-mission.**

   This indicator measures the behavior of individual operators in the context of their mission and the principle of "leave no trace."

   The indicator would be calculated by dividing post-mission spatial density of debris for a given region by the pre-mission spatial density of debris for that region. If the quotient is greater than 1 (i.e., more than 100%), this suggests that the mission has generated debris (i.e., left the region of space in a worse condition than when the mission first occupied it). The value would represent the percentage increase in spatial density of debris in that region. If the quotient is less than 1, then the mission reduced the density of debris in the region (i.e., left it less cluttered than when the operation began), which may be possible in the future. Licensing and regulatory entities could use this indicator to judge operators' past performance. This consideration may incentivize behaviors that improve opportunities for future operations, such as active debris removal.

   The value may be affected not just by operator behavior but also by improved technology: improved detection and tracking of orbital debris over time likely will detect and catalogue "new" debris that has long existed but previously was not known. Efforts will need to be made to differentiate debris resulting from new operational action (or inaction) from newly detected but likely previously present debris (i.e., improved SSA).

   Recognizing a likely margin of error in the calculation, the indicator can still be useful to the commercial GSTC enterprise by making operator behavior—and consequences for all operators—more transparent.

3. **Change over time in the accuracy of lifecycle estimates for assets in orbit.**

   Managing use of space requires planning for operations to come and go, which requires estimating how long assets will remain in orbit.

   This indicator would be generated by calculating the actual life span of the asset (before the beginning of deorbit) divided by its projected lifecycle pre-launch. If the value is less than 1 (i.e., less than 100%), then the original lifecycle estimate overstated the probable life span of the asset. If the value is greater than 1 (i.e., greater than 100%), then the original lifecycle estimate underestimated the viability of the asset.

These estimates are critical for managing operating regions in space for all actors in the system. If the lifecycle is shorter than estimated, there could be disruptions and risks associated with unplanned deorbit. If longer, the delay in vacating the orbit presents opportunity costs for subsequent occupants and creates unexpected risks associated with delayed deorbit. Consistently under- or over-estimating lifecycle estimates would suggest faulty assumptions on the part of the operator, warranting improvements in methodology. Alternatively, it may suggest motivations with impacts to other approved and pending operations. Federal policy interventions may be needed to manage this over time.

4. **Change over time in the number and type of operators in orbit.**

This indicator would calculate the percentage change over time in the number of unique operators and disaggregate the total by categories or interests of operators.

The number and type of operators in orbit helps to understand who is engaging in space and their respective interests. Changes over time in the absolute number of operators, and in the distribution across types of operators, would suggest different dynamics in the system that should be assessed by the stakeholders in context with changes in the broader environment.

Continued growth could suggest that the perceived value of, and risk associated with, deploying orbital operations remains acceptable in the marketplace to enable new entrants. It could also suggest that the space economy remains competitive, one of the desired outcomes of effective GSTC.

A decrease in the number and type of operators in orbit could mean different things. It could reflect consolidation in the marketplace, the reasons for which should be understood and the implications for public and commercial interests assessed. It could also reflect the diminishing number of viable orbits to accommodate operations. A diminishment of non-commercial operators could reflect other changes in the broader system—for example, a consolidation of public-oriented missions (e.g., there is currently one International Space Station serving many countries). These changes should be understood to provide context for policy choices.

5. **Change over time in conjunction warning accuracy.**

An early indicator of the maturation of GSTC over the next three to five years is the accuracy of conjunction warnings. This is a compound indicator that measures whether and when conjunctions are anticipated, the estimated timing, and the proximate distance proven to be accurate within an acceptable and ever-smaller margin of error. This indicator depends on establishing orbital elements of an object and predicting those orbital elements ahead of time. In other words, it highlights how accurately we know where things are (and their velocity) and how accurately we can predict that ahead of time in the presence of perturbing events (e.g., atmospheric variables, solar pressure, and unwarned maneuvers).

The transparency of this indicator is critical to building confidence in the system and in the information available to operators and new entrants.

6. **Change over time in the frequency and magnitude of incidents, in terms of absolute number, casualties, and estimated dollar value in 2019 dollars.**

   This indicator reflects the overall safety and security of space operations, in orbit, in transit, and on the ground. It is relevant to considering all three outcomes—preservation of operating regions of space, advancement of the space economy, and promotion of mission assurance.

   Enhanced SSA and GSTC should minimize the frequency of incidents, such as conjunctions and collisions, that can impede function or safety and cause casualties in orbit or on the ground. Such events can have compounding effects on other current or future operations. A growth in the frequency and/or magnitude of conjunctions and collisions, for example, may indicate that close-approach data is inaccurate; close-approach data are available too late for avoidance maneuvers; operators disbelieve the warnings; operators resist maneuvering because of other implications for the operation (e.g., fuel expenditure; an asset approaching end of life); and/or usable orbits have reached capacity and have become unsustainable. Transparency about these incidents will help stakeholders determine how to strengthen GSTC, impose consequences on actors that jeopardize it, and mitigate risks to the overall space domain, much like the success seen with the Federal Aviation Administration Aviation Safety Information Analysis and Sharing system in sharing safety information and best practices with all operators.

   Civilian GSTC will need to develop a classification system for incidents, in terms of their nature and magnitude. The types of incidents should be defined (e.g., cyber events, radio frequency interference, close approach, impeded operations) and classified as natural or man-made. A classification system should take into account incidents causing loss of life on- or off-planet; loss of assets or unexpected disturbance of services; and loss of economic or public benefit associated with the affected operation(s) (e.g., consequences on-planet due to unexpected disturbances in PNT operations). Policy mechanisms, perhaps in conjunction with the commercial insurance industry, will be necessary to encourage reporting and root cause diagnosis—a conjunction, for example, may be the symptom of the actual incident, a cyberattack.

   To help to understand the magnitude of the incidents, the authors suggest using 2019 as a baseline (before the pandemic affected activity and before the nature of space activity changed to include tourism) and using 2019-equivalent dollars for monetizing the incidents and their consequences.

7. **Change over time in the size of the U.S. space economy, in absolute 2019 dollars, as a percentage of U.S. GDP (calculated in 2019 dollars), and as a percentage of the total estimated global space economy.**

   This indicator measures the value of the U.S. space economy, helping to reflect the extent to which the system is realizing one of the intended outcomes—the advancement of the space economy. The reference to the global space economy is intended to provide context for considering the importance of space to nation-state interests.

   As with indicator six, above, the authors propose using 2019 because it is both pre-pandemic and before the introduction of commercial space travel (tourism).

Section II: Considerations for the Next Three to Five Years

Informed by the performance logic model and multiple stakeholder interviews, the authors propose a set of goals and objectives to advance, over the next three to five years, near-term outcomes critical to GSTC. These near-term outcomes, and corresponding activities, are captured in Table 3. The table also reflects indicators that will characterize progress toward these near-term outcomes.

TABLE 3. THREE- TO FIVE-YEAR GOALS, OBJECTIVES, INDICATORS, AND CRITICAL ACTIVITIES

Three-to five-year goals*	Greater cyber resilience and cybersecurity	Timelier maneuvers on the part of operators	Prevention of space monopolization
Objectives*	Greater transparency in data sharing		Fewer bilateral agreements between owners/operators
	Greater software supply chain security	Greater timeliness and accuracy of conjunction projections	Efficient and safe scheduling of launch and re-entry
	Greater ground and authentication systems security	Greater awareness of debris	Efficient and safe permit process for missions
	Greater space asset communications encryption security	Greater protection of intellectual property	
		Clearer rules of space for GSTC	
Indicators (change in)	• Percentage of actors adopting cyber standards • Percentage of insurers who have integrated cyber standards into their policies • Frequency and scope of cyber incidents in U.S.-backed and global space infrastructure • Timelapse between infiltration and detection • Timelapse between identification of cyber vulnerability and mission recovery	• Timelapse between identification of a potential conjunction, assessment, and the warning notification • Timelapse between warning notification and the operators' maneuver or event termination • Risk of collision resulting from unilateral maneuvers • Rate of operators' maneuvering appropriately following notification	• Market share (by company, by sector, domestic and international) • Insurance approvals for operators • Competitiveness of insurance options for operators • Level of transparency among space operators
Key Activities	1. Develop consensus amongst the key stakeholders, including international entities, on needed regulatory and policy changes		
	2. Develop consensus amongst the key stakeholders, including international entities, on standards and norms for GSTC		
	3. Shape and research agenda to lead technological and organizational innovation in support of GSTC		

** This goal/objective structure reflects the guidance provided by OMB through Circular A-11, Part 6 and the statutory framework reflected in GPRAMA.*

Outcome 1: Greater cyber resilience and cybersecurity

Cyber vulnerabilities are one of the most concerning threats for the integrity of GSTC. The highly digital nature of this operating infrastructure makes it vulnerable to cyberattacks that could have disastrous consequences. For example, the loss of precision timing provided by the Global Positioning System (GPS) constellation would affect energy grids, banks, communication systems, food supply, and many of the services that citizens use daily. The National Institute of Standards and Technology estimated that the economic impact of such a loss to the U.S. alone could exceed $1 billion per day.[20]

In particular, cyber resilience is key to mitigating threats to operators' ability to execute a mission successfully.[21] Cyber resilience refers to the reduction in vectors of failure across a system or architecture, as well as the speed with which assets can return to normal operations. In other words, a resilient cyber infrastructure protects against communication disruptions and, by extension, ensures that operators maintain control of their assets. This directly impacts the other outcomes discussed in this section.

Cybersecurity, by contrast, refers to operators' ability to identify, protect, detect, respond to, and recover from cyber incidents to retain control of the asset and the overall mission.[22] Among other things, this means building cybersecurity intentionally in every aspect of the lifecycle: securing the code through the supply chain; securing ground systems through access management; and encrypting data for secure transfer. A reduction in the frequency and scale of cyber incidents is a lagging indicator of cybersecurity; adoption of cyber standards and shorter patch times are leading indicators to reduce cyber intrusions.

Regulations that compel or incentivize cyber preparedness are important tools for improving cyber resilience and cybersecurity. Private insurance underwriters, through their decisions on coverage or premium rates, also can influence behavior by incentivizing best practices and better design or sustainment.

Indicators of progress to realize this outcome are change over time in the:

- Percentage of actors adopting cyber standards
- Percentage of insurers who have integrated cyber standards into their policies
- Frequency and scope of cyber incidents in U.S.-backed and global space infrastructure
- Timelapse between infiltration and detection
- Timelapse between identification of cyber vulnerability and mission recovery

Outcome 2: Timelier maneuvers on the part of operators

Today operators receive notifications of potential conjunctions or collisions so that they can determine whether and how to maneuver to avoid other vehicles, debris, or launch trajectories. Timely, highly accurate tracking notifications can build confidence in the space traffic system and in fellow operators, promoting stewardship as well as mission assurance. Operators use this information to weigh the possible maneuver options against their operational and mission considerations. Earlier notifications provide operators greater flexibility to determine the timing and nature of their own maneuvers in response. After all, earlier and fewer maneuvers save fuel, which is a finite and precious resource for orbital assets.

For reasons of national security, limited data is provided with the notification, making it challenging for newer, less well-funded operators to interpret and act upon. Private sector solutions will be useful to supplement the federal notification process. Highly accurate tracking and notifications can reduce the margin of uncertainty, reducing the number of notifications that do not represent a high risk of collision. Fewer false alarms and less statistical noise will allow operators to focus more fully on the few events that represent significant risk.

A pervasive challenge with regard to avoiding potential conjunctions or collisions is the absence of "right of way" rules or standards to compel operator maneuver behavior. Currently, operators are not compelled to maneuver in response to a warning notification and may have reasons (e.g., limited fuel, end of life of the asset, lack of confidence in the data) not to act so long as they give "due regard" to the safety of other operations and act on a "non-interfering" basis. The operator may consider the costs of a conjunction or collision to be relatively small, but the implications for the broader system are often great in terms of orbital debris and degradation of regions of space.

There are enormous benefits to looking at the totality of space for the long term and collaboratively working toward devising common, specific, operational standards. The norms regarding attacks and interference against space systems are not perfect and may represent an area that can be expanded to improved SSA and GSTC. (Indeed, it has been argued that these norms could form the basis for improved cybersecurity for space systems.) It is inevitable that the GSTC community must consider options that impose consequences for failure to maneuver and to assign legal liability for incidents. Ideally, the discussion on "right of way" will need to stabilize into globally acknowledged standards and norms that support the long-term outcomes. Such standards and norms could substantially shorten maneuver decision timelines, as responsibility for a maneuver would be predesignated. Insurance policies could reinforce proper behavior, even in the absence of global norms.

Indicators of progress to realize this goal are change over time in the:

- Timelapse between identification of a potential conjunction, assessment, and the warning notification
- Timelapse between warning notification and the operators' maneuver or event termination
- Risk of collision resulting from unilateral maneuvers
- Conjunction warning accuracy

Outcome 3: Prevention of space monopolization

Advancing the global space economy rests on an open market system that encourages evolution over time. The influence of large and powerful actors in the maturation of GSTC should not limit access, orbits, and spectrum to the exclusion of innovation fostered in an open market system. A vibrant and innovative space economy is contingent upon letting new actors in the door.[23]

Without deliberate policy and regulatory action, single actors or commercial sectors may come to dominate the domain.

To encourage access, nation-states can take policy and regulatory action to mitigate the risk of individual actors coming to dominate the domain. For example, nation-states can facilitate an open information architecture to promote transparency of regulations, spectrum assignments, permit issuance, and the terms dictated in bilateral and multilateral agreements.

They can also streamline permitting and licensing processes to make them more accessible to new and smaller actors.

Indicators of progress to realize this goal are change over time in the:

- Market share (by company, by sector, domestic and international)
- Insurance approvals for operators
- Competitiveness of insurance options for operators
- Percentage of space activity governed by bilateral versus multilateral agreements

Section III: What the GSTC Community Needs to Do in the Next Three to Five Years to Advance the Short-term Outcomes

What should the GSTC community value in the short-term to enable success?

Organizational culture refers to "the basic tacit assumptions about how the world is and ought to be that a group of people share and that determines their perceptions, thoughts, feelings, and their overt behavior."[24] This also applies to the space domain, influencing how the GSTC community engages and participates.

Values describe what communities want their cultures to be, and when developed with intention, become a tool for making those tacit assumptions more explicit and transparent. It is critical, then, before leaders make changes within the GSTC community, that a set of values is articulated and communicated to stakeholders. Reiterating the importance of organizational characteristics within the Academy's report, the authors propose the following values to catalyze the community in creating a culture of safe and sustainable GSTC.

- Trusted
- Transparent
- Collaborative
- Adaptive/responsive
- Entrepreneurial
- Creative
- Technical functions are resilient and stable (i.e., 'safety is not political')

Using these values, explicitly articulated and communicated to stakeholders, leaders in the SSA and GSTC communities can make intentional choices about structures, roles, relationships, authorities, expectations, rewards, and incentives. In other words, where do leaders see these values reflected in the current system, and how can they be strengthened while helping achieve the outcomes?

Why is the recommendation for a convener so important to short-term success?

As part of the execution for these outcomes and values, the function of a convener is critical given the diverse set of stakeholders, missions, functions, and interests across the SSA and GSTC communities.

In its report, the Academy recommended that Congress designate and fund OSC, under DoC, as the primary owner of the requisite SSA and GSTC functions for civilian space. It further recommended that OSC operate as a convener across GSTC stakeholders to develop the policy, regulations, standards, and norms expected of the organization, consistent with its mission.

The Academy's report further defined the work of a convener as "bringing actors together and collaboratively driving them to find common objectives and coalesce to enhance safety and precision in space.… This collaborative model places the highest priority on serving as a trusted coordinator and provider of respected and respectful leadership for the larger domestic and international community." This collaboration forms the backbone of the necessary cooperation and alignment to achieve the long-term outcomes.

While OSC is favorably situated to perform this role, the need for a convening function is broader than OSC's operations. There is growing expectation on the part of spacefaring nations and the global space operator community to be a more equal partner with the U.S. and make more substantive contributions to the global SSA enterprise. As a result of this growing demand and foreign technological developments, many of the options for GSTC involve a segmented approach such that different organizations can service each part. The convening function should be further integrated into other mission spaces within the federal government, state and local governments, as well as international entities. Conveners at multiple levels should be adept at developing networks and fostering collaboration, as well as coordinating plans in development across the community so that distributed efforts will be aligned. Conveners can harness the capacity and depth of players within the system and engage that collective capacity in a more organized, coordinated, and efficient manner.

What are the activities that the GSTC community needs to accomplish in the short-term?

1. **Develop consensus amongst the key stakeholders, including international entities, on needed regulatory and policy changes.**

   GSTC communities will need to coordinate efforts across a broad range of stakeholders to streamline processes such as launch scheduling, permitting, and spectrum allocation. These communities will also need to encourage smarter regulations that eliminate obstacles for innovation while encouraging participation, stewardship, and accountability. This work will need to acknowledge the multinational solution for GSTC that will likely emerge and should seek to maintain a level playing field for U.S. commercial space interests.

   At the federal government level, new or different authorities may be needed to support necessary regulation, such as cybersecurity protocols that promote resilience and interoperability, data collection and sharing to improve transparency across the system, or vehicle or launch safety features that lower the risk of debris generation or mishap.

   Different types of actors in the system will have different interests and perceptions of risk, so a convener could be used to balance and prioritize these potentially competing interests to make recommendations for the system as a whole. Regulations should be balanced with acceptable levels of risk-even regulations deemed necessary must be executed in ways that account for capabilities and limitations of the actors, timelines for the regulations to measurably impact the domain, and potential negative second order effects. A convener can also monitor and recommend budget inputs to ensure vital pieces of the system are fully funded and delivered in a stable manner.

2. **Develop consensus amongst the key stakeholders, including international entities, on standards and norms for GSTC.**

   Achieving the outcomes requires shared agreement and adoptions for a set of standards and norms by which nation-states and other actors operate in space. Multinational solutions must be backed by standards that are interoperable, connected by consistent norms and behaviors.

   Global norms can promote the protection of intellectual property and create opportunities for actors to compete in a global market; lay the foundation for international agreements, including standards of behavior for collision avoidance or practices for debris mitigation; and define open architecture technological solutions to improve data accuracy and transparency globally.

   Conveners can play a significant role in coordinating U.S. government, industry, and academic partners to develop rules and norms that comport with U.S. values; begin implementation of these norms; and lead the community toward global acceptance. Conveners can help domestic actors to speak with one voice in proposing standards that are helpful to the GSTC community and that advance the long-term outcomes. Broad agreement across these norms will directly impact the safety and sustainability of the space domain. In the absence of consensus on international norms, stakeholders at a minimum must achieve agreement incrementally and build where possible.

3. **Shape a research agenda to lead technological and organizational innovation in support of GSTC.**

   The dynamic environment of GSTC requires a constant eye to new technology and organizational solutions. A robust and up-to-date research agenda can ensure that GSTC services stay relevant. It can also encourage new technology solutions that improve needed capabilities, like attribution and maneuver optimization, while also supporting mutually beneficial solutions that foster greater optimization of operating regions of space. Technological approaches, like blockchain, may offer solutions that encourage greater transparency and data sharing.

   Conveners, through real-time stakeholder engagement and collaborative platforms, can ensure that technical functions advance the outcomes, are adequately resourced, and enhance security.

Section IV: Moving Forward

In response to the U.S. Space Priorities Framework, and in preparation for the second NSpC meeting of the Biden administration, this paper sets goals for advancing GSTC. It proposes a definition of success by identifying performance outcomes and indicators for the system in the long term, and it provides a strategy for advancing the necessary values and activities in the short term.

The content mentioned here will require further input and endorsement from relevant GSTC community stakeholders. The NSpC and relevant stakeholders can leverage the content from this paper to drive conversations around the NSpC's priority for advancing SSA and GSTC. In practice, this means using the content to shape, prioritize, and make decisions around organizational changes, investments, legislative and policy activity, as well as future considerations for research. Building on the Academy's 2020 recommendation to use a convener model in the context of OSC, applying this model more broadly across the GSTC community may facilitate any necessary refinement. This includes, but is not limited to, the NSpC and OSC, as well as other places the convener model may be utilized to garner additional stakeholder input, such as state and local governments, international entities, academia, and private sector.

Moving forward, additional research is required to explore organizational mechanisms that promote accountability across the GSTC community, including the convener model and other complementary solutions. In the process, this research should consider how the environment is changing and possible future developments, what the implications are for long-term outcomes and performance indicators, as well as what values the GSTC community should manifest.

Endnotes

1. The White House, "United States Space Priorities Framework," December 2021. [Online]. Available: https://www.whitehouse.gov/wp-content/uploads/2021/12/United-States-Space-Priorities-Framework-_-December-1-2021.pdf.
2. National Academy of Public Administration, *"Space Traffic Management: Assessment of the Feasibility, Expected Effectiveness, and Funding Implications of a Transfer of Space Traffic Management Functions,"* Department of Commerce, Washington, DC, 2020.
3. An 'outcome' is an articulation of the desired impact, or the result, an entity hopes to achieve after executing a set of activities. Outcomes are specific and measurable, and they are captured in terms of the long- versus short-terms (Kellogg Foundation, 2004).
4. A. Panda, *"The Dangerous Fallout of Russia's Anti-Satellite Missile Test,"* Carnegie Endowment for International Peace, 17 Nov 2021. [Online]. Available: https://carnegieendowment.org/2021/11/17/dangerous-fallout-of-russia-s-anti-satellite-missile-test-pub-85804.
5. M. Sheetz, "*CNBC,"* April 10, 2020. [Online]. Available: https://www.cnbc.com/2020/10/02/why-the-space-industry-may-triple-to-1point4-trillion-by-2030.html.
6. National Space Council, *"Space Policy Directive-3, National Space Traffic Management Policy,"* White House, Washington, DC, 2018.
7. Congress, *"Consolidated Appropriations Act 2020,"* January 2020. [Online]. Available: https://www.govinfo.gov/content/pkg/CPRT-116HPRT38678/html/CPRT-116HPRT38678.htm.
8. National Academy of Public Administration, *"Space Traffic Management: Assessment of the Feasibility, Expected Effectiveness, and Funding Implications of a Transfer of Space Traffic Management Functions,"* Department of Commerce, Washington, DC, 2020.
9. The White House, *"United States Space Priorities Framework,"* December 2021. [Online]. Available: https://www.whitehouse.gov/wp-content/uploads/2021/12/United-States-Space-Priorities-Framework-_-December-1-2021.pdf.
10. Bhavya Lal, Asha Balakrishnan, Becaja Caldwell, Reina Buenconsejo, and Sara Carioscia, *"Global Trends in Space Situational Awareness and Space Traffic Management,"* The Science and Technology Institute, Washington, DC, 2018.
11. United Nations, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), 1967.
12. National Aeronautics and Space Administration, *Artemis Accords*, 2020.
13. The authors define a region of space refers to the orbital altitudes and inclinations that an operator occupies to accomplish its intended mission. A region also includes a "spatial buffer" around the operation to accommodate safe maneuvers, minimizing possible interference with operations in other regions.
14. Leave No Trace Center for Outdoor Ethics, *"Leave No Trace Seven Principles,"* [Online]. Available: https://lnt.org/why/7-principles/. [Accessed 13 January 2021].
15. Inter-Agency Space Debris Coordination Committee, *"IADC Space Debris Mitigation Guidelines,"* March 2020. [Online]. Available: https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf.
16. The performance logic model is an evaluative tool that has been endorsed by the Government Accountability Office (GAO) and the Office of Management and Budget (OMB). It is used for developing organizational strategy and for program evaluation, and it reflects a hypothesis about how to achieve long-term outcomes (Kellog Foundation, 2004).
17. This logic model is a simplified version of the detailed model developed in the working sessions.
18. The timeframe within which change may be expected or quantified will vary for each indicator.
19. Federal Communications Commission, 2 April 2020. [Online]. Available: https://docs.fcc.gov/public/attachments/DOC-363486A1.pdf.

20. National Institute of Standards and Technology, "Economic Benefits of the Global Positioning System (GPS)," RTI International, June 2019. [Online]. Available: https://www.nist.gov/system/files/documents/2020/02/06/gps_finalreport618.pdf.

21. Developing Cyber-Resilient Systems: A Systems Security Engineering Approach, Volume 2, Revision 1. National Institute of Standards and Technology. December 2021.

22. Framework for Improving Critical Infrastructure Cybersecurity, Version 1.1. National Institute of Standards and Technology. April 16, 2018.

23. Harvey Reed, Dr. Nate Dailey, Dr. Ruth Stilwell, and Dr. Brian Weeden, "Decentralized space information sharing as a key enabler of trust and the preservation of space," Advanced Maui Optical Space Surveillance Technologies Conference, Maui, Hawaii: 2021.

24. Edgar Shein, "Organizational Culture and Leadership", 4th edition, Jossey-Bass, 2010.

List of Acronyms and Abbreviations

Acronym or Abbreviation	Definition
DoC	Department of Commerce
GDP	Gross domestic product
GPS	Global Positioning System
GSTC	Global Space Traffic Coordination
IADC	Inter-Agency Space Debris Coordination Committee
NSpC	National Space Council
OADR	Open Architecture Data Repository
OMB	Office of Management and Budget
OSC	Office of Space Commerce
PNT	Positioning, navigation, and timing
SPD	Space Policy Directive
SSA	Space Situational Awareness
The Academy	National Academy of Public Administration
U.S.	United States

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