Research Report

DAN MCCORMICK, DOUGLAS C. LIGOR, BRUCE MCCLINTOCK

Cross-Domain Lessons for Space Traffic Management

An Analysis of Air and Maritime Treaty Governance Mechanisms

Space traffic management (STM), sometimes referred to as *space traffic coordination* (STC),[1] is one of the daunting challenges facing spacefaring nations, operators, stakeholders, and all who rely on critical space services, benefits, and activities, such as weather monitoring and prediction; position, navigation, and timing; communications; internet service; broadcasting; remote sensing; financial transactions; scientific exploration and experimentation; and defense and national security activities. These services and benefits rely on the safe and secure movement and maneuver of active space objects, whether they are satellites or manned stations. However, the ability to move and maneuver is at great risk and is coming at an increasing cost in terms of both the fuel expended for these maneuvers and the resulting disruption to operations and shortened lifespan of the satellites.[2] Moreover, there is now a general consensus among scientists that without robust STM (among other efforts to ensure space sustainability), collisions in space and the debris that is generated from such collisions could lead to the loss of

KEY FINDINGS

- The international community lacks agreed-upon space traffic management governance processes, procedures, mechanisms, and institutions (collectively, a *governance framework*)
- Successful traffic management in the air and maritime domains began with international treaties enabling key governance institutions: the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO).
- ICAO and IMO provide six key governance benefits: international representation, bottom-up development or rules, nonstate/private actor participation, democratic processes, conflict adjudication, and compliance via soft and hard enforcement tools.
- Elements of the ICAO and IMO governance frameworks may serve as analogues for the creation of an international space traffic management organization.

Abbreviations

AIS	automatic identification system
ANC	Air Navigation Commission
COLREG	Convention on the International Regulations for Preventing Collisions at Sea
ICAN	International Commission for Air Navigation
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
MSC	Maritime Safety Committee
OST	Outer Space Treaty
PICAO	provisional International Civil Aviation Organization
SARP	standard and recommended practice
SOLAS	Safety of Life at Sea
SSA	space situational awareness
STC	space traffic coordination
STM	space traffic management
STMO	Space Traffic Management Organization
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea

entire orbital shells—a theory known as the *Kessler Syndrome*.[3]

This situation will only get worse as the numbers of active satellites and debris steadily rise, forcing more maneuvers to be executed. As of July 2022, there are approximately 6,100 active satellites and over 36,500 pieces of trackable debris (10 cm or larger) that object operators must avoid, a number that continues to grow steadily.[4] To avoid interference and collision, the maneuver of satellites and other active space objects requires coordination in the form of communications, data and information exchange, and defined governance processes and procedures to determine who is going to move, as well as when and how the maneuver will occur. Robust STM both relies on and enhances the ability of operators to maintain space situational awareness (SSA). Both SSA and STM are essential to mitigate against and resolve interference and collisions before they occur.[5]

Notwithstanding the need for traffic management in space, STM does not have a standard, internationally agreed-upon definition.[6] Without consensus on what constitutes STM's defining elements, conditions, or objectives, it is difficult for space operators across the international community to understand what their roles, responsibilities, and duties are with respect to operating their spacecraft. Correspondingly, this lack of individual understanding makes it difficult, if not impossible, for space operators to plan and coordinate traffic management in a synchronized and integrated fashion.

In addition to the lack of an agreed-upon definition, the current method of STM is ad hoc.[7] Operators have sole responsibility to collect the necessary data and information they need to avoid interference and collisions and to operate safely.[8] Many operators rely on information provided for free by the U.S. Space Command's space-track.org to make their independent judgments of what the risk of interference or collision may be at any given point.[9] In the event of such risk, operators contact each other and determine among themselves who will maneuver.[10] The international community lacks agreed-upon STM governance processes, procedures, mechanisms, and institutions (collectively, a *governance framework*) and is without a dedicated coordination mechanism or organization that may be relied on to collect data, track objects, provide notifications, and assist in the resolution and/or adjudication of potential interference and collisions. Many nations recognize the lack of international consensus regarding STM and have expressed commitments to address the issue.[11]

The objective of this report is to address the challenge presented by STM by examining analogous traffic management aspects of both the air and maritime domains.[12] We do not attempt to specifically define STM, given that such a definition will likely require international negotiation and consensus. That said, and for the purpose of our examination and analysis of traffic management in the air and maritime domains, we define STM generally as the ability of all operators to maneuver, or coordinate the maneuver, of space objects to avoid interference and collision in space. Using our examination of traffic management solutions developed in the air and maritime domains, we provide a preliminary analysis and insights that may offer promise for STM or may warrant further investigation by the space community. The air and maritime domains are not physically analogous to space, but the international community developed many governance processes, procedures, mechanisms, and institutions to address similar traffic management challenges. Both domains have been successful in maintaining extremely low collision rates due, at least in part, to their governance frameworks.[13]

We note that other eminent scholars and subject-matter experts have also examined the applicability of air and maritime governance to space.[14] Many of these works focus on specific technologies, policies, or processes. Our approach differs in this report in that we examine the air and maritime domains holistically to determine which governance framework aspects (1) facilitate successful traffic management and (2) may be generalizable or applicable to space. Additionally, although there are other critical aspects related to STM, such as debris mitigation, insurance regimes, and spectrum regulations, we have limited the scope of this report to governance framework aspects that relate directly to improving active spacecraft maneuver and collision avoidance.

To analyze the governance frameworks applicable to air and maritime domains, we conducted an abbreviated thematic literature review to identify and collect publicly available materials, documents, data, and information relevant to the topic of traffic management. We conducted open online searches (using Google, Google Scholar, ResearchGate, LexisNexis, Westlaw, HeinOnline) and targeted online searches of websites associated with international air and maritime governance (e.g., UN.org, ICAO.org, and IMO.org). To select source material based on relevance, materiality, and importance, we applied a series of keyword terms and phrases to our searches and reviewed abstracts, summaries, and full documents to assess the frequency and applicability of the keyword terms.[15]

Air Domain Review

First International Debates

In air domain governance, the International Civil Aviation Organization (ICAO) plays the largest role in universalizing standards of air traffic management.[16] Under the terms of the Chicago Convention on International Civil Aviation, ICAO was established in 1947 as a specialized agency of the United Nations (UN) to support international cooperation for air transport.[17] As other researchers have discussed, the development of ICAO's procedures, functions, and aviation standards present lessons for general space governance.[18] However, the initial debate over international air traffic featured a key obstacle: disagreement between key states over the scope of ICAO's oversight authority within the domain and whether it would regulate commercial competition or limit its rules to safety, standardization, and technical monitoring.

The post–World War I allies debated international air traffic regimes at the 1919 Paris Convention, but the United States refused to adhere to the resulting International Commission for Air Navigation (ICAN) agreement, leaving out one of the new industry's leading players.[19] The United States also engaged in regional negotiation at the Pan-American Convention on Commercial Aviation in Havana in 1928, but American officials delayed ratifying the resulting agreement until 1931.[20] The Havana Convention served as a counterpart to ICAN and created confusion by offering a second set of similar, but not identical, air rules.[21] Therefore, serious progress waited until the waning years of World War II, when the rapid development of airframes and radar technology created a clear need to fully deconflict international air travel.[22]

Air Traffic Developments Before ICAO

Despite its refusal to participate in ICAN, the United States could not ignore the agreement's provisions when, in 1920, many European nations and Canada adopted the rules outlined in Paris.[23] ICAN-adherent states required aircraft registration, pilot licensing, and reciprocal agreements to allow cross-border air travel.[24] Canada adopted each of those provisions and the ICAN rules of the air, creating immediate friction with the United States, which had no national registration or licensing scheme.[25] Because the U.S. Congress failed to act, pressure built in the air travel industry, particularly among aircraft insurers.[26]

A group of U.S. insurers adopted a private regulatory system in 1921 that largely mirrored Canada's, and therefore ICAN's, provisions. Specifically, the system required registration and licensing, adopted 32 rules of the air found in ICAN, and mandated aircraft inspection.[27] The air rules were nearly verbatim restatements of those found in ICAN and Canada on right of way (motorized aircraft yield to balloons and airships), course correction (the aircraft with another aircraft to its right side has the duty to avoid), and safe distance (duty to maneuver if current course brings you within 600 feet of other aircraft).[28] This effort ultimately failed to reach most pilots because of its voluntary nature, but similar industry efforts followed suit and continued to copy the ICAN rules.[29] For example, another informal committee led by multiple industry firms copied ICAN's air rules on lighting—white lights in front and rear, green on the right, and red on the left.[30] Although these efforts failed to achieve national-level support, they served to push the U.S. government toward standardization.

In the lead-up to the 1926 Air Commerce Act, U.S. government officials interacted with multiple informal industry coalitions to formulate draft rules.[31] The act, passed in May 1926, created an aeronautics branch under the Commerce Department with the authority to create air routes and flight safety regulations.[32] The resulting Air Commerce Regulations largely matched those in ICAN, with some decrease in safe distance and more-stringent requirements on flight over cities.[33] The United States was not alone in adopting provisions to match ICAN; by 1929, nearly the entire air-faring world had safety rules analogous to ICAN.[34]

Creation of ICAO, Debate on Scope

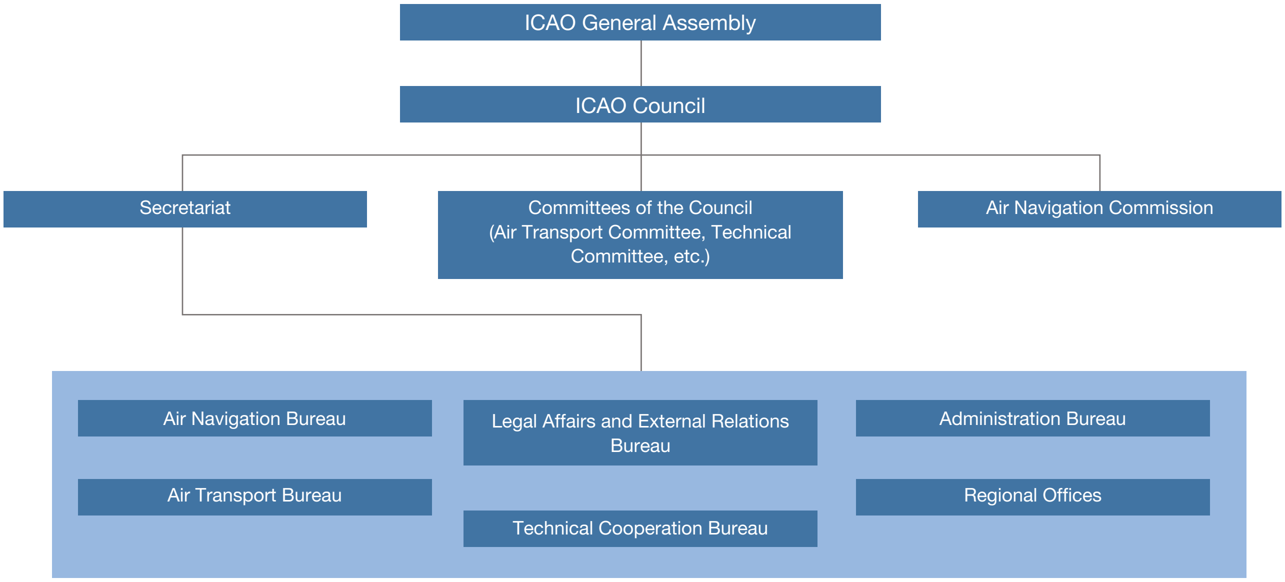
The world's air traffic regime remained somewhat ad hoc and in need of formal universalization through World War II. To address this, the United States invited 55 states to attend the Chicago Convention in 1944; the host nation and Great Britain sent the largest delegations.[35] Most states agreed on the need for an international body to standardize rules of the air and facilitate international air service.[36] However, the United States pushed for mostly open competition in providing air travel services, whereas the British hoped for a more internationally regulated air service.[37]

The convention agreed to nearly 100 articles, the first 36 of which set out state control of local airspace, standards of navigation, rights of transit, and basic air rules.[38] The parties also agreed that, through ICAO, they would pursue as much uniformity of regulations as possible on standard operations, lighting, communications, and other safety rules.[39] However, the British had to accept a fallback position, and ICAO limited its involvement in commercial matters. Agreeing to limit the organization's role ensured the support not only of the United States but of several Latin American nations as well.[40] This compromise over the scope of the organization allowed the parties to pass a major milestone and begin the work of coordinating best practices in air travel.

ICAO Structure

The initial structure laid out for the provisional ICAO (PICAO) at the Chicago Convention has largely persisted through today (see Figure 1). ICAO has two primary decisionmaking bodies; the assembly comprises all member states and meets at least once every three years,[41] and the council comprises 36 member states elected by the assembly.[42] The assembly manages ICAO's budget and may suspend any state's voting rights when the state fails to meet financial obligations.[43] The council directs the Air Transport Committee, appoints members of the Air Navigation Commission, appoints leadership of the secretariat (see below), and may act to settle disputes between member states in matters of application of the convention and annexes.[44] In practice, the council has served as a mediator between states bringing conflicts before ICAO and reached a negotiated settlement in nearly every instance.[45] In those rare instances in which a party chooses to appeal the council's decision, the states can mutually agree on an arbitrator, but if they cannot come to terms, the council has the authority to appoint one from a list of candidates that the council maintains.[46] States that fail to adhere to these dispute settlement procedures have voting rights in both the assembly and council suspended.[47]

FIGURE 1
ICAO Organizational Structure



SOURCES: Adapted from Civil Aviation Authority, "ICAO's Structure and Upcoming Events in the Field of Civil Aviation (Infographics)," Government of Poland, June 11, 2013, and from discussions with Ruth Stilwell, Executive Director, Aerospace Solutions, LLC, October 3, 2022.

The assembly and council share the duty of considering amendments to the convention, but the assembly has final approval.[48] The council may make procedural decisions by an internal majority vote, but amendments to the convention require an affirmative two-thirds vote in the Assembly.[49] Under Article 94 of the convention, a state may lose its membership in ICAO if it fails to ratify a convention amendment within the time specified by the assembly.[50]

Air Traffic Management Under ICAO

Following the establishment of ICAO, the first assembly of the organization agreed to become a UN specialized agency in 1947, and the assembled representatives prioritized the adoption of air safety measures.[51] Mirroring the later development of the International Maritime Organization (IMO) (discussed below), ICAO relied on the division of labor, creating plenary sessions and five commissions on specific issues: general policy, air navigation, air transport, legal questions, and administration and finance.[52] Many of the first recommendations published by the PICAO Rules of the Air Division were updated versions of those adopted in Paris in 1919 by ICAN.[53] The division easily reached an agreement in principle on recommendations for general flight rules, visual and instrument flight, and specific lights and signals used for navigation.[54]

At the second ICAO Assembly, in 1948, the parties settled objections over the structure of the Air Navigation Committee. The United States insisted that it remain under the control of the council, and the Air Navigation Committee officially came into operation in 1949.[55] Now the Air Navigation Commission, the ANC has the responsibility of considering and recommending modifications to the annexes on technical standards, but crucially, it remains under the direction of the council and can only suggest rules updates, not adopt them.[56] The council appoints the 19 ANC experts; there was some debate over eligibility, but the council elected to allow every contracting ICAO state to nominate representatives with sufficient aeronautic experience.[57]

Over the following few years, the ANC considered technical rulemaking proposals and submitted corresponding annexes to the council for approval.[58] Among the most relevant adoptions were

Annex 2: Rules of the Air; Annex 6: Operation of Aircraft, International Commercial Air Services; and Annex 11: Air Traffic Services. Each of these fell under the ANC's purview and aimed at building universalization of standards across ICAO's membership.[59] Upon passage by the council, it then fell to the individual member states to adopt the standards and recommended practices (SARPs) in their domestic regulatory schemes, a process that occurred as ICAO's regional offices distributed documents and collected statistics that would inform future revisions.

Contracting states agree to adopt, as far as is practicable, rules that ICAO recommends "from time to time," which includes the council's role in adopting SARPs outlined in Article 37.[60] The ANC proposes SARPs to the council, which approves them by a two-thirds vote.[61] States finding themselves unable to adopt a new rule must notify the council within a set time, and the council will in turn notify the other member states and publish differences between the state and ICAO version in supplements to the annexes.[62] Members can then take action to limit interaction with noncompliant states or their carriers. Thus, ICAO relies on transparency and the collective actions of member states to ensure compliance, but it possesses no further enforcement powers against noncompliant states.

ICAO has also maintained an expert bureaucracy—the ICAO secretariat, led by the council-appointed secretary general—to identify new priorities, support diplomatic interactions, and research new policies and practices as directed by the assembly or council.[63] The secretariat relies on input from invited organizations such as industry, regional, and civil society groups.[64] The secretariat's five bureaus and seven regional offices collect data and assemble reports to inform ICAO rulemaking.[65]

Once a new rule is proposed, ICAO aims to develop consensus among its members, but it still has no direct authority over national governments and relies on its member states to adopt and enforce all its provisions.[66] For example, ICAO has convened several panels on separation to determine best practices.[67] Because of the advent of commercial turbojets, vertical separation requirements of 2,000 feet cost airlines significant additional fuel, so ICAO initiated the Review of the General Concept of Separation Panel in 1982 to analyze the feasibility of a 1,000-foot vertical separation rule to save fuel and increase airspace capacity.[68] ICAO found the standard safe and technically feasible in 1988.[69] However, aircraft altimeters had regional issues based on proximity to the equator, so individual states adopted the 1,000-foot standard, and ICAO's regional planning groups phased implementation in various air traffic regions as improved sensors became available throughout the 1990s and early 2000s.[70]

Maritime Domain Review

Many researchers have noted the parallels between the maritime and space domains.[71] The lack of sovereign control over most of the maritime domain and the necessity of multiple states to exercise jurisdiction over individual operators both lend themselves to comparisons with space governance.[72] However, one major difference becomes apparent in reviewing key developments in maritime law—the norms and rules of the domain have a long history and came together over centuries of debate, diplomacy, competition, conflict, and state practice. Adopting centuries-old norms into formal rules required major international efforts.

Procedural Obstacles During UN Convention on the Law of the Sea Debates

The international law of the sea remained customary or norm-based well into the late 1800s, but significant debate occurred in the preceding centuries that affected rulemaking in the 20th century. The Dutch jurist Hugo Grotius published *Mare Liberum* in 1609, in which he argued that the seas must be free from state control by their nature—that is, they could not be occupied like land.[73] His argument received immediate pushback, as many states held interests in their coastal waters and resources, leading to the "cannon shot rule" that developed in the early 1700s, which extended states' sovereignty over waters within weapons' range of their coasts.[74] The debate over territorial seas set the stage for what would become the central hurdle to building an international maritime system of governance. By the mid-1800s, common practice included a general freedom of the seas, an undefined band of territorial sea ranging from three to 12 miles, and limited exceptions for certain criminal enforcement actions—all of which suited the era's major naval powers, including Britain, France, the Netherlands, and the United States.[75]

The creation of the League of Nations in 1920 and the Conference for the Codification of International Law at the Hague in 1930 presented opportunities to formalize laws of the sea, but the territorial sea debate remained an impediment.[76] Disagreement over the breadth of this zone, including the exclusive right to fisheries within coastal waters, prevented adoption of any draft convention.[77] Individual states and regional groups adopted their own rules that served to push the debate forward.

In 1945, the United States issued the Truman Proclamation, which claimed exclusive sovereignty over the continental shelf and resources therein, extending farther from the coast than had been previously accepted.[78] In reaction, a group of states without a significant continental shelf (Peru, Chile, and Ecuador), signed a joint proclamation claiming resource rights over 200 nautical miles from their respective coasts.[79] At the international level, procedural issues stymied progress. The First United Nations Convention on the Law of the Sea (UNCLOS I) in 1958 also failed to address disagreements over coastal waters; the 86 states in attendance could not find a measure that would receive the required two-thirds of votes in plenary.[80] Likewise, UNCLOS II in 1960 failed to achieve a two-thirds vote on a proposed 12-mile limit for exclusive fishery rights, leading many states to simply adopt such measures on their own.[81]

The proceedings in UNCLOS III from 1973 to 1982 finally allowed for a breakthrough on territorial seas and resource rights. Using information from the first two conferences, the general assembly broke the work into three committees on seabed extraction, territorial jurisdiction, and other issues (pollution, research).[82] Each committee chairperson produced a nonbinding single negotiating text (SNT) based on the theme or consensus of their debate rather than by a vote.[83] The committees then produced a revised SNT that was still nonbinding but required states wishing to amend it to organize larger coalitions and produce considerable dissent during debates.[84] The three revised SNTs combined into an informal negotiating text, and consensus-building progressed over the late 1970s, leading to the first draft convention on the Law of the Sea in 1980, and formal adoption in 1982.[85]

IMO Creation and Structure

IMO is the sole UN specialized agency responsible for global standards on safety, security, and environmental matters for international shipping.[86] IMO came into being several years after ICAO and faced similar obstacles to its inception. The 1948 UN conference in Geneva adopted the convention, creating the Governmental Maritime Consultative Organization, later changed to IMO.[87] However, the convention did not enter into force until 1958; it required at least 21 states to become parties for adoption, but many countries resisted because of concerns that IMO's scope would involve it in commercial or economic activities.[88] Therefore, IMO's main purview has been technical and safety matters. The initial assembly in 1959 apportioned IMO's funding between member states based both on overall contribution to the UN and on registered tonnage of their shipping, a unique arrangement in the UN.[89]

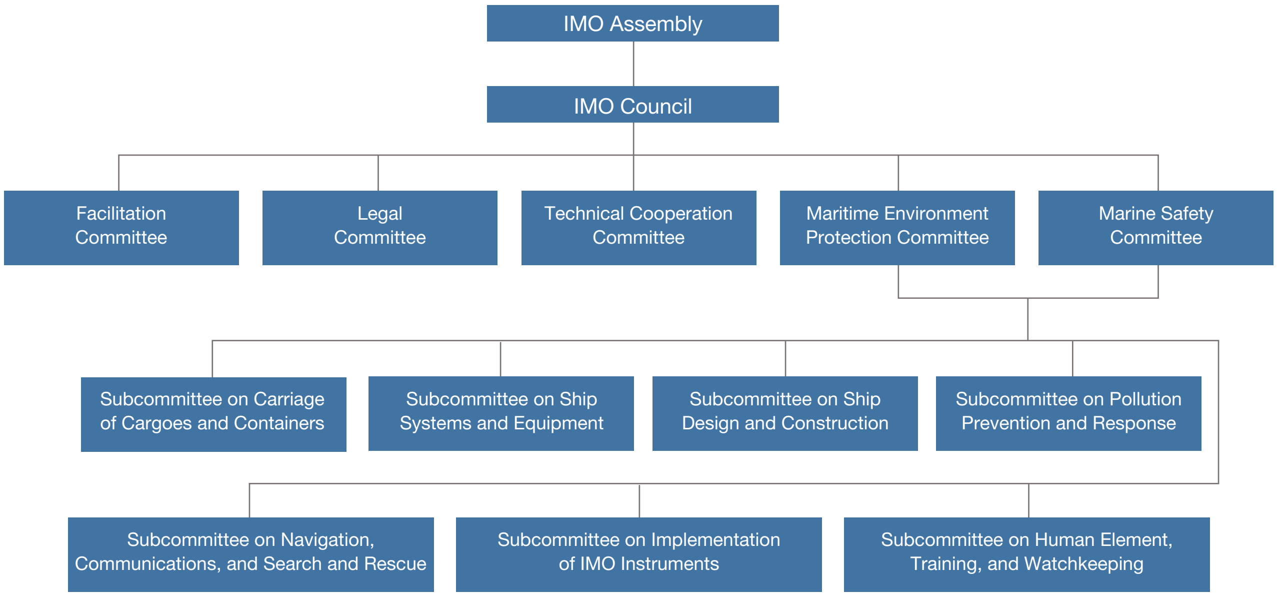
IMO consists of an assembly of all members that vote on budgeting and elect the council—a rotating group of 40 states from three categories to ensure diversity of interests.[90] The council supervises the committees and subcommittees, which consider and recommend rules and amendments in their respective subject areas.[91] Finally, IMO maintains the secretariat—approximately 300 civil servants based at the IMO headquarters that runs the organization's daily operations.[92] IMO currently has 175 members and three associate members (see Figure 2).[93]

Procedural Solutions in IMO

IMO has employed several procedural rules to ensure safety regulations are kept up to date and widely adopted. International law on safety at sea has seen many iterations; versions were adopted following the Titanic disaster in 1914, as well as in 1929 and 1948;

FIGURE 2

IMO Organizational Structure



SOURCE: Adapted from United Arab Emirates Ministry of Energy & Infrastructure, "International Maritime Organization," webpage, undated.

by IMO in 1960; and—the current version of the convention for the Safety of Life at Sea (SOLAS)—in 1974.[94] The 1960 convention required that two-thirds of contracting governments accept an amendment, generally by introducing national legislation, before it could enter into force.[95] This explicit acceptance procedure placed the burden on all accepting states to act, which caused delays as many states did not prioritize domestic legislation on maritime safety.[96] The 1960 SOLAS procedures could not keep up with technical developments and lessons learned from major incidents, especially as IMO's membership grew throughout the decade.[97]

To address this issue, the 1974 convention included procedural measures to ensure the greatest degree of adoption possible. The *tacit acceptance procedure* states that an amendment to the rules will enter into force on a given date, usually two years from introduction, unless one-third of states object to it before then.[98] The 1981 amendments, for example, entered into force in 1984, less than three years after their initial adoption, and the 1983 amendments came into effect just over two years after adoption.[99] Although IMO initially faced legal questions on this procedure because of the Maritime Safety Committee's (MSC's) limited membership, IMO opened the MSC to all member states soon after adopting the tacit acceptance procedure.[100] The MSC is the highest body in IMO that addresses technical requirements. The expanded MSC also includes nonmember states that are parties to conventions under its jurisdiction, such as SOLAS.[101] In addition to adopting amendments to SOLAS, the MSC considers and makes recommendations on rules on all safety and traffic-related matters under IMO's purview.[102]

IMO has also delegated full authority on certain aspects of technical rulemaking to the MSC, in contrast to ICAO, where the council retains final approval of any standards that the ANC proposes.[103] IMO adopted the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) in 1972, with entry into force in 1977.[104] The COLREGs replaced the 1960 collision regulations and include 41 rules on traffic separation, lighting, steering, speed, lookout requirements, and safe operation in channels and straits.[105] Other rules cover how to cross traffic lanes at correct angles and establish traffic separation schemes—specific procedures in crowded waterways to avoid collisions.[106] The United States adopted the COLREGs in the

International Navigation Rules Act of 1977,[107] and over 150 member states have since adopted them into law.[108] Notably, the COLREG update procedures were previously joined to the SOLAS conference, but IMO broke these into separate efforts, and the 1972 COLREG adoption used the same tacit acceptance procedure as SOLAS.[109]

IMO has adopted 86 COLREG amendments in seven tranches from 1981 to 2013, and one of the main subjects of these updates is traffic separation schemes.[110] New traffic separation schemes come about often, and the danger of collision in areas without an adopted scheme is significant.[111] Therefore, in the interest of rapid adoption of these key plans, the MSC has the authority to adopt and amend traffic separation schemes on behalf of the greater IMO.[112]

The MSC also oversees the overall framework for navigation safety and approves technical requirements, and IMO adds relevant safety measures to SOLAS Chapter V regularly.[113] For example, in the 1994 SOLAS amendments, IMO adopted ship reporting systems and made use of such systems mandatory.[114] As part of an update to SOLAS Chapter V in 2000, the MSC adopted a rule that all ships above a certain tonnage—and any ship carrying passengers—maintain an automatic identification system (AIS) capable of providing the ship's identity, position, course, and other safety information automatically to other ships and shore stations.[115] The AIS requirement entered into force for all ships in 2004.[116]

Insights

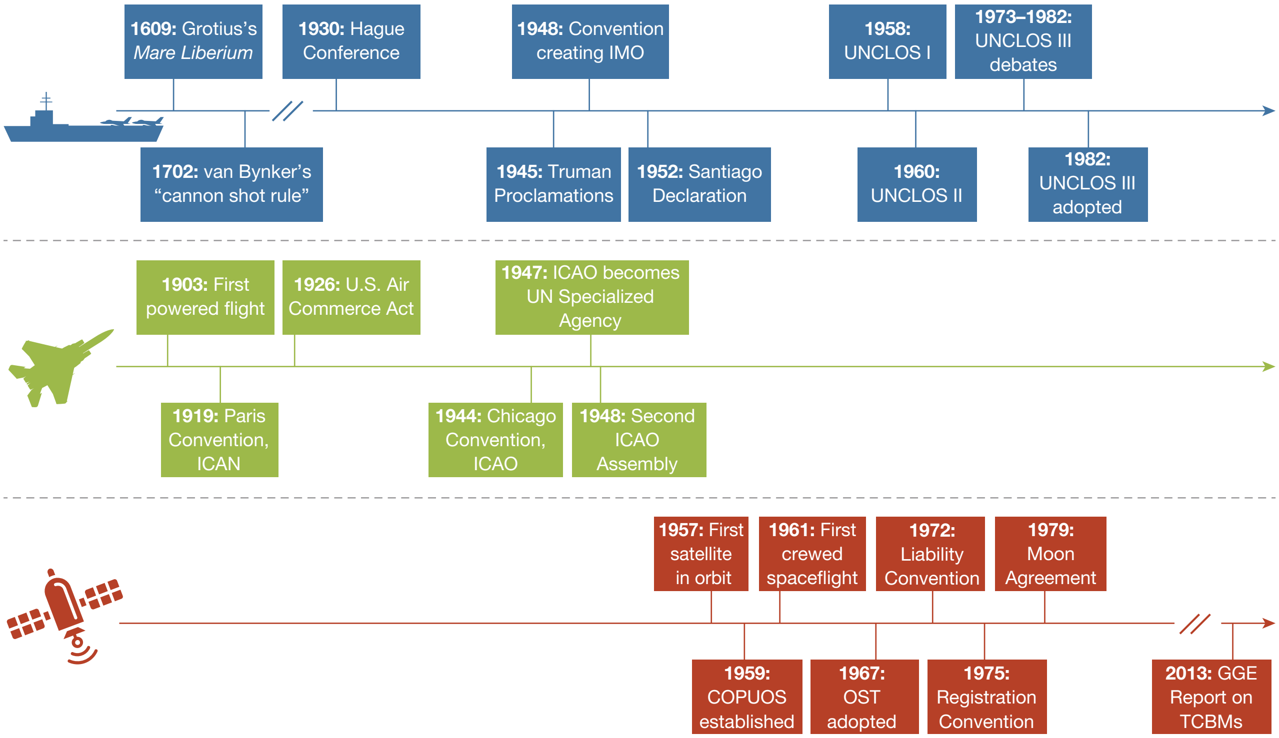
Both the air and maritime domains offer elements of governance directly applicable to space for the development of STM. In all three domains, norms and standards have evolved through private actions or state-to-state legal diplomacy rather than as a hierarchical governance scheme forming and imposing such rules from the top down.[117] The air and maritime governance frameworks are mature and robust, and they represent a high degree of international agreement and consensus with respect to addressing challenges of traffic management. Additionally, both governance frameworks empower and balance both public and private interests. For example, commercial and industrial interests are provided mechanisms and venues to inform rulemaking and allow for practice and rule development that align with technological advancement and market growth. At the same time, and perhaps most importantly, these frameworks also provide opportunities and means to induce or compel compliance and adjudicate or resolve conflict among system actors and stakeholders. These opportunities are, of course, dependent on the states' level of commitment to abiding to the relevant treaty provisions. These characteristics provide predictability and stability to air and maritime traffic management. Adopting these characteristics for a space governance framework would likely yield the same benefits.

Governance Development Timelines

Governance frameworks, mechanisms, and organizations for each of the three domains have developed and matured over differing periods of time (see Figure 3). Although the maritime domain—from a customary international law aspect—took centuries to develop, the UNCLOS treaty regime took shape over a period of approximately 50 years: from the Conference for the Codification of International Law at the Hague in 1930 to finalization of UNCLOS III in 1982. Air domain governance developed at a quicker rate: from the first flight in 1903 to establishment of ICAO 45 years later. However, the air domain did not encompass a long period of customary international law development. It essentially skipped this period in favor of an immediate treaty development period. Space governance development has differed from both domains in that an immediate period of treaty development followed the launch of Sputnik in 1957. However, since the last of the four broadly accepted treaties came into effect in 1972, no further development of binding international (treaty or customary) law has occurred (for a period of 50 years). Of critical importance is that, whereas both the maritime and air domains developed to a point of detailed and robust governance when their treaty regimes took effect, the implementation of the space treaties failed to provide this level of governance (or foster its immediate growth).

FIGURE 3

Maritime, Air, and Space Governance Development Timelines



NOTES: COPUOS = Committee on the Peaceful Uses of Outer Space; GGE = group of governmental experts; TCBM = transparency and confidence-building measures.

General Takeaways

Successful traffic management and coordination in the air and maritime domains began with the international treaties: the Chicago Convention and UNCLOS. It is these treaties that enabled the formation of both ICAO and IMO—the organizations that make air and maritime traffic management and coordination possible. In turn, both of these organizations provide for six key governance framework benefits:

- international representation by sovereign states
- bottom-up development of practices and rules
- substantive participation of nonstate private actors
- decisionmaking through democratic processes and procedures
- adjudication of conflict through mediation and arbitration
- compliance through the application of both soft and hard enforcement tools.

Successful STM would also require the above elements and characteristics. Relying on the Outer Space Treaty (OST) as a legal basis and using the UN as the venue and the overarching organizational support system,[118] sovereign states could create a specialized UN agency focused on addressing STM—much like ICAO and IMO—perhaps the *Space Traffic Management Organization* (STMO) or similar. To gain consensus for its creation, states could agree to tightly limit the jurisdiction and authority of the agency to STM functions only.[119] The compliance authority of the STMO could also be strictly limited to suspension or expulsion, otherwise relying heavily on its member states' regulatory regimes, so as not to put an undue burden on ultimate state sovereignty.

Both ICAO and IMO reveal potential structural elements for an STMO: an assembly, a council, a bureaucratic arm to maintain expertise, and technical committees to design rules and standards. Likewise, the organizations both developed their councils to draw members from three separate categories to ensure a wide diversity of interests represented.[120] To ensure participation of as many spacefaring nations as possible, it may be necessary to model an executive-type council within the STMO similar to ICAO and IMO. ICAO selects states from those of chief importance to air transport, states "not otherwise included but which make the largest contribution" to civil aviation, and a group of states that ensure diverse geographic representation.[121] Likewise, in IMO, those categories are ten states with the largest interest in providing shipping services, ten states with the largest interest in international maritime trade, and 20 states that "have special interests in maritime transport or navigation and whose election to the council will ensure the representation of all major geographic areas of the world."[122]

In the space domain, this could translate to a rotating council that includes currently nonspacefaring states. Although they are without space assets or programs of their own, such states are equally affected by the current degradation of the space environment and the orbital slots in which they have an equitable stake under OST Articles I and II. Additionally, the inclusion of states with aspirational or nascent space programs on the rotating council would help guard against the domination of space governance by a few well-resourced, politically powerful first mover states and private commercial or industrial entities. This would be necessary to comply with Article I of the OST, which states that the exploration of space, "shall be carried out *for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development*" and "shall be free for exploration and use by States *without discrimination of any kind, on a basis of equality*" (emphasis added).[123]

The general advantages and inducements to creating such an agency would be not only the six key benefits listed above. Another powerful incentive would be the opportunity to centralize data and information collection and distribution to the member parties—data and information that is essential to STM and both low earth orbit and geostationary earth orbit stability and sustainability.[124] The STMO could serve as an organizing clearinghouse for both public and private entities that maintain and collect data and information on space objects and debris. To ensure a robust data system, the price of access for each state to the clearinghouse would be the agreement to enact national laws and/or regulations requiring space operators under their jurisdiction to provide such data and information, which the state would then be obligated to provide to the STMO.

Moreover, a corollary inducement could be for the STMO to also provide access to a robust international collision avoidance notification and maneuver adjudication system. Such a system would help to ensure a safe, secure, predictable, and stable orbital environment. Processes, procedures, best practices, and rules (of notification and maneuver)—COLREGs for space—could be developed, drafted, and determined by designated STMO subcommittees tasked with collecting and incorporating input from industry, commercial, civil, scientific, and academic entities.

Lessons from the Air Domain

Even before ICAO came into being, air domain law had established several key features worth applying to STM. First, industry leaders have a role to play in shaping norms and, eventually, rules of the road for traffic separation and safe operation. As occurred in the United States in the early 1900s, insurers and manufacturers can create model rules and build coalitions across the industry to apply them. However, it is also worth noting that voluntary or industry-led nonbinding regimes were not able to achieve significant participation in the growing air industry. The failure of this voluntary regime is a stark and compelling example for the space community, which currently relies exclusively on voluntary, nonbinding, informal practices to conduct STM. Safe and secure air traffic management required the formation of ICAO as an internationally representative agency with sufficient jurisdiction and authorities to universalize standards and incentivize states to participate via a transparent rulemaking process. Because of the lack of sovereign territory in outer space, ICAO's chief enforcement measure—that is, member states' ability to deny noncompliant members entry into their airspace—is not feasible. However, other collective member actions in an STMO could serve as a similar deterrent.[125]

Following ICAO's creation, the industry and private participants continued to play a role in rulemaking, a key feature that allows ICAO to respond dynamically to changes in technology, the market, and the environment. The ICAO's secretariat, the civil bureaucracy arm of the organization, interacts with and receives input from invited organizations, including industry leaders. The secretariat seeks input from other UN specialized agencies, intergovernmental organizations, and nongovernmental foundations for research, standards committees, and professional federations.[126] This established access and network connectivity also aid in facilitating negotiation and compromise over standards and rules where entities with diverse interests may otherwise be tempted to act autonomously out of fear or frustration of not having a seat at the table. The STMO should seek and formally incorporate similar input from the various private and public entities, corporations, and international organizations with stakeholder interests in space and space governance.

In terms of ensuring compliance with traffic management standards and rules (in addition to other aviation standards and rules), the Chicago Convention gives the ICAO council the authority to act as a mediator in disputes over interpretation of the convention and its annexes, and—if necessary—the convention requires the parties to go to arbitration.[127] More importantly, Article 88 provides that the assembly may suspend the voting rights of a member for nonconformity with the prescribed dispute procedures.[128] To be effective, an STMO would need to be granted similar authority. Disputes and aberrant conduct in space related to traffic management must have a path to resolution that all member states can accept as legitimate. The physics of space mean that a rogue, negligent, or malicious actor can substantially damage or destroy space objects belonging to other nations or pollute orbital shells to the point where they are unusable.[129] Compliance adjudications, even if imperfect, can provide due process, finality, and predictability to the system while still relying on member states to police each other and ensuring the highest possible degree of participation.

Lessons from the Maritime Domain

The pre-IMO development of international maritime governance also has lessons for STM. As demonstrated by the Truman Proclamations and the creation of the exclusive economic zone, such spacefaring nations as the United States can begin shaping future space standards and rules by adopting STM regulations now, either unilaterally or in coalitions. Likewise, the lengthy negotiations over UNCLOS show the value of breaking the most hotly contested issues into separate streams of debate. The STMO could place separate committees in charge of governance frameworks for the following STM challenges: data collection, sharing, and integration; proximity and collision notifications; and maneuver requirements. Doing so would compartmentalize negotiations and likely shift the burden of coalition-building to states that dissent and impede consensus. This approach could allow breakthroughs on STM as it did for negotiating the various maritime topics (including navigation and traffic issues) during the UNCLOS III debate.

IMO's development also lends itself to a possible STM organization. First, IMO's unique funding model could serve as a model for how an STMO may be funded: The number or mass of orbital objects would stand in for the overall tonnage of shipping to determine each state's contribution. However, IMO excludes military and other state vessels from its measure, which presents a problem for an STMO given the number of dual-use platforms in space. Moreover, mass may not correspond neatly to the actual use or risk presented by space objects, perhaps necessitating other measures, such as volume of data traffic. Second, IMO has made steady use of procedural elements to prioritize collision prevention, and an STMO could employ the tacit acceptance procedure for updates to orbital separation and maneuver schemes to avoid requiring explicit two-thirds approval of members. This would also allow the process of standards and rules development to progress more quickly. Likewise, creating such a technical committee as the MSC that is empowered to adopt updates to orbital separation and maneuver requirements and technical capabilities for spacecraft would allow an STMO to dynamically adapt to what will remain a rapidly evolving domain.

Additionally, in terms of ensuring compliance, the maritime domain—like the air domain—offers a model to consider and borrow from for STM. Although there is no mechanism to suspend states for noncompliance, several UNCLOS articles require states to enact and enforce national laws and regulations that are in accordance with UNCLOS provisions.[130] UNCLOS also requires states to allow for dispute recourse within their legal systems and/or before the International Tribunal for the Law of the Sea or the International Court of Justice.[131]

Conclusion

Earth's orbital environment is getting crowded. By 2030, based on deployment estimates, it is expected that tens of thousands of additional satellites may occupy low earth orbit.[132] These satellites will vary in size and maneuver capability.[133] The need for international STM rules, standards, norms, and best practices will only increase as more spacefaring nations join the domain. An internationally agreed-upon and composed STMO (or an equivalent organization), invested with sufficient jurisdiction and authority, can start the hard work of debating and determining the necessary rules and standards for spacecraft traffic maneuvers. An STMO could successfully universalize these rules across all space stakeholders, providing for STM predictability, reliance, safety, and stability.

As space congestion has increased, and with it the challenge of STM, researchers have noted key differences among the space, air, and maritime domains that make the development of the STMO difficult to compare directly with ICAO or IMO. ICAO has dealt with the interaction of national and international airspace, allowing it to draw on regional governance schemes. However, all of space is akin to international airspace or the high seas (as opposed to regional geographies and territories).[134] Conversely, IMO had the task of standardizing a body of laws and norms that had developed over centuries, whereas an STMO will inherit a relatively undeveloped domain.[135]

Notwithstanding these differences, the air and maritime domains offer insights that are clearly applicable to the development of an STM governance framework. Applying these insights, and the lessons learned as governance in these domains matured, could enable an STMO to avoid early hurdles and pitfalls that could jeopardize space sustainability. One key insight is that an STMO should limit its initial jurisdiction, authority, and scope to rules and technical standards that would enable a robust collision notification and safe maneuver system.[136] This focus is more likely to gain international consensus. A second key insight is to ensure that the organization represents a diverse set of states throughout its governance structure. Likewise, an STMO should adopt methods and mechanisms (similar to those used by both ICAO and IMO) to incorporate private entity input into rulemaking. This will empower the STMO to take advantage of the most relevant and developed technical data, technology, and expertise of industry stakeholders who must contend with current and emerging STM challenges. Finally, an STMO would also benefit from taking ICAO's and IMO's lead in crafting compliance procedures and mechanisms that avoid or mitigate against noncompliance, burden-shifting impasses between actors, and conflict-generating behaviors and conduct.

Notes

[1] We contrast STM with STC. Because of the lack of agreed-upon definitions of both terms, *STC* is occasionally cited in the literature as an alternative term for STM. In some cases, the use of STC may be preferred because it does not necessarily apply active management of the space system—management that would imply an authority over space operators beyond their national governments. For a discussion on this distinction, see P. J. Blount, "Space Traffic Coordination: Developing a Framework for Safety and Security in Satellite Operations," *Space: Science and Technology*, Vol. 2021, May 23, 2021, pp. 2–3. Because our focus in this report is on an analysis of governance mechanisms (i.e., treaties and treaty-created organizations and processes), we use the term *STM* because it denotes more-active governance application.

[2] See Tereza Pultarova, "SpaceX Starlink Satellites Responsible for over Half of Close Encounters in Orbit, Scientist Says," Space.com, August 20, 2021 ("an operator managing about 50 satellites will receive up to 300 official conjunction alerts a week"); and Marit Undseth, Claire Jolly, and Mattia Olivari, *Space Sustainability: The Economics of Space Debris in Perspective*, Organisation for Economic Co-operation and Development, Policy Paper No. 87, April 20, 2020, pp. 22–35.

[3] See National Academy of Public Administration, *Space Traffic Management*, August 2020; and European Space Policy Institute, *Space Environment Capacity*, April 11, 2022.

[4] European Space Agency, "Space Debris by the Numbers," webpage, undated. Additionally, nontrackable debris measuring 1 cm to 10 cm, which is large enough to damage or disable a space object, numbers approximately 1,000,000 pieces.

[5] We consider *SSA*, defined generally as the ability to keep track of objects in orbit and predicting where they will be at any given time, to be an essential precursor to a functional system of STM. (See Space Foundation, "Space Situational Awareness," in *The Space Briefing Book: A Reference Guide to Modern Space Activities*, 2019.) In this report, we address the issue of STM but acknowledge the interconnection with SSA and the need to expand research into both topics.

[6] For example, the Atlantic Council recently offered the following definition of STM: "the ability of the international and national authorities to track spacecraft and space debris, to regulate where space operators position their spacecraft, and to oversee debris mitigation and remediation." (See Mir Sadat and Julia Seigel, "Space Traffic Management: Time for Action," Atlantic Council, issue brief, August 2, 2022.) The International Academy of Astronauts defines STM as "the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference." (See Corinne Contant-Jorgenson, Petr Lála, and Kai-Uwe Schrogl, "The IAA Cosmic Study on Space Traffic Management," *Space Policy*, Vol. 22, No. 4, 2006, p. 284.) The United States recently offered the following definition of STM: "the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment." (See Space Policy Directive-3, *National Space Traffic Management Policy*, White House, June 18, 2018.)

[7] Michael P. Gleason and Travis Cottom, "U.S. Space Traffic Management: Best Practices, Guidelines, Standards, and International Considerations," Aerospace Corporation, August 2018, pp. 7–8.

[8] Gleason and Cottom, 2018, p. 8. We note that commercial satellite operators formed the Space Data Association (SDA) in 2009 to facilitate STM, but the SDA is voluntary. It also lacks codified standards and/or guidelines and is not empowered to adjudicate disputes or require compliance.

[9] The functions of providing space object tracking and collision warning performed by space-track.org for the public were designated for transfer to the U.S. Department of Commerce in 2018 by presidential directive. See Space Policy Directive-3, 2018.

[10] Glenn Peterson, Marlon Sorge, and William Ailor, *Space Traffic Management in the Age of New Space*, Aerospace Corporation, April 2018, pp. 2–4.

[11] See, for example, White House, *National Security Strategy*, October 12, 2022, p. 45 ("We must lead in updating outer space governance, establishing a space traffic coordination system and charting a path for future space norms and arms control."); and Jeff Foust, "European Union Lays Out Plan to Bolster Space Traffic Management Capabilities," *SpaceNews*, February 20, 2022. See also Kuan Yang, "Chinese Perspective on an International Regime of Space Traffic Management," *Journal of Space Safety Engineering*, Vol. 6, No. 2, 2019.

[12] We recognize that other domains may also offer analogous governance frameworks that may be applicable to space, such as radio spectrum, governed by the International Telecommunications Union and its corresponding treaty. Although we limit our examination in this report to the air and maritime domains, we acknowledge that these other domains represent fruitful areas of research for developing STM solutions.

[13] See Insurance Information Institute, "Facts and Statistics: Aviation and Drones," webpage, undated; and Hasan Ugurlu and Ismail Cicek, "Analysis and Assessment of Ship Collision Accidents Using Fault Tree and Multiple Correspondence Analysis," *Ocean Engineering*, Vol. 245, February 2022. We note that more research would need to be conducted to determine whether, and to what extent, there is causation between specific governance mechanisms in the air and maritime domains. Data examined here may indicate only a correlation between the two. However, even if low collision rates are correlative with particular governance mechanisms, this may be sufficient reason to consider their adoption in the space domain given the concomitant benefits of predictable and stable governance generally.

[14] See Ruth Stilwell, Diane Howard, and Sven Kaltenhauser, "Overcoming Sovereignty for Space Traffic Management," 70th Annual International Astronautical Congress, October 2019; Diane Howard, Ruth Stilwell, Thomas Gellenthien, Nathaniel Dailey, and Scott

Kordella, "The Policy Construct for Space Traffic Management: Summary of Obligations, Authorities, and Enforcement Mechanisms for Pre-Launch, Launch, On-Orbit and Reentry Phases of Flight," International Astronautical Congress 2019 Special Session on Space Traffic Management, October 2019; and Stephen Garber and Marissa Herron, "How Has Traffic Been Managed in the Sky, on Waterways, and on the Road? Comparisons for Space Situational Awareness (Part 2)," *Space Review*, June 15, 2020.

15 Keyword search terms and phrases included *traffic*, *traffic management*, *air traffic*, *air traffic management*, *air traffic control*, *maritime traffic*, *maritime traffic management*, *governance*, *governance processes/procedures/mechanisms/organizations*, *treaty mechanisms*, *Chicago Convention*, *ICAO*, *ICAN*, *IMO*, and *UNCLOS*.

16 ICAO, "About ICAO," webpage, undated-b.

17 ICAO, "The History of ICAO and the Chicago Convention," webpage, undated-f.

18 See Ruth Stilwell, "Decentralized Space Traffic Management," Space Traffic Management Conference, 2019, arguing that air traffic development mirrors space because of the initial limited needs for coordination, followed by increased access leading to more-formal governance mechanisms. See also Garber and Herron, 2020.

19 Sean Seyer, *Sovereign Skies: The Origins of American Aviation Policy*, Johns Hopkins University Press, 2021, pp. 50–54. One proposal was to mandate radio for any aircraft with more than ten passengers, suggesting adoption of new technologies would play a prominent role in air traffic movement. The United States primarily refused to recognize the Paris Convention because it would also require recognizing the League of Nations, a nonstarter in the U.S. Senate at the time.

20 Clement Bouvé, "The Development of International Rules of Conduct in Air Navigation," *Air Law Review*, Vol. 1, No. 1, 1930, p. 3. The United States was a signatory to both agreements but never ratified either one. ICAO, "1928: The Havana Convention," webpage, undated-a.

21 ICAO, undated-a.

22 ICAO, undated-f.

23 Seyer, 2021, p. 128.

24 Albert Roper, "The Organization and Program of the International Commission for Air Navigation (C.I.N.A.)," *Journal of Air Law and Commerce*, Vol. 3, No. 2, 1932, p. 168.

25 Seyer, 2021, p. 128.

26 Seyer, 2021, pp. 126–128.

27 Seyer, 2021, pp. 136–138.

28 Chester W. Cuthell, "Development of Aviation Laws in the United States," *Air Law Review*, Vol. 1, No. 1, 1930, pp. 87–88.

29 Seyer, 2021, pp. 140–150.

30 Seyer, 2021.

31 Seyer, 2021, pp. 152–153.

32 Andrew Glass, "Congress Passed Air Commerce Act, May 20, 1926," *Politico*, May 20, 2013.

33 Seyer, 2021, pp. 154–155. Other rules adopted from ICAN included the head-on meeting rule (each aircraft alters its course to the right).

34 Seyer, 2021, p. 156. It is noteworthy that all air-faring states enacted or otherwise adopted binding traffic management rules a very short, 26-year period between the first flight at Kitty Hawk in 1903 and 1929. In the 55 years since the Outer Space Treaty came into force, spacefaring nations have yet to adopt binding traffic rules, notwithstanding the growing need.

35 David MacKenzie, *ICAO: A History of the International Civil Aviation Organization*, University of Toronto Press, 2010, pp. 30–35.

36 Bouvé, 1930, pp. 7–8.

37 MacKenzie, 2010, p. 35.

38 ICAO, *Convention on International Civil Aviation Done at Chicago*, Document 7300, December 7, 1944.

39 ICAO, 1944, Chapter VI, Article 37.

40 MacKenzie, 2010, pp. 35–52.

41 ICAO, "Assembly," webpage, undated-d; ICAO, 1944, Chapter VIII, Article 48(a)–(b).

42 ICAO, "The ICAO Council," webpage, undated-h. The council's membership is drawn from several different categories to ensure it represents a diversity of interests. ICAO, 1944, Chapter IX, Article 50(b).

[43] ICAO, 1944, Chapter XII, Articles 61 and 62.

[44] ICAO, 1944, Chapter IX, Article 54; ICAO, 1944, Chapter XVIII, Article 84. Note that this dispute resolution process addresses interstate disputes, not states' refusal to adhere to the air rules that ICAO adopts.

[45] Ludwig Weber, *International Civil Aviation Organization (ICAO)*, 4th ed., Kluwer Law International, 2021. Although the Council has settled matters of legislative interpretation, more often complaints are by one state directed at the conduct of another.

[46] ICAO, 1944, Chapter XVIII, Article 85.

[47] ICAO, 1944, Chapter XVIII, Article 88.

[48] ICAO, 1944, Chapter XVIII, Article 88; ICAO, 1944, Chapter XVIII, Article 49(j).

[49] Weber, 2021, Chapter 2. See the discussion in the Procedural Solutions in IMO section of this report.

[50] Weber, 2021, Chapter 2; ICAO, 1944, Chapter XVIII, Article 94(b). In practice, updates to the convention rarely occur.

[51] ICAO, "ICAO and the United Nations," webpage, undated-g.

[52] MacKenzie, 2010, p. 74.

[53] ICAO, "Building on a Strong Foundation: ICAO's Precursors," webpage, undated-e. An interim agreement in 1945 created PICAO, the provisional version of ICAO, with the provision that when ICAO came into force, all of PICAO's records and property would transfer to the permanent organization. Weber, 2021, Chapter 1.

[54] MacKenzie, 2010, p. 69.

[55] MacKenzie, 2010, p. 101.

[56] ICAO, "Air Navigation Bureau," webpage, undated-c; ICAO, 1944, Chapter X, Articles 56–57. The council also appoints the ANC president. The council adopts updates to the annexes by a two-thirds vote. ICAO, 1944, Chapter XX, Article 90.

[57] MacKenzie, 2010, p. 102.

[58] MacKenzie, 2010, p. 103.

[59] MacKenzie, 2010, p. 104.

[60] ICAO, 1944, Chapter IV, Articles 28(b) and 37.

[61] ICAO, "Making an ICAO SARP," March 5, 2018.

[62] ICAO, 1944, Chapter VI, Article 38.

[63] ICAO, undated-b.

[64] ICAO, undated-b.

[65] ICAO, "ICAO Secretariat," webpage, undated-i.

[66] ICAO, undated-b.

[67] Brian Colamosca, "A Brief History of the Reduced Vertical Separation Minimum (RVSM)," ICAO, June 16, 2003, pp. 6–9. Additionally, we note that some research indicates that state compliance with ICAO rules is not uniform and can result in a lack of standardization and other deficiencies—problems that may need to be addressed by additional resourcing and better integration of ICAO into the UN system. See CAPA Centre for Aviation, "ICAO in Need of Reforms to Enhance Its Relevance—Now Is Opportune," October 30, 2021. These issues with the current governance and infrastructure of ICAO represent additional fruitful areas of research so that lessons may be learned for STM and the space domain generally.

[68] Colamosca, 2003, p. 8.

[69] Federal Aviation Administration, "Reduced Vertical Separation Minimum (RVSM)," webpage, undated.

[70] Colamosca, 2003, pp. 18–22.

[71] Garber and Herron, 2020.

[72] Garber and Herron, 2020; Ruth Stilwell, "Space Situational Awareness: Key Issues in an Evolving Landscape," statement before the Committee on Science, Space, and Technology, U.S. House of Representatives, February 11, 2020.

[73] Tullio Treves, "Historical Development of the Law of the Sea," in Donald Rothwell, Alex Oude Elferink, Karen Scott, and Tim Stephens, eds., *Oxford Handbook of the Law of the Sea*, 2015, pp. 1–2.

[74] Treves, 2015, p. 3.

[75] Treves, 2015, pp. 5–6.

[76] Daniel Patrick O'Connell, "The History of the Law of the Sea," in Ivan Anthony Shearer, ed., *The International Law of the Sea,* Vol. 1, 1st ed., Clarendon Press, 1982, p. 20.

[77] Treves, 2015, pp. 8–9.

[78] Rodrigo Fracalossi de Moraes, "The Parting of the Seas: Norms, Material Power, and State Control over the Ocean," *Revista Brasileira de Política Internacional*, Vol. 62, No. 1, 2019.

[79] Treves, 2015, p. 11.

[80] O'Connell, 1982, pp. 24–25.

[81] O'Connell, 1982, pp. 24–25.

[82] O'Connell, 1982, p. 26.

[83] O'Connell, 1982, p. 27.

[84] O'Connell, 1982, p. 27.

[85] O'Connell, 1982, pp. 28–29.

[86] IMO, "Introduction to IMO," webpage, undated-e.

[87] IMO, "Convention on the International Maritime Organization," webpage, undated-b.

[88] IMO, undated-b.

[89] IMO, undated-b.

[90] IMO, "Structure of IMO," webpage, undated-h.

[91] IMO, undated-h.

[92] U.S. Coast Guard, "USCG IMO Homepage," webpage, undated-b.

[93] IMO, "Member States," webpage, undated-f. The three associate members are the Faroe Islands, Hong Kong, and Macao.

[94] IMO, "International Convention for the Safety of Life at Sea (SOLAS), 1974," webpage, undated-d.

[95] IMO, *Focus on the IMO: SOLAS: The International Convention for the Safety of Life at Sea, 1974*," October 1998, pp. 2–3.

[96] IMO, 1998, pp. 2–3.

[97] IMO, 1998, p. 2.

[98] IMO, 1998, pp. 3–4. A grouping of states can also reject an amendment if together they represent greater than 50 percent of gross merchant tonnage. ICAO uses a somewhat similar procedure to create SARPs: After adoption by the ICAO council, a SARP becomes effective after a set time if a majority of members do not register disapproval. ICAO, 2018.

[99] IMO, 1998, pp. 7–8.

[100] Lei Shi, "Successful Use of the Tacit Acceptance Procedure to Effectuate Progress in International Maritime Law," *University of San Francisco Maritime Law Journal*, Vol. 11, No. 2, 1999, pp. 307–309. IMO's legal committee also dealt with a question of customary international law and whether a provision can become binding on a state that does not explicitly agree to it. However, both IMO and other UN organizations have found that tacit acceptance is legal—states can opt out and avoid being bound by the new rules, although this presents problems for developing states. See Shi, 1999, pp. 309–311.

[101] IMO, undated-h.

[102] IMO, undated-h.

[103] See IMO, "Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs)," webpage, undated-c; UN, *International Convention for the Safety of Life at Sea, 1974*, November 1, 1974, Articles VIII(b)(iv)–(vi). See above discussion of ICAO SARPs.

[104] IMO, undated-c.

[105] IMO, undated-c.

[106] IMO, undated-c. We note, however, that IMO (like ICAO) does have issues and deficiencies that have been described in the existing research and literature. See, for example, Jane Lister, René Taudal Poulsen, and Stefano Ponte, "Orchestrating Transnational Environmental Governance in Maritime Shipping," *Global Environmental Change*, Vol. 34, September 2015 (discussing procedural delays associ-

ated with IMO rulemaking processes and the weak enforcement of regulations once enacted). These issues with the current governance IMO framework represent additional fruitful areas of research so that lessons may be learned for STM and the space domain generally.

[107] U.S. Coast Guard, "Rules of the Road," webpage, undated-a.

[108] IMO, *Status of Multilateral Conventions and Instruments in Respect of Which the International Maritime Organization or Its Secretary-General Performs Depositary or Other Functions*, July 31, 2013.

[109] IMO, 1998, p. 6.

[110] IMO, *List of Conventions, Other Multilateral Instruments and Amendments in Respect of Which the Organization Performs Depositary and Other Functions*," July 2022; U.S. Coast Guard, undated-a.

[111] IMO, undated-c.

[112] IMO, undated-c.

[113] IMO, "Safety of Navigation," webpage, undated-g.

[114] IMO, 1998, p. 18.

[115] IMO, "AIS Transponders," webpage, undated-a.

[116] IMO, undated-a. We note that additional research would likely be necessary to examine the performance of AIS since 2004 with regard to specific traffic management criteria and categories.

[117] We note, however, that the physical characteristics between the air and maritime domains, contrasted with the space domain, present challenges. It is significantly easier to maintain sovereign control over an airspace, a port, or a coastline. This has allowed governance in the air and maritime domain to develop from a point and perspective of sovereign territorial control. The same is not true for space, where the physics of space make it impossible to control an orbit or an orbital area in terms of traffic management. Thus, insights presented here focus on the governance structures in the air and maritime domain that may serve as models for space, but not necessarily one-to-one solutions.

[118] See Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, January 27, 1967. The 1967 OST is the overarching, foundational, and legally binding international agreement for space. It has been ratified by 110 nations, including all spacefaring countries. Frequently referred to the as the *Magna Carta of space*, the OST delineates principles related to space exploration, use and access, appropriation, nuclear weapons, treatment of astronauts, liability for damage, and the supervision of space actors. For a more-detailed discussion on the OST and other space treaties, see Bruce McClintock, Katie Feistel, Douglas C. Ligor, and Kathryn O'Connor, *Responsible Space Behavior for the New Space Era: Preserving the Province of Humanity*, RAND Corporation, PE-A887-2, 2021, pp. 5–7 and 23–25. Notwithstanding its explication of binding principles, the OST does not address STM in any detail or specificity. It is this gap in governance that requires further action by the international community, as it has done similarly in the air and maritime domains.

[119] The STMO, or a similar special agency, could address other issues, such as debris mitigation and management, safety regulations, insurance requirements, dual-use technologies, rendezvous and proximity operations, and use of force issues. However, it may be difficult to gain consensus on creating such an expansive UN agency, at least initially. A focus on STM—where there is already widespread international agreement as to the significant need—may prove to be easier to negotiate and create, at least as a first step in developing much-needed international cooperation in the space domain.

[120] Both ICAO and IMO draw membership on their councils from three categories; however, the methods applied to separate and identify members from each category differ. ICAO, undated-h; IMO, undated-h. The comparative makeup and rules of each council merit further research.

[121] ICAO, undated-h.

[122] IMO, undated-h.

[123] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, 1967, Article I.

[124] *Low earth orbit* is defined generally as "an orbit that is relatively close to Earth's surface . . . normally at an altitude of less than 1000 kilometers but could be as low as 160 kilometers above the Earth"; *geostationary (or geosynchronous) orbit* is defined generally as an orbit in which satellites "circle Earth above the equator from west to east following the Earth's rotation . . . an altitude of 35,786 kilometers." See European Space Agency, "Types of Orbits, webpage, March 30, 2020.

[125] Among possible actions, members could prevent domestic companies from participating in space-based actions in coordination with entities from a noncompliant state.

[126] ICAO, "Organizations Able to Be Invited to ICAO Meetings," webpage, undated-j.

[127] ICAO, 1944, Articles 84 and 85.

[128] ICAO, 1944, Article 88.

[129] See Andy Lawrence, Meredith L. Rawls, Moriba Jah, Aaron Boley, Federico Di Vruno, Simon Garrington, Michael Kramer, Samantha Lawler, James Lowenthal, Jonathan McDowell, and Mark McCaughrean, "The Case for Space Environmentalism," *Nature Astronomy*, Vol. 6, April 2022.

[130] See UN, 1974, Article 194, pp. 204–207 and 213–222.

[131] UN, 1974, Article 235.

[132] Inmarsat, *Space Sustainability Report*, June 22, 2022, pp. 16–20.

[133] McClintock et al., 2021, pp. 14–15.

[134] See Garber and Herron, 2020.

[135] See Emily S. Nightingale, Bhavya Lal, Brian C. Weeden, Alyssa J. Picard, and Anita R. Eisenstadt, "Evaluating Options for Civil Space Situational Awareness (SSA)," Institute for Defense Analyses, August 2016.

[136] As an initial matter, the international stakeholder community would likely benefit from additional research that would be geared toward identifying and prioritizing the key rules and technical standards (e.g., rules and standards related to proximity distances, maneuver notifications, communications mechanisms, and so forth).

References

Blount, P. J., “Space Traffic Coordination: Developing a Framework for Safety and Security in Satellite Operations,” *Space: Science and Technology*, Vol. 2021, May 23, 2021.

Bouvé, Clement, “The Development of International Rules of Conduct in Air Navigation,” *Air Law Review*, Vol. 1, No. 1, 1930.

CAPA Centre for Aviation, “ICAO in Need of Reforms to Enhance Its Relevance—Now Is Opportune,” October 30, 2021.

Civil Aviation Authority, “ICAO’s Structure and Upcoming Events in the Field of Civil Aviation (Infographics),” Government of Poland, June 11, 2013.

Colamosca, Brian, “A Brief History of the Reduced Vertical Separation Minimum (RVSM),” International Civil Aviation Organization, June 16, 2003.

Contant-Jorgenson, Corinne, Petr Lála, and Kai-Uwe Schrogl, “The IAA Cosmic Study on Space Traffic Management,” *Space Policy*, Vol. 22, No. 4, 2006.

Cuthell, Chester W., “Development of Aviation Laws in the United States,” *Air Law Review*, Vol. 1, No. 1, 1930.

de Moraes, Rodrigo Fracalossi, “The Parting of the Seas: Norms, Material Power, and State Control over the Ocean,” *Revista Brasileira de Política Internacional*, Vol. 62, No. 1, 2019.

European Space Agency, “Space Debris by the Numbers,” webpage, undated. As of August 2, 2022:
https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

European Space Agency, “Types of Orbits,” webpage, March 30, 2020. As of December 19, 2022:
https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits#GEO

European Space Policy Institute, *Space Environment Capacity*, April 11, 2022.

Federal Aviation Administration, “Reduced Vertical Separation Minimum (RVSM),” webpage, undated. As of December 13, 2022:
https://www.faa.gov/air_traffic/separation_standards/rvsm/

Foust, Jeff, “European Union Lays Out Plan to Bolster Space Traffic Management Capabilities,” *SpaceNews*, February 20, 2022.

Garber, Stephen, and Marissa Herron, “How Has Traffic Been Managed in the Sky, on Waterways, and on the Road? Comparisons for Space Situational Awareness (Part 2),” *Space Review*, June 15, 2020.

Glass, Andrew, “Congress Passed Air Commerce Act, May 20, 1926,” *Politico*, May 20, 2013.

Gleason, Michael P., and Travis Cottom, “U.S. Space Traffic Management: Best Practices, Guidelines, Standards, and International Considerations,” Aerospace Corporation, August 2018.

Howard, Diane, Ruth Stilwell, Thomas Gellenthien, Nathaniel Dailey, and Scott Kordella, “The Policy Construct for Space Traffic Management: Summary of Obligations, Authorities, and Enforcement Mechanisms for Pre-Launch, Launch, On-Orbit and Reentry Phases of Flight,” International Astronautical Congress 2019 Special Session on Space Traffic Management, October 2019.

ICAO—*See* International Civil Aviation Organization.

IMO—*See* International Maritime Organization.

Inmarsat, *Space Sustainability Report*, June 22, 2022.

Insurance Information Institute, “Facts and Statistics: Aviation and Drones,” webpage, undated. As of August 2, 2022:
https://www.iii.org/fact-statistic/facts-statistics-aviation-and-drones

International Civil Aviation Organization, “1928: The Havana Convention,” webpage, undated-a. As of December 20, 2022:
https://applications.icao.int/postalhistory/1928_the_havana_convention.htm

International Civil Aviation Organization, “About ICAO,” webpage, undated-b. As of December 13, 2022:
https://www.icao.int/about-icao/Pages/default.aspx

International Civil Aviation Organization, “Air Navigation Bureau,” webpage, undated-c. As of December 13, 2022:
https://www.icao.int/safety/airnavigation/Pages/default.aspx

International Civil Aviation Organization, “Assembly,” webpage, undated-d. As of December 13, 2022:
https://www.icao.int/about-icao/assembly/Pages/default.aspx

International Civil Aviation Organization, “Building on a Strong Foundation: ICAO’s Precursors,” webpage, undated-e. As of December 13, 2022:
https://www.icao.int/about-icao/History/Pages/civil-aviation-pre-icao.aspx

International Civil Aviation Organization, “The History of ICAO and the Chicago Convention,” webpage, undated-f. As of December 13, 2022:
https://www.icao.int/about-icao/History/Pages/default.aspx

International Civil Aviation Organization, “ICAO and the United Nations,” webpage, undated-g. As of December 13, 2022: https://www.icao.int/about-icao/History/Pages/icao-and-the-united-nations.aspx

International Civil Aviation Organization, “The ICAO Council,” webpage, undated-h. As of December 13, 2022: https://www.icao.int/about-icao/Council/Pages/council.aspx

International Civil Aviation Organization, “ICAO Secretariat,” webpage, undated-i. As of December 13, 2022: https://www.icao.int/about-icao/Pages/Invited-Organizations.aspx

International Civil Aviation Organization, “Organizations Able to Be Invited to ICAO Meetings,” webpage, undated-j. As of December 13, 2022:
https://www.icao.int/secretariat/Pages/default.aspx

International Civil Aviation Organization, *Convention on International Civil Aviation Done at Chicago*, Document 7300, December 7, 1944.

International Civil Aviation Organization, “Making an ICAO SARP,” March 5, 2018.

International Maritime Organization, “AIS Transponders,” webpage, undated-a. As of December 13, 2022: https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

International Maritime Organization, “Convention on the International Maritime Organization,” webpage, undated-b. As of December 13, 2022:
https://www.imo.org/en/About/Conventions/Pages/Convention-on-the-International-Maritime-Organization.aspx

International Maritime Organization, “Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs),” webpage, undated-c. As of December 13, 2022:
https://www.imo.org/en/About/Conventions/Pages/COLREG.aspx

International Maritime Organization, “International Convention for the Safety of Life at Sea (SOLAS), 1974,” webpage, undated-d. As of December 13, 2022:
https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

International Maritime Organization, “Introduction to IMO,” webpage, undated-e. As of December 13, 2022: https://www.imo.org/en/About/Pages/Default.aspx

International Maritime Organization, “Member States,” webpage, undated-f. As of December 13, 2022: https://www.imo.org/en/OurWork/ERO/Pages/MemberStates.aspx

International Maritime Organization, “Safety of Navigation,” webpage, undated-g. As of December 13, 2022: https://www.imo.org/en/OurWork/Safety/Pages/NavigationDefault.aspx

International Maritime Organization, “Structure of IMO,” webpage, undated-h. As of December 13, 2022: https://www.imo.org/en/About/Pages/Structure.aspx

International Maritime Organization, *Focus on the IMO: SOLAS: The International Convention for the Safety of Life at Sea, 1974*,” October 1998.

International Maritime Organization, *Status of Multilateral Conventions and Instruments in Respect of Which the International Maritime Organization or Its Secretary-General Performs Depositary or Other Functions*, July 31, 2013.

International Maritime Organization, *List of Conventions, Other Multilateral Instruments and Amendments in Respect of Which the Organization Performs Depositary and Other Functions*,” July 2022.

Lawrence, Andy, Meredith L. Rawls, Moriba Jah, Aaron Boley, Federico Di Vruno, Simon Garrington, Michael Kramer, Samantha Lawler, James Lowenthal, Jonathan McDowell, and Mark McCaughrean, “The Case for Space Environmentalism,” *Nature Astronomy*, Vol. 6, April 2022.

Lister, Jane, René Taudal Poulsen, and Stefano Ponte, “Orchestrating Transnational Environmental Governance in Maritime Shipping,” *Global Environmental Change*, Vol. 34, September 2015.

MacKenzie, David, *ICAO: A History of the International Civil Aviation Organization*, University of Toronto Press, 2010.

McClintock, Bruce, Katie Feistel, Douglas C. Ligor, and Kathryn O’Connor, *Responsible Space Behavior for the New Space Era: Preserving the Province of Humanity*, RAND Corporation, PE-A887-2, 2021. As of December 14, 2022:
https://www.rand.org/pubs/perspectives/PEA887-2.html

National Academy of Public Administration, *Space Traffic Management*, August 2020.

Nightingale, Emily S., Bhavya Lal, Brian C. Weeden, Alyssa J. Picard, and Anita R. Eisenstadt, “Evaluating Options for Civil Space Situational Awareness (SSA),” Institute for Defense Analyses, August 2016.

O’Connell, Daniel Patrick, “The History of the Law of the Sea,” in Ivan Anthony Shearer, ed., *The International Law of the Sea*, Vol. 1, 1st ed., Clarendon Press, 1982.

Peterson, Glenn, Marlon Sorge, and William Ailor, *Space Traffic Management in the Age of New Space*, Aerospace Corporation, April 2018.

Pultarova, Tereza, “SpaceX Starlink Satellites Responsible for over Half of Close Encounters in Orbit, Scientist Says,” Space.com, August 20, 2021.

Roper, Albert, “The Organization and Program of the International Commission for Air Navigation (C.I.N.A.),” *Journal of Air Law and Commerce*, Vol. 3, No. 2, 1932.

Sadat, Mir and Julia Seigel, “Space Traffic Management: Time for Action,” Atlantic Council, issue brief, August 2, 2022.

Seyer, Sean, *Sovereign Skies: The Origins of American Aviation Policy*, Johns Hopkins University Press, 2021.

Shi, Lei, “Successful Use of the Tacit Acceptance Procedure to Effectuate Progress in International Maritime Law,” *University of San Francisco Maritime Law Journal*, Vol. 11, No. 2, 1999.

Space Foundation, “Space Situational Awareness,” in *The Space Briefing Book: A Reference Guide to Modern Space Activities*, 2019. As of December 9, 2022:
https://www.spacefoundation.org/space_brief/space-situational-awareness/

Space Policy Directive-3, *National Space Traffic Management Policy*, White House, June 18, 2018.

Stilwell, Ruth, “Decentralized Space Traffic Management,” Space Traffic Management Conference, 2019.

Stilwell, Ruth, “Space Situational Awareness: Key Issues in an Evolving Landscape,” statement before the Committee on Science, Space, and Technology, U.S. House of Representatives, February 11, 2020.

Stilwell, Ruth, Diane Howard, and Sven Kaltenhauser, “Overcoming Sovereignty for Space Traffic Management,” 70th Annual International Astronautical Congress, October 2019.

Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, January 27, 1967.

Treves, Tullio, “Historical Development of the Law of the Sea,” in Donald Rothwell, Alex Oude Elferink, Karen Scott, and Tim Stephens, eds., *Oxford Handbook of the Law of the Sea*, 2015.

Ugurlu, Hasan, and Ismail Cicek, “Analysis and Assessment of Ship Collision Accidents Using Fault Tree and Multiple Correspondence Analysis,” *Ocean Engineering*, Vol. 245, February 2022.

UN—*See* United Nations.

Undseth, Marit, Claire Jolly, and Mattia Olivari, *Space Sustainability: The Economics of Space Debris in Perspective*, Organisation for Economic Co-operation and Development, Policy Paper No. 87, April 20, 2020.

United Arab Emirates Ministry of Energy & Infrastructure, “International Maritime Organization,” webpage, undated. As of December 14, 2022:
https://www.moei.gov.ae/en/about-ministry/imo.aspx?DisableResponsive=1

United Nations, *International Convention for the Safety of Life at Sea, 1974*, November 1, 1974.

U.S. Coast Guard, “Rules of the Road,” webpage, undated-a. As of December 13, 2022:
https://www.dco.uscg.mil/NavRules/

U.S. Coast Guard, “USCG IMO Homepage,” webpage, undated-b. As of December 13, 2022:
https://www.dco.uscg.mil/IMO/International-Maritime-Organization-Sub-committees-HWT/

Weber, Ludwig, *International Civil Aviation Organization (ICAO)*, 4th ed., Kluwer Law International, 2021.

White House, *National Security Strategy*, October 12, 2022.

Yang, Kuan, “Chinese Perspective on an International Regime of Space Traffic Management,” *Journal of Space Safety Engineering*, Vol. 6, No. 2, 2019.

Acknowledgments

The authors are grateful to Laura Baldwin and Michael Spirtas for their vision and efforts in supporting this report and the RAND Space Enterprise Initiative. We also thank our reviewers, Ruth Stilwell and Aaron Bateman, for their detailed and thoughtful assistance in making this report a stronger product. Additionally, we thank Chandra Garber for designing the graphics for this report.

About This Report

In this report, the authors examine the issue of space traffic management (STM) and the significant challenge that it poses to spacefaring nations, operators, stakeholders, and all who rely on critical space services and benefits. The ability to maneuver safely in space is at significant risk from increasing space debris and satellite congestion. These risks compound existing spectrum limits for satellite communications and decrease the limited number of useful orbits into which satellites and other objects can be placed. STM is essential to avoid interference and collision. Yet, the international community lacks both an agreed-upon STM governance framework and a dedicated coordination mechanism to resolve risks and limitations. In this report, the authors examine the treaty-based governance systems from both the maritime and air domains as potential models for space and offer key insights from each that may serve as building blocks for an international STM system. This report is part of a body of research by the RAND Corporation to address challenges and impediments to ensure long-term space sustainability for the global community. This research should be of interest to government leaders, policymakers, space operators, and stakeholders concerned with space safety, security, stability, and sustainability. The analysis and insights provided should assist both established and emerging spacefaring nations in developing space governance in a manner that addresses STM dilemmas.

The research reported here was completed in September 2022 and underwent security review with the sponsor and the Defense Office of Prepublication and Security Review before public release.

RAND National Security Research Division

This research was sponsored by the Office of the Secretary of Defense and conducted within the Acquisition Technology Policy Program of the RAND National Security Research Division (NSRD), which operates the National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense intelligence enterprise.

For more information on the RAND Acquisition Technology Policy Program, see www.rand.org/nsrd/atp or contact the director (contact information is provided on the webpage).

For more information on this publication, visit www.rand.org/t/RRA2208-2.

www.rand.org