

THE COLOGNE MANUAL ON THE INTERNATIONAL LAW OF SPACE TRAFFIC MANAGEMENT

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ABSTRACT

Space traffic is increasing, heightening the risks of collisions and debris accumulation. These threaten the accessibility and usability of orbits. Without addressing mitigating both, orbits could potentially be rendered beyond reach and unusable. The Outer Space Treaty, emphasising the need for responsible use of outer space, supports the adoption of an international space traffic management, however, State practice showcases that individual and diverse measures are being undertaken only on an ad hoc basis, revealing gaps in communication and coordination among operators as well as States. The Cologne Manual on Space Traffic Management aims to address these gaps by compiling best practices and expert insights to create effective concrete guidelines for space traffic management in a structured framework to facilitate safer future space activities by focusing on enhancing international cooperation, encouraging technological advancements, and ultimately ensuring a clean and safe orbital environment.

Keywords: Space Traffic Management, Space Traffic Coordination, Space Traffic, Orbital Traffic, Space Objects, Space Debris, Space Situational Awareness, Space Law

1 INTRODUCTION

Space activity is on the rise. Space traffic has reached unprecedented numbers and is projected to continue growing. Yet an international space traffic management (STM) does not exist.

In recent decades space activity has reached new unprecedented heights. The evolution of nanotechnology, small satellites and reusable launch vehicles has decreased space sector costs and enabled many more actors to enter the space sector. Among others, the most notable development has been the birth of NewSpace and the ensuing fast-paced commercialisation of outer space. (A special mention must be made of large constellations of satellites such as

OneWebb or SpaceX's Starlink, which operate hundreds even thousands of satellites flying in a single formation.) Where once only two States competed for dominance with support of a few select national non-State actors, today over 70 States and a wide catalogue of non-State actors operate an estimated 10.000 active satellites navigating an increasingly congested orbital environment populated by millions of debris pieces. Where once collision warnings were issued a few times a year, now hundreds are issued in a single week, more and more frequently exceeding the 1 in 10.000 probability threshold and thus amounting to orbital manoeuvres [1].

The aforementioned requires space object operators to perform space traffic coordination (STC) measures, to mitigate collision risk. At presently, these measures are performed on an ad hoc basis. While often time-consuming and imbued with a level of uncertainty (especially when dealing with emerging space object operators struggling to learn the customs and rules associating with operation or launch of a space object), these measures are successfully preventing more catastrophic collision in-orbit and in airspace. However, as space traffic is projected to increase further, these measures will no longer suffice, warn experts [2]. An international systematic and clear STM is required to enlighten and guide space object operators as well as launch operators in their tasks.

The Institute of Air Law, Space Law and Cyber Law at the University of Cologne in Germany has taken up the challenges to produce not simply an academic study on STM, but to create actual concrete guidelines for STM, which can be directly implemented by space object and launch operators as well as by national and international legislators. The Cologne Manual on Space Traffic Management will provide the necessary systematisation, internationalisation and clarity required for a seamless, efficient, functional and acceptable international STM.

2 SPACE TRAFFIC

Space traffic has become the centre of attention in the last few years as constellations such as Starlink,

currently making up almost 50 % of all active satellites in orbit [3], are challenging the status quo of STC and space safety.

2.1 The Evolution of Space Traffic

At the beginning of the space age in 1957 only two States possessed the requisite capabilities to launch and operate space objects; the United States of America (hereinafter the USA) and the Soviet Union. In the first fifty years less than 12.000 objects, including active as well as in-active objects and debris, populated Earth orbits [4]. Less than 1000 were estimated to be active satellites [5]. Today, functioning space objects alone account for an estimated 11.100 [6]. Space debris (objects greater than 10 cm) account for a further 40.500 objects [7]. Over one million more in-orbit space debris are smaller than 10 cm, and several million more are smaller than 1 cm [8].

Since the inception of space activities, outer space has been a major player in the field of national security. Earth observation, satellite telecommunications, the support of critical infrastructure on Earth, and especially the establishment of space supported navigation systems are key to military activities and defence mechanisms of States [9]. Military activities have been joined by scientific missions that have explored the cosmos as well as the Earth from outer space, providing numerous scientific breakthroughs in various fields, including medicine and environmental protection [10]. For a time all of the aforementioned activities were performed exclusively by governmental actors until commercialisation of outer space began in the 1980s [11], exploding with the evolution of the so-called NewSpace in the 2000s [12].

These activities have already led to an immense increase in space traffic over the last few years, e.g., in 2023 an increase of 35 % was reported in active satellites orbiting the Earth compared to the year before [13].

2.2 Investments into the Future

Through the evolution of nanotechnology and the consequent development of smaller satellites (e.g. CubeSats or Nano-Sats) capable of retaining capabilities of larger satellites, the production of e.g. space objects has become easier and cheaper. Consequently, the number of space objects and space actors has exponentially increased. CubeSats and Space and Earth Science Satellites etc. are on the rise and expected to rise constantly in the next years. Primarily utilised in scientific missions and NewSpace, these new smaller satellites are drivers of a significant change in space activities [14].

The aforementioned developments are inter alia fuelling space commercialisation as well as space exploration, contributing to an exploding space economy [15]. Satellite imagery, telecommunications, provision of internet connectivity services, and other satellite services are becoming a crucial element of modern life.

The aforementioned activities make outer space not only interesting for current spacefaring nations, but also to more and more new spacefaring States that are building up their capabilities in the space sector. This growth is combined with the prospect of future space activities such as space resource activities (also known as space mining), space tourism, space settlement and deep-space exploration, such as the Argonaut mission and ExoMars mission by ESA, attracting even more space actors (governmental and non-governmental) and promising to add to space traffic thus intensifying orbital traffic and valuable space assets [16]. Space settlement, tourism and resource activities furthermore project a large-scale increase in the participation and presence of humans in outer space. Consequently, space traffic is projected to increase to even further new dizzying heights in the next decades, with experts predicting 65.000 active space objects in-orbit by 2030 [17]. Organising it will be an essential development in the exploration and use of outer space.

3 REDUCTION OF SPACE DEBRIS

The foregoing is added to by the ever-growing population of non-controllable objects and non-functioning space debris. As space traffic intensifies, especially through the ever-growing NewSpace, the collision risks increase as well. Collisions will not only endanger the assets involved, but also other space assets in the affected orbital plane. The collision of Iridium 33 and Cosmos 2251 in 2009 displayed the negative effects of in-orbit collisions with the debris cloud produced in the aftermath of the collision remaining in-orbit until today [18]. Collisions not only destroy the space assets involved, inflicting financial damage and loss of services of the involved stakeholders, but also create space debris which, depending on the orbit concerned, can stay in outer space for decades, in GEO even indefinitely.

Space debris in turn often poses lethal danger to active objects due to its high orbital velocity [19]. Even in instances where damage is non-lethal, repairing damage caused by space debris has been valued to have increased costs of space activity by at least 10% [20]. Furthermore, as space debris collides with other space debris, it creates new masses of space debris in what has been termed the Kessler effect [21]. Thus, as space traffic increases, the ensuing rise in collision risk, ultimately space debris production risk, threatens to fill

Earth's orbits to a point where active space object could no longer safely (or in most catastrophic scenarios not at all) access or use Earth's orbits. This would be a catastrophic end to the exploration and use of outer space.

The sustainable use of outer space therefore necessarily includes the principle to keep orbits in a state that allows for their future use [22]. With the rapid increase in space traffic, the potential for catastrophic collisions like the mentioned Iridium 33 – Kosmos 2251 collision in 2009 or otherwise rapid growth of space debris via e.g. partial or complete non-adherence to the legally non-binding IADC/UNCOPUOS Space Debris Mitigation Guidelines threatens to cut humanity's access and use of Earth's orbits (and with it access to Deep Space and celestial bodies) [23]. An organised space traffic management must therefore include considerations for space debris. As new technological developments provide for mitigation measures such as appropriate space object design to minimise production of debris during normal operations, post-mission de-orbiting, and even remediation or active space debris removal possibilities to reduce existing space debris numbers, adherence and legal instruments lag behind. These will need to be encouraged and enforced to ensure manageable numbers of debris allowing for continued space exploration and use.

4 SPACE LAW

International Space Law is part of general international law – a concept centred around States and their freedoms and obligations [24]. The challenge with Space Law is that it, perhaps more than other fields of international law, focuses on an area with many technical developments and thus, needs to remain open to unforeseen changes [25].

4.1 Basic Legal Framework for Outer Space

Outer space is not a lawless space. All human activities in outer space are subject to space law, both international and national. International space law developed during the 1960s and 1970s culminating in the adoption of five treaties that laid the foundations of space exploration and use, chief among them the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies or shortly the Outer Space Treaty (hereinafter OST) [26]. These present binding legal norms that have delineated outer space as an area beyond national jurisdiction, a province of all humankind, where all States have the right of exploration and use and where national appropriation is prohibited [27].

This in essence decrees that outer space is not subject to the supreme legal authority or State sovereignty of any one State [28]. However, space objects used for space exploration and use are subject to State jurisdiction of the State, which nationally registers the object launched into outer space or intended to be launched [29]. As a central aspect of States sovereignty [30], jurisdiction thereby created States sovereignty in space objects [31]. With his States internationally agreed that outer space may be accessed and used by all, but the space objects used for space exploration and use remain the property and subject to the authority of the State that registers them in national registry. As such these objects may not be interfered with, without the consent of the registering States [32]. (The latter is a particular issue for active debris removal or space debris remediation, since space actors may only remove their own objects or those for which the registering State gave its consent. [33]) As a child of the Cold War and the Arms Race between the USA and the Soviet Union, the OST was an innovative and impressive compromise that encouraged cooperation [34]. This meant that the OST primarily focused on the rights of States rather than obligations or the space environment [35], and furthermore utilised wide and general language. The latter permitted the OST to encompass the newest technologies but simultaneously meant that its treaty provisions often lacked sufficient detail to provide operational clarity [36]. The subsequent four treaties gave little additional detail and space law norms remained open to interpretation.

4.2 From International to National Law

Since 1979 no further treaties have been adopted and space law instead began to evolve through legally non-binding United Nations General Assembly Resolutions, which may help interpret the legal norms set by the treaties. These have been joined by additional non-binding governance instruments at regional or international level such as cooperation agreements establishing regional space cooperation [37] or at an international political level indicating collaboration (e.g. Artemis Accords, Russo-Chinese MoU).

Clear from the foregoing is therefore that space activities are governed by several governance instruments on international, regional and national level with varying degrees of legal force and detail. Nonetheless, these instruments portray that while, as indicated above, the decreasing costs and the steady commercialisation of outer space have brought a number of non-State actors to the space sector, today operating more than half of all active space objects in orbit [38], legally at least outer space remains primarily the domain of States, which regulate its various aspects with wide discretionary powers. States therefore began adopting national space

legislation to suffice requirements from Article VI OST, which mandates that States carry international responsibility for all national space activities, whereby they must authorise, supervise and ensure compliance with the OST for their non-governmental actors. Today, United Nations Office for Outer Space Affairs evaluates that around 50 States have a form of national instrument on space activities in place. These are not all comprehensive and detailed laws, but at minimum indicate a State's space strategy and should be consulted by national launch and space object operators.

While the aforementioned instruments still address (at least indirectly) various aspects of STM such as, encouraging information-sharing, international cooperation and space object registration, as well as in some cases even mandating space debris mitigation, their primary is focused on encouraging and building up space exploration and use capabilities and industry. To maintain accessibility and usability of orbits for space exploration and use, including commercialisation, however, a more concrete STM re-orientation will be required to guarantee safety of space assets in outer space and in airspace.

5 SPACE TRAFFIC MANAGEMENT

The growth in space traffic and the consequent rise in collision risk and through it the increase in space debris production risk, can only be mitigated, organised and managed via an international systematic and effective STM. The required measures, capabilities, challenges and possible future frameworks have been the subject of discussion for the last two decades, with several national instruments as well as a wide range of studies being produced as a consequence.

5.1. Current standpoint

As mentioned before, STM has become the centre of attention in the last few years, which can also be seen by e.g. the "Proposal for a Study Group on Perspectives for Space Traffic Management" [39] and the guidelines on "Long-Term Sustainability of Outer Space Activities" [40] in the UN.

The numerous studies on STM [41] all poignantly emphasise that to avoid the above-illustrated chaotic outcome of losing access and usability of orbits, both legal and technical measures and developments will be required.

Legal measures have been evaluated to provide the necessary clarity with regard to measures that should or indeed must be taken, thus fostering adherence and acceptance of STM, including political acceptance. For

these, several open questions of space law have been identified and their re-orientation or further study encouraged, e.g. the parameters and soft (open) language of space object registration requirement or the open language of Article IX OST mandating a measure of environmental protection and due regard to the activities of other space players.

Technical measures on the other hand are necessary to provide the required guidance on actual measures to be taken to ensure effective STM, e.g. tracking and monitoring of space objects and their operational environment through more detailed space environment information, identification of concrete collision risks, coordination and space debris management (mitigation as well as remediation measures).

Among the required measures, mixing elements of both legal as well as technical, the continued precision-sharpening and upgrading of space situational awareness (SSA) capabilities has been identified along with determining traffic rules for outer space or collision avoidance measures and manoeuvres to ensure seamless and quick STC. In correlation, it has been analysed that space objects with manoeuvrability capability are the desired way forward. For example, sustainable operations of objects in outer space through international coordination can not only help prevent collisions between active space objects, but help reduce the creation of space debris and the collision with such. Nonetheless, in 2009 out of the approx. 20.000 trackable objects in orbit, only around 1300 were evaluated to have the capability to perform in-orbit manoeuvre [42]. These numbers have risen in the last decade, but the number of space objects able to perform an on-orbit manoeuvre remains lower than the number of space debris and other non-manoeuverable objects. Neither can manoeuvrability be legally mandated as all States have freedom of exploration and use.

An international system organising and guiding space traffic has been analysed as the ideal goal that should be pursued. In regard to this, numerous agencies such as the International Civil Aviation Organization (ICAO) or the International Telecommunications Union (ITU) have been invoked as useful examples or even possible carriers of STM related tasks. Ideally, however, a central new agency in charge of STM has been studied and proposed (without visible success so far).

However, whatever form STM is to take, it is clear that chaos and the endangerment of the most valuable orbits such as LEO and GEO will be the result of an unregulated space traffic. Therefore, systematisation of STM is crucial to ensure safety of space operations, a sustainable operational environment and cost-efficiency including viability of space activities long-term). These

measures must, however, be international as outer space is an international environment, thus requiring legally as well as logically that any questions regarding STM should likewise be addressed internationally. The concept of STM in this manner represents the goal of keeping outer space free and accessible for every space participant, including established space actors as well as new (State) actors, governmental and non-governmental.

5.2 Current Practices

Currently, assessment of close conjunction events and ensuing warnings are evaluated based on existing SSA capabilities possessed by only a few States, the main players being the USA, European countries under the umbrella of the European Space Agency (ESA), Russia and China [43]. Several of them share this information via cooperation agreements on a State-to-State level [44]. Evaluations are performed by space object operators or specialised entities on contractual basis. Then space object operators enter into ad hoc voluntary communication fuelled by self-interest of protecting their space assets. Collision avoidance manoeuvres are then taken on a bilateral level, which can result in a state of heightened tension for the duration of the process, owing e.g. to the fact that one of the parties does not respond in a timely manner [45]. The aforementioned is functioning for the time, but still some collisions occur such as the loss of the Ecuadorian Pegasus satellite in 2013, which allegedly launched without appropriate or sufficient SSA information [46]. Relatively recently some States have issued STM specific policies and guidelines to their national actors. Examples are the USA, which adopted Space Policy Directive 3 [47] and the NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook [48].

Additionally, space debris leads to collision avoidance manoeuvres and in case of the ISS also to rescheduling of space walks and astronauts having to take shelter [49]. However, space debris remediation remains in infant phases with notable projects such as the ESA CleanSpace or JAXA CRD2 gearing to begin testing phases. Several legal questions continue to surround space debris remediation as State jurisdiction in space objects, arguably continuing in space debris as jurisdiction is not dependent on functionality [50], prohibits States and non-State actors from interfering with objects registered by other States, thereby restricting active debris removal to one's own objects or those for which consent of the State of Registry has been ensured [51]. Space debris mitigation is more widely accepted and performed [52]. An evaluated 17 States have national mechanisms on space debris mitigation in place, with a further 18 supporting mitigation measures despite not having a national mechanism in place [53].

5.3 Current challenges

Several challenges have been outlined in the studies and have been arisen during the current course of developments in outer space.

Central to the development and adoption of collision avoidance measures is the uniqueness of the orbital environment and its mechanics. Terrestrial traffic rules, whether in air, maritime or road traffic, heavily rely on an operator's ability to see and detect its operational environment and the incoming traffic [54]. This is not possible in outer space where assessments of possible conjunction events are made with help of tracking and monitoring capabilities coupled with calculations [55] that predict collision probability based on more or less accurate assumptions of where two objects are in relation to one another in space. This spells out a high reliance on tracking and monitoring precisions and capabilities, rather than an ability to detect left, right, up or down, and another object.

Consequently, one of the most important challenges to STC and STM is information, e.g. the availability of information, reliability (or rather precision) of information and informational sharing. Information is thus key to safe and sustainable access and use of outer space. However, many States depend on other States for crucial information, however, as no mechanism for information-sharing has been developed as to which information an operator of a space objects or launch vehicle should be sharing and at what time of the mission, information sharing remains erratic and flawed, subject to uncertainties and political or economic pressures.

This leads to a second major topic: cooperation and coordination. Lack of traffic rules coupled with flimsy information sharing presents a lack of foundation on which to build STC or even international cooperation, resulting in an enchanted merry-go-around. In the end, even the national licensing mechanisms for non-governmental space missions vary tremendously [56] along with registration of space objects, both nationally and providing information about it to the UN in accordance with the registration Convention, aiding in transparency measures, are in need of harmonisation.

6 THE COLOGNE MANUAL ON SPACE TRAFFIC MANAGEMENT

Even though STM has been widely discussed in the last years [57], no international STM exists to date. Ad hoc measures for STC are being undertaken by operators, however, the lack of internationally uniform guidelines or rules are resulting in different national and regional

approaches, time delays and uncertainties that endanger active space assets and their operational environment. To close this gap, the Institute of Air Law, Space Law and Cyber Law at the University of Cologne is developing the Cologne Manual on Space Traffic Management (CM-STM) [58] funded by the German Aerospace Center. The aim of the CM-STM is to establish practicable guidelines focusing on relevant topics to systematise the existing STC approaches and propose foundational building blocks of an international comprehensive STM. It therefore addresses both the technical and legal aspects of STM, taking account of the geo-political sensitivities to presents non-legally binding guidelines appropriate for direct implementation by national as well as international legislators, as well as space object operators themselves. The goal is to keep outer space free, accessible and usable through its sustainable use. Thus, it does not intend to in any manner obstruct access to outer space but, on the contrary, to guarantee it.

The CM-STM project started in 2022 and will finish with the publication of the CM-STM in May 2025. Along with its project director and eminent space law expert Prof. Dr. Dr. h.c. Dr. h.c. Stephan Hobe, more than 40 international experts from five different continents, including experts from the European Space Agency (ESA), the Japanese Space Agency (JAXA), the Brazilian Space Agency and the German Aerospace Center, have been discussing and researching four separate aspects of STM. It therefore brought together experts from various backgrounds, including legal and technical fields, academia, industry and space agencies to ensure a unique and valuable contribution to the space sector. It recruited a Scientific Advisory Board assembled of figure heads of the space sector to guarantee its high value and foster acceptance [59]. This presents the uniqueness of the CM-STM project adding the diverse knowledge possessed by the Institute. Thus, working groups on the topic “Space”, “Air”, “Sustainability”, and “Cyber” were established and have been providing the general discussion with specific issues, concerns and proposals. The interaction and input of these working groups broadens the focus and allows for an integrative approach, supporting the interdisciplinary context of space traffic. The CM-STM thereby reflects the futuristic approach of outer space activities and the openness for technological advancements.

Through the different backgrounds (legal and technical) of its experts and the Institute’s proven expertise and innovative strength, a comprehensive research outcome has been assured. The scientific advisory board of the CM-STM project, set up of prominent leaders and figureheads in the space sector, will approve the academic and practical excellence of the CM-STM prior

to its publication. Therefore, the CM-STM represents a research study with concrete valuable outcomes in form of usable guidelines, taking into consideration the existing legal framework, including both international space law and arising national space legislation, current State and best practices, and technical as well as political challenges of space traffic.

In the following the the guiding aspects of the drafting process of the CM-STM will be presented.

6.1 The Legal Backbone

Activities in outer space will first and foremost have to abide by the legal limitations set out in the Outer Space Treaty. The OST is a treaty of principles, and as such, has been drafted to allow for the incorporation of technological developments, an objective that is also pursued by the guidelines of the CM-STM. Consequently, the interpretation of the OST principles must incorporate the newest standards, practices as well as binding and non-binding governance instruments to ensure the OST’s contemporary applicability as the living evolving foundation for all outer space activities able to address the newest challenges. Treaties and other relevant legal instruments include the additional four UN space treaties which are of relevance when performing activities in outer space [60].

The main principles, especially relevant for STM, are first and foremost the right of every State to have the freedom to explore and use outer space enshrined in Article I OST. However, this is only allowed to the degree that the activities performed do not interfere with the same freedoms of other participants, thus, States must pay due regard (Article IX OST and indirectly Article I OST) to the corresponding interests of other States. Second, the non-appropriation principle on Article II OST, outlining that outer space is and remains an area beyond national jurisdiction, as well as the principle of performing activities in accordance with international law (Article III OST) are well known principles, which in light of the developments associated with new space activities, especially private space activities of so-called NewSpace, are important to highlight in the context of STM. Third, principles such as authorisation and supervision of non-governmental space activities by States (Article VI OST), liability for damages caused by space objects (Article VII OST and provisions of the Liability Convention), as well as registration of space objects (Article VIII OST and provisions of the Registration Convention) are of significant importance when participating in space traffic and when establishing STM.

Lastly, Articles IX and XI OST provide the foundations for international cooperation, environmental protection and information sharing. Three invaluable elements, when considering an international practicable STM, able to reduce collision risk during all phases of space activity and mitigate the future increase in space debris, while allowing for continued access and usability of all orbits and outer space in general.

Keeping the aforementioned legal references in mind when drafting the guidelines, provides for feasibility, credibility and confirms the necessity of STM. Currently, the exploration and use of outer space by States and non-governmental actors is performed along the lines of the so far provided legal framework. To continue this practice and combine it into a working international system in reference to a future-oriented STM is the goal the Institute is pursuing with the CM-STM project. This will be done *inter alia* by defining in as much detail as required, the aforementioned principles.

6.2 Current Practices

Important for an internationally accepted STM is the connection to current State practice and industry best practices, which also includes the already established national laws as well as those, currently being developed [61].

In the working process of the CM-STM, the recruited experts from around the world have shared their diverse expertise and experiences from their State and/or region to identify common grounds as well as different views and interest relating to a certain pertinent topic. As each guideline of the CM-STM is undergoing a development process, the outcome will present the input from all experts as well as the currently utilised mechanisms that are established concerning the use of outer space, e.g. national laws, policies or other governance instruments including standards. Such details will be outlined in the commentary section to each guideline.

When looking at concrete parts of STM that are currently practiced, the most outstanding fact is that most actions and processes are done nationally and coordinated bilaterally. For example, SpaceX has a bilateral agreement in place with the US National Aeronautics and Space Administration (NASA) that stipulates that all NASA space assets have priority, and SpaceX must manoeuvre its space objects (e.g. Starlink satellites) out of the way [62]. These types of bilateral agreements are commendable and should remain in practice. Firstly, they provide the possibility of having a workable system in place until an internationally agreed upon system has been established and secondly, even

when such an international system is established it should leave room for such agreements as an expression of private cooperation and contract freedom.

Furthermore, the CM-STM working process took note of national space legislation. Out of the over 70 space active States, around 50 have been evaluated to have a form of national instrument in place [63]. Around 25 of these national instruments address questions of registration, authorisation and supervision, but only partially (if at all) address other STM pertinent subjects such as SSA [64]. However, this portrays the international character of outer space, as most SSA information is not gained by one State separately but shared through international organisations and their programs such as the programs of the European Space Agency, the International Scientific Optical Network [65], and the Asia-Pacific Space Cooperation Organization [66] pooling tracking and monitoring capabilities. However, some major space actors such as China and Russia do obtain SSA information nationally and separately.

6.3 Addressees

The CM-STM “aims to offer a comprehensive and well-organised blueprint for an effective and sustainable STM system.” [67] The CM-STM therefore primarily addresses States, and their national lawmakers, as the subjects responsible under space law for regulation of space activities, including those under their supervision, performed by non-governmental entities. Nonetheless, it secondarily refers also directly to operators and other relevant actors, such as launch providers, operators, owners, and other relevant personnel, which in the course of a mission in outer space are the subjects actually performing STM measures as they operate the relevant space objects, launch vehicle or required infrastructure and process. This results in an innovative approach taking stock of the traditional dogma of international law, focusing on States as its primary subjects and creators, as well as the evolving trend of including non-State entities in international instruments and processes, as these are often the subject actually performing a certain action [68].

To ensure a workable STM, its international character is of high relevance. Legally, outer space is an area beyond national jurisdiction meaning that it does not belong to any one State or non-State actor but instead belongs to all of humanity as *res communis* [69], where all States have the freedom of exploration and use. Second, considering that space traffic is composed of space objects from over 70 countries and their non-governmental entities, purely national STM will not suffice to ensure long-term safety of space assets. Therefore, the CM-STM requests (especially) States to

enter into international agreements and to support international cooperation. Especially regarding technical standards and designs, international effort should be mounted to ensure steady and continued development of international standards. Hereby, participation of all stakeholders should be ensured as launch providers and space object operators are the actors which can contribute to and influence these processes the most, regardless of their governmental status.

Addressing operators, both launch and space object operators, as well as personnel of requisite infrastructures, the Manual gained several insights and made proposals as to which action these must undertake in support of STM.

International and national space law(s) (and associated instruments) have revealed that space object owners and operators should and must at all times be aware of their space object's essential information such as its trajectory and status (e.g. malfunctioning, experiencing difficulty, normal operational expectedness) in order to be able to exchange necessary information with the entity responsible for space object registration and to enable STC in case collision avoidance manoeuvres need to be performed. Logically the latter entails maintaining an active and responsive point of contact within the operator's framework and furthermore portrays the necessity of a close working cooperation between the owner and the operator.

Furthermore, other personnel, such as ground station personnel taking care of relevant tasks, personnel on board of a space object, or personnel of connected infrastructure, should stay up-to-date on the information about their space object as well as any relevant information from other space objects, educated in cyber security measures and concerns, and generally present the relevant level of technical knowledge required for performance of their tasks. Additionally, it is their duty to share relevant information with the operator and/or owner and to keep the respective space object safe from any outside or inside interferences.

As can be seen, the tasks of each space actor might overlap with the tasks of other space actors. Therefore, it is essential to provide a clear structure of responsibilities and tasks within each operator's enterprise as well as within the STM framework itself.

6.4 National Impact

As it has been highlighted multiple times, to have a STM that is practicable and workable, it needs to be developed and adopted on an international level. However, this will

of course have effects on national levels as well. In this context, it is of uttermost importance to highlight that the sovereignty of States as well as the sovereignty free nature of outer space are two untouchable facts that will be emphasised and safeguarded by the CM-STM.

Present trends indicate a renewal in development and adoption of national space legislation. India, a fast growing space actors, is one such example, currently developing its own national space law. Nevertheless, most national laws, existing or developing, do not concentrate on including measures relevant to STM or STM itself. It is hoped that the guidelines of the CM-STM will impact and prompt the drafting processes into including certain measures, such as the safeguarding and further evolving SSA capacities or information sharing parameters (i.e. identifying the possibilities and willingness of sharing of the necessary information), into national legal mechanisms.

Additionally, it is hoped that guidelines of the CM-STM will help clarify, simplify and streamline national processes such as 1) space object registration performed by State authorities, whereby time constraints should be accepted to allow timely provision of required information, 2) national licensing process of non-governmental space activities, by clarifying that certain minimum standards should be adhered to during the design and development of a space object, including noting its functionality and capabilities for STC as well as tracking and monitoring purposes.

Finally, without a doubt, the exchange of necessary information and the cooperation with other States regarding STM will affect every State and enhance the safety in outer space, hopefully resulting in further innovation and steps in STM.

6.5 Security Concerns

Addressing outer space means addressing a high security relevant area, i.e. an area that is relevant for environmental risk mitigation, disaster management, and national security. With many commercial satellites in outer space, it also represents an area that is of high economic value and relevance for everyday life of humanity [70]. Considering the reliance of space traffic on tracking and monitoring capabilities and mindful of the rising numbers of space debris and the fear of shutting off access to outer space, the security of outer space is an important topic for everyone.

The CM-STM is mindful of the national security aspect of outer space, but views it as undesirable to grant any participant the possibility to violate the basic necessary guidelines for STM. Thus, both military and non-

military operators, including governmental and non-governmental actors, should adhere to STM (e.g. the Guidelines of the CM-STM) as much as possible. It is therefore important to provide the possibility to adhere to STM (e.g. the guidelines of the CM-STM) without the necessity to openly share data. This is a topic that should be handled especially carefully with regard to military activities, by e.g. taking stock of military best practices, focusing on mitigating space debris and avoiding any possible collision(s).

Additionally, the infrastructure required for safe operation of space objects must be safeguarded as it is essential for STM as well as to ensure the goal of not producing new space debris. Therefore, space actors must ensure the up-keep of such infrastructure, including the maintenance of its component parts and systems as well as its protection from internal and external factors. This can be viewed similarly to the protection of other critical infrastructure on Earth or air traffic managements systems.

6.6 Future development

Technical development and constant change in use are part of the ongoing process in the space sector. The CM-STM provides guidelines that support this development and provide timeless proposals on how to keep the orbits clean by inter alia reducing the collision risk between active as well as in-active space objects. Any discussion on STM should keep the aforementioned at its core, providing for guidance that leaves room for future development and advancement in outer space technology. Especially with new goals set and missions charted to reach destinations beyond the Earth's orbits [see 2.2], new innovations will be key and should be integrated into STM.

The increase in space debris has given great concern to the space community as it contemplates actions to tackle and stop this issue as soon as possible. As discussed, these efforts should also be mirrored in STM, by firstly, identifying relevant (technical) mechanisms already in place, which might only need to be slightly modified, and by secondly, looking at the bigger picture by planning appropriate international (technical and legal) solutions. However, notably the first step should never slow down the second step and should be worked on in parallel. Hereby note should be taken of limited capacity of orbits, which should be safeguarded via e.g. space debris remediation.

At the base of all STM is a great need for an international system capable of supporting STM. On the way to such a system, cooperation is the key. Even with no international body in place to focus on STM, the most

necessary immediate steps can be achieved through international cooperation and coordination e.g. STC. This also includes the cooperation with already existing international organisations and systems such as ITU (International Telecommunication Union) and ATM (Air Traffic Management) systems, primarily the ICAO. The existing links established through such international cooperation can be the ground base for future work.

6.7 The goal

Via the above-mentioned topics as well as by being mindful of the addressed challenges and concerns, the CM-STM will provide a future-oriented STM that will be capable of ensuring humankind's access to and the possibility to keep using outer space i.e. making use of the freedoms to do so enshrined in Article I of the OST.

The CM-STM symbolises the international cooperation needed for a functioning STM, represented for example by the experts contributing and discussing crucial topics at a hybrid meeting in Milan in October 2024 during the International Astronautical Congress, symbolised in Pic. 1, taken at the project's second hybrid interim conference.



Picture 1: Group Picture of experts at the International Astronautical Congress in Milan 2024

7 CONCLUSION

STM is a long-debated topic, which's importance is well documented and established. The exponential increase in space traffic over the last decade that has resulted in approx. 10.000 active space objects and several hundred thousand more space debris, from over 80 State actors and numerous non-State actors, is severally testing the status quo. Ad hoc measures on STC are helping avoid catastrophic collisions in-orbit and in airspace, however, with space traffic continuing to grow these are quickly

being challenged. Space actors are realising that without a systematic STM, collisions will become inescapable. Already presently the damage inflicted by incidental small abrasions with space debris is driving up cost of space activities more than collision avoidance measures would.

Several States as well as non-State actors are therefore designing their own approaches to STM, in varying degrees of detail and systematism, however, given the international nature of space traffic composed of space objects from around 80 States (and growing) these fragmented approaches are facing challenges in practice, which result in dangerous time delays and uncertainties.

Numerous studies have approached the topic of STM, analysing the challenges presented by the uniqueness of space traffic and space activities, but have normally constraint themselves to an academic study and identification of problems with existing space law and technology, challenges and general future possibilities, with few exceptions. The challenges and opportunities of STM have therefore been well documented and researched and have inter alia raised the issue of constricting geo-political sensitivities and the current state of technology available in support of STM, such as limited SSA capabilities.

In light of the latter, it is important to note that the existing space law provides an appropriate legal foundation for STM. However, the space treaties in an effort to escape being outpaced by technology were formulated in wide and general language. This portrays the permissive nature of the space treaties, favouring the freedom of States over constraints and obligations encumbered by those freedoms, international space law has historically left determining details to the national competences of States. Nonetheless, space law predicates an important agreed to dogma: STM is legally required and must be international.

The CM-STM took the latter as its underlying foundation building on it with technically sound and practical proposals. The Institute thus elected to produce a practical Manual more than an academic study of existing space law and technical capacities. The proposed guidelines therefore present a future-oriented innovative concrete measures founded on existing best practices and, as already mentioned, space law. These are formulated in a manner that permits the further evolution of technology while presenting sufficiently concrete measure to enable direct implementation in practice, whether by space object and launch operators, or by national and international legislators.

The CM-STM thereby acknowledges the challenges posed by outer space and its exploration and use, while at the same time supporting the endless possibilities they offer. However, being aware that outer space will only be explorable and usable, if space traffic is regulated in a manner that decreases collision risk and the production of space debris, the CM-STM urges space actors, State and non-State actors alike, to voluntarily adopt the proposed guidelines in their own self-interest as well as the interest of the international community as a whole, including presents as well as future space actors.

In essence, the Cologne Manual on Space Traffic Management considers the interests of space actors around the world accounting for past, current, and future developments in its proposed guidelines. Through its broad information intake and room for discussion it hopes to provide a first concrete step to internationally accepted guidelines on STM.

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