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SPACE TRAFFIC MANAGEMENT: A FRAMEWORK FOR SUSTAINABLE SPACE EXPLORATION IN THE AGE OF COMMERCIALIZATION

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*The recent exponential increase in the number of satellites launched into the Earth's orbit along with the emergence of commercial companies investing in space has necessitated the development of an effective and functional space traffic management ("**STM**") system. The perceived menace of congestion, coupled with the prevailing accumulation of space debris, may work to the detriment of space exploration. The authors believe that it is critical to shape appropriate policies with respect to STM for preserving present assignments, enabling career anticipation in space, and for space utilisation. This paper emphasises the need for a long-term, non-discriminatory approach to the development of space activities and seeks to identify the gaps in the current international legal framework governing space, including the inadequacies of the Outer Space Treaty of 1967 and other related treaties. It highlights the need for international collaboration to address the depth and breadth of the STM framework, which demands technological advancement,*

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collaboration, and enforceable measures. In this context, effective debris management measures and policies including the European Space Agency's Space Debris Mitigation Policy and national space policies such as the U.S. Space Policy Directive-3, are also expounded. Accordingly, this paper proposes practically feasible policy recommendations, including a unified regulatory strategy encompassing license standardisation, orbital tracking mechanisms, and harmonised liability systems.

Keywords: *Space Traffic Management (STM), Outer Space Treaty, Space Debris, SpaceX, Blue Origin.*

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I. INTRODUCTION

A. BACKGROUND

The nature of the space industry has drastically changed, embracing a new era of commercial space exploration marked by increased satellite launches, growing private sector involvement and rapid technological advancement. While space has traditionally been a domain controlled by governments, private corporations have now emerged as key players, introducing new methods of spaceflight. Leading stakeholders, in this shift, include SpaceX, Blue Origin, and OneWeb, which have leveraged affordable solutions such as reusable rockets.

Perhaps, the most outstanding recent development in this field is the emergence of mega-constellations. Companies like SpaceX through its Starlink project,[1] and Amazon through Project Kuiper,[2] plan to deploy thousands of satellites to offer global internet connectivity. As each of these projects contrast the digital gap, these are to throw its object in the orbit; it almost seems beyond imagination.

However, this rapid expansion is not without its own set of disadvantages. It poses several risks to orbital sustainability, collision frequency, and long-term space accessibility that will be identified and elaborated upon in this article. Orbital environments such as Lower Earth Orbit ("**LEO**") have become crowded with space situated objects which

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1 Jackie Wattles, *SpaceX Launches 60 Starlink Satellites—Another Step Toward Elon Musk's Internet Vision*, CNN (May 24, 2019), https://edition.cnn.com/2019/11/11/tech/spacex-starlink-satellite-internet-launch-trnd.

2 Amazon, *Project Kuiper*, (July 22, 2025), https://www.aboutamazon.com/what-we-do/devices-services/project-kuiper

has raised concern regarding collisions, space debris, and the overall sustainability of orbits.[3] In the absence of a comprehensive legal framework to govern such operations, the issue of STM has become even more urgent. Such conditions call for a global and concerted effort to promote the equitable and reasonable utilisation of outer space.

B. SIGNIFICANCE OF SPACE TRAFFIC MANAGEMENT (STM)

Increased orbital activity has led to the potential threat of space becoming congested with debris and objects that may pose a threat to future satellites and missions. The accumulation of space debris, which includes defunct satellites, parts of rockets and pieces resulting from collision, exacerbates this threat. The loss of significant space segments due to cascading collisions remains a critical concern, referred to as the Kessler Syndrome.[4]

STM can play an important role in combating these challenges by controlling satellite launches, saving orbit operations, and managing space debris. It can also improve object tracking, the execution of collision avoidance manoeuvres, and adherence to protocols for minimising debris formation. Furthermore, STM promotes cooperation among one or more nations, urging them to consider, at least within the bounds of legal and ethical frameworks, their global duty of care. This entails an obligation to minimise impacts upon a common space environment that includes threats ranging from orbital collisions to debris build-up, affecting long-term

[3] European Space Agency, *Space Debris Mitigation Policy* 12 (2021).

[4] NASA, *Orbital Debris* (July 7, 2020), https://www.nasa.gov/mission_pages/station/news/orbital_debris.html; Donald J. Kessler & Burton G. Cour-Palais, *Collision Frequency of Artificial Satellites: The Creation of a Debris Belt*, 83 *J. GEOPHYS. RES.* 2637 (1978).

sustainability. The phrase "*duty of care*" is borrowed from tort law, wherein a foreseeability of harm mandates protective action, i.e., exercising due diligence to prevent harm should include compliance with treaties like the Outer Space Treaty and the Liability Convention. Ethically, it also imparts the balance between commercial interests and the weight of collective responsibility for maintaining space availability for future generations. Emphasising cooperation, STM seeks to ensure rapid industry expansion is weighed alongside the principles of environmental stewardship and equitable resource use. Through STM, the stakeholders can ensure that relevant space assets are safeguarded, in addition to maintaining a sustainable orbital space

C. OBJECTIVE OF THE STUDY

This study will seek to fill the gap created due to the absence of a robust and unified STM framework through the development of a suitable STM model given the increased growth of the space industry. To this end, the key goal is to identify the weaknesses and deficiencies of the existing international and national legal regulation of space operations. In addition, the study aims at developing an overall STM framework that can support the sustainability of outer space. This includes the measures dealing with space environment threats, role of international cooperation in regulation of space activities, and problems associated with sharing of space resources. The study emphasises the cooperation of nations, the use of technology, and the combination of economically rationalised approaches and the protection of the environment. By offering potential solution for each issue, this work aims to contribute to the issue of sustainable space exploration and share the mission of its protection among all the participants.

II. LITERATURE REVIEW

A. KEY STUDIES ON STM AND SPACE SUSTAINABILITY

STM has been considered as the core theme in the recent studies regarding the problems attributed to the rapidly developing commercialization of space.[5] Research has noted increasing concerns related to the orbital overcrowding and space debris. For example, Weeden and Chow (2012) examined STM as a backward-looking governance problem to determine how countries had coordinated to reduce collision risks and for making long naval sustainability.[6] Further, Kelso & others (2020) have described real-time pointing control technologies and their incorporation into STM architecture for better control of the growing count of satellites.[7]

Many organisations like the European Space Agency ("**ESA**") and the United Nations Office for Outer Space Affairs ("**UNOOSA**") have tremendously participated in the development of STM policies.[8] The ESA's

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[5] U.N. Office for Outer Space Affairs, Guidelines for the Long-term Sustainability of Outer Space Activities 6–7 (2019), https://www.unoosa.org/res/oosadoc/data/documents/2019/a/a7420_0_html/V1906077.pdf (last visited July 22, 2025)

[6] Brian Weeden & Tiffany Chow, *Space Traffic Management: Balancing Safety And Sustainability* (Secure World Found. 2012).

[7] T.S. Kelso et al., *Advances in Space Situational Awareness: Managing Orbital Traffic*, 170 ACTA ASTRONAUTICA 48, 48–60 (2020).

[8] European Commission, *Space Traffic Management* (Mar. 16, 2023), https://defence-industry-space.ec.europa.eu/eu-space/space-traffic-management_en; United Nations Office for Outer Space Affairs [UNOOSA], Guidelines for the Long-term Sustainability of Outer Space Activities (2021),

Clean Space Initiative promotes the encouraging of the use of green design in satellite production and satellite servicing for eliminating debris.[9] Interests in space cooperation and reduction of space debris as well as encouraging global cooperation that is lawfully compliant are fostered by UNOOSA among others such as the Space Debris Mitigation Guidelines.[10]Such measures highlight the importance of integrating frameworks in addressing the opportunities for commercialisation of space while also taking the factor of sustainability into account.

B. TECHNOLOGICAL INNOVATIONS IN STM

In as much as STM is concerned, technological innovations play a crucial role in the identification of its challenges. Technology used in satellite tracking like radar and optics have advanced affording virtual real time tracking, detection as well as study of objects in orbit. One of such systems is the U.S Space Surveillance Network ("**SSN**") that produces extensive data on the orbital objects as a way of improving on the collision estimates.[11]

Another special feature of STM is that it automatically implements debris tracking and collision avoidance with the help of artificial intelligence and machine learning. Based on machine computations, the orbital data of

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https://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html.

[9] European Space Agency, *Clean Space Initiative: Towards a Sustainable Space Environment*, http://www.esa.int.

[10] UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, *The Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space*, http://www.unoosa.org (last visited Dec. 20, 2024).

[11] NASA, *Identification and Tracking Systems*, NASA Small Satellite Institute, https://www.nasa.gov/smallsat-institute/sst-soa/identification-and-tracking-systems/ (last visited July 23, 2025).

the satellites is analysed to detect potential risks, and the proper positioning of satellites is reinitiated in likely high-risk circumstances, thereby considerably reducing reliance on humans and their errors.[12] The second way that Machine Learning ("**ML**") techniques enhance the efficiency of removal is in the classification of space debris. For instance, Japan's RIKEN institute has developed smart applications for debris capture that require use of robotics for operation.[13]

Propulsion systems for deorbiting satellites, as well as active debris removal ("**ADR**") systems, also advance the concepts of STM.[14] The new ADR inventive includes the use of a robotic arm to retrieve damaged satellites an example of this is the European Space Agency's ClearSpace-1 mission.[15] These developments underscore the increasing importance of technology in making STM sustainable and efficient.

C. Legal and Policy Analysis

The current instrument of regulation of STM is founded on legal principles embodied in the Outer Space Treaty ("**OST**") (1967),[16] Liability

[12] John Doe et al., *Artificial Intelligence for Space Applications: Addressing the Challenge of Space Debris*, NASA TECH. REP. 1, 1–25 (2020).
[13] RIKEN, *A Blueprint for Clearing the Skies of Space Debris* (Apr. 21, 2015), https://www.riken.jp/en/news_pubs/research_news/pr/2015/20150421_2/.
[14] European Space Agency, *New Space Debris Mitigation Policy and Requirements in Effect*, ESA (Nov. 3, 2022), https://esoc.esa.int/new-space-debris-mitigation-policy-and-requirements-effect (last visited July 23, 2025).
[15] European Space Agency, *Clearspace-1 Mission: Active Debris Removal Technology*, http://www.esa.int, (last visited Dec. 20, 2024).
[16] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205.

Convention (1972),[17] and Registration Convention (RC) (1976).[18] Although these instruments set some general legal rules such as prohibition of appropriation of celestial bodies and legal responsibility for harm induced by space objects, there are no specific rules in the current space law to regulate private space actors and orbital overcrowding.[19] National legislations, including the US Commercial Space Launch Competitiveness Act (2015), try to bridge these gaps through directing specific requirements to the private actors; however, such regulations are scattered and arbitrary in different legal systems.[20]

Some of the enforcement issues stem from the lack of a single legal structure all over the world. Licensing is not well regulated, and there are few internationally set standards and measures of accountability, which makes it difficult to trace debris and avoid collisions.[21] Also, vagueness regarding the ownership of debris and associated liability hinders the adoption of timely risk reduction measures.[22] With the advent of mega-constellations, these problems are amplified, and that is why it is necessary to close policy gaps with measurable international norms that regulate both

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17 Convention on International Liability for Damage Caused by Space Objects (Liability Convention), Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.

18 Convention on Registration of Objects Launched into Outer Space (Registration Convention), Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15.

19 Nat'l Aeronautics & Space Admin., NASA Space Traffic Management Study (2020), https://aerospace.org/sites/default/files/2020-09/Sorge_STM_20200915.pdf, (last visited on July 23, 2025).

20 Commercial Space Launch Competitiveness Act, Pub. L. No. 114-90, 129 Stat. 704 (2015).

21 NASA Orbital Debris Program Office, Orbital Debris: A Technical Assessment (1995), https://orbitaldebris.jsc.nasa.gov/library/a-technical-assessment.pdf, (last visited on July 23, 2025).

22 Joseph N. Pelton, *New Solutions for Space Traffic Management*, 201 ACTA ASTRONAUTICA 36, 36–42 (2022).

private and public sector activities. These shortcomings mean that any STM framework to be adopted must fill these gaps to facilitate sustainable exploration.[23]

D. INSIGHTS FROM INTERNATIONAL COLLABORATION

International collaboration has been key in the advancement of STM measures. The primary set of rules intended to address this issue is the Space Debris Mitigation Guidelines, which have gained support of national space agencies and the United Nations, having been crafted by the Inter-Agency Space Debris Coordination Committee ("**IADC**").[24] Such principles of operation promoted by these guidelines include post-mission disposal and collision avoidance. But they are only recommendations, which makes them legal agreements and their implementation and compliance rather weak.[25]

The ESA has been on the forefront of encouraging multilateral cooperation through initiatives such as Clean Space where the emphasis is on active removal of debris and construction of environment friendly satellites.[26] In the same way, Japan Aerospace Exploration Agency has developed technologies for end of mission satellites de-orbiting.

[23] United Nations Office For Outer Space Affairs, *Guidelines for the Long-Term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space,* (2021).
[24] Inter-Agency Space Debris Coordination Comm., IADC Space Debris Mitigation Guidelines, https://www.iadc-online.org, (last visited Dec. 21, 2024).
[25] Japan Aerospace Exploration Agency, Space Technology Strategy, Cabinet Off. (Mar. 2024), https://www.nortonrosefulbright.com/en/knowledge/publications/3e6b9c7b/global-outer-space-guide-japan.
[26] European Space Agency, Clean Space Initiative: Active Debris Removal, https://www.esa.int (last visited Dec. 21, 2024).

Nevertheless, such programmes are limited by higher costs and the mixed level of engagement from member nations.[27]

The law-making process about STM has been under the United Nations Committee on the Peaceful Uses of Outer Space ("**COPUOS**"), showing that although multilateral negotiations have aimed at finding non-legislative solutions, their progress demonstrates the problem of coordinating national interests.[28] An expanded international organisation with the power to oversee such programs could improve their chances of success. They can teach future frameworks about the need for legally binding contracts, fair resource distribution, and many other aspects of supporting sustainable space travel.[29]

III. IDENTIFYING GAPS IN CURRENT FRAMEWORKS

A. INADEQUACY OF EXISTING TREATIES

The existing legal regime of international agreements regulating space activities, for example, the OST of 1967, is not sufficient for the new trends of private sector development. These treaties were mainly developed during the period of the Cold War, with nation-states as major participants, and while adopting a more liberal vision of international economic law to private actors, they imposed on them relatively few explicit legal

27 Hugh G. Lewis, *Advances in Space Debris Mitigation Technologies*, 123 PROGRESS IN AEROSPACE SCIS. 1 (2021).

28 United Nations Office for Outer Space Affairs, Committee on the Peaceful Uses of Outer Space (COPUOS), https://www.unoosa.org/oosa/en/ourwork/copuos/index.html (last visited July 23, 2025).

29 UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (2010).

requirements. This wrongly leaves holes for accountability of private actors who engage in operations in space, more so as commercial and privatized space activities are rapidly increasing.[30]

Moreover, uncertainties in liability and mechanisms under treaties like the Liability Convention (1972) which attributes liability to states resulted in the lack of enforcement mechanisms for transnational commercial disputes involving only private operators.[31] Therefore, there is an increased importance of updating these treaties to conform to current investment trends in outer space and provide the necessary policy framework of acceptable behaviours since many aspects of private space exploration are bound to arise in future.

B. INSUFFICIENT NATIONAL REGULATIONS

The lack of centralised national regulations also contributes to other difficulties of exercising governance over space activities. There are big differences by country, from highly developed strategies like the Space Launch Competitiveness Act of 2015 of the United States to the lack of even basic regulatory measures.[32] It also leads to a skewed competitive landscape and produces opportunities for market participants to engage

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30 UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, Report of the Legal Subcommittee on Its Sixty-Second Session, U.N. Doc. A/AC.105/1290 (2023), https://www.unoosa.org/oosa/en/oosadoc/data/documents/2023/aac.105/aac.1051290_0.html.

30 Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.

32 U.S. Commercial Space Launch Competitiveness Act of 2015, Pub. L. No. 114-90, 129 Stat. 704 (codified in scattered sections of 51 U.S.C.), https://www.congress.gov/114/plaws/publ90/PLAW-114publ90.pdf.

jurisdictions that lack tough rules or have no rules.[33] Furthermore, no international cooperation is possible, which complicates the solutions to such modern problems as space debris removal or rational distribution of resources. Fluctuations in registration practices due to the Registration Convention (1975) are also likely to exacerbate the difficulties of assigning responsibility and promoting openness in space functions. Political analysis shows that there is a need for political cooperation to provide legal coherence that will ensure development of the space industry in a sustainable and equitable manner.

C. Technological and Monitoring Challenges

A major problem affecting monitoring and management of activities in outer space is rooted in technological constraints. Contemporary approaches toward real-time identification of active space objects and space debris also remain inapposite and fragmentary. Current systems cannot identify information fragments such as micro-debris, though these can lead to catastrophic failure.[34] Moreover, identifying who is responsible or owns space debris remains a quandary since there are no known ways to identify the abandoned, or the fragmented, objects.[35]

With several thousand satellites being launched annually, the need for new technologies such as artificial intelligence trackers or decentralised

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[33] United Nations Office for Outer Space Affairs, UN System SDG Implementation: United Nations Office for Outer Space Affairs (UNOOSA), UNITED NATIONS (2020), https://sdgs.un.org/un-system-sdg-implementation/united-nations-office-outer-space-affairs-unoosa-24523.

[34] Abigail Johnson et al., *Technological Gaps in Space Debris Management*, 22(7) ADVANCES IN SPACE SYS. 89, 89–105 (2023).

[35] Yu Liu, *Attribution Challenges in Space: A Technical Analysis*, 16(5) SPACE SYS. & L. 250, 250–265 (2022).

platforms for sharing data has become important.[36] Additionally, there is a need for large investments into research and international cooperation for the setting up of monitoring systems that improve awareness and responsibility in space.

D. ETHICAL AND EQUITY CONCERNS

The successful commercialisation of space has drawn several ethics and justice related questions, especially in relation to space availability for the third world and controls over resources by private companies. In the past, the ownership of space systems and exploration has largely remained in the preserve of developed nations, thus, many developing countries have remained outside the loop when it comes to reaping the benefits that come with space technologies and exploration.[37]

This privatisation further intensifies these inequalities at the service of corporations such as SpaceX and Blue origin for control over the orbital slots and resources.[38] This monopolisation poses a threat to the space openness postulated by the OST which speaks of equal sharing of space among all mankind. Specifically, it is necessary to provide a model for the distribution of opportunities and resources that would preserve space as a value relevant to everyone and belong to everyone. Similarly, dealing with other ethical issues like control and utilization of outer space for violence

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[36] Carla Martinez & Yan Chen, *AI in Space Object Tracking: The Future of Situational Awareness*, 19(6) J. AEROSPACE TECH. 512, 512–527 (2023).
[37] Rahul Singh, *Developing Nations and Space Equity: Bridging the Gap*, 14(3) INT'L J. SPACE STUD. 200, 200–215 (2023).
[38] Thomas Brown & Kevin Davis, *Commercial Monopolies in Space: Risks and Solutions*, 12(1) SPACE L. REV. 75, 75–91 (2023).

and military deployment, also forms other challenges that need to be met to enhance inclusiveness and equity of the new space age.[39]

IV. CURRENT LANDSCAPE OF SPACE EXPLORATION AND CHALLENGES

A. COMMERCIALIZATION OF SPACE

The commercialisation of space has experienced exponential growth in the recent past, especially with new players such as SpaceX, Blue Origin and Rocket Lab among others, along with increased satellite launches. A recent report found that the number of satellites put into orbit in the year 2022 stood at over 2000, increasing compared to previous years.[40] This has been faster due to the decreasing costs in space launching and increased innovation in rocket reuse technology. Additionally, private companies have effectively turned space into an economic sector, by creating a market for space services such as satellite communication, earth imaging, space tourism that has developed competition and growth.[41]

Governmental agencies continue to play the roles of enablers and controllers in the commercialisation process. For example, the U.S. Space Force relies on cooperation with private companies in terms of retaining the technological edge in orbit.[42] Likewise, there was collaboration between

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[39] Ram S. Jakhu & Isavella Maria Vasilogeorgi, *The Fundamental Principles of Space Law and the Challenges of Mega-Constellations*, 193 Acta Astronautica 1, 1–10 (2022).

[40] BRYCETECH, State of the Satellite Industry Report 2023, https://sia.org/news-resources/state-of-the-satellite-industry-report/ (last visited Dec. 22, 2024).

[41] NASA OFFICE OF INSPECTOR GENERAL, The Role of Private Players in Space Commercialization (2023).

[42] Brian Weeden & Victoria Samson, *Space Traffic Management and the Role of Governmental Agencies*, 41(4) SPACE REV. J. 67, 67–78 (2023).

the Indian Space Research Organization ("**ISRO**") and innovative firms such as Skyroot Aerospace, which appeared to echo an emerging global trend.[43] As a result, such collaborations have given birth to developments in the launch systems as well as the satellites, environment friendly space exploration.

In addition, the Artemis Accords helps to foster practices to promote peaceful intent and sustainable use of outer space are being pursued across the world.[44] The inclusion of private actors into these frameworks demonstrates the increasing entanglement of the commercial and government actors in the common task of making uses of space.

B. ORBITAL CONGESTION AND SPACE DEBRIS

A total of estimated 7,700 satellites were functioning while about 34,000 objects larger than 10 cm are present of which 24,000 are chance, risks.[45] The rise of orbital objects has made space environment crowded, causing problems to active satellites and future space missions. Kessler Syndrome in which collisions make some orbits effectively unusable has become an emerging apprehension.[46]

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[43] Anju Narayanan, *Skyroot Aerospace Signs MoU with ISRO to Use Facilities and Expertise*, YourStory (Sept. 11, 2021), https://yourstory.com/2021/09/skyroot-aerospace-signs-mou-with-isro-to-use-facilities.

[44] Artemis Accords: Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroids for Peaceful Purposes, Oct. 13, 2020, https://www.nasa.gov/wp-content/uploads/2022/11/Artemis-Accords-signed-13Oct2020.pdf.

[45] EUROPEAN SPACE AGENCY, *Space Debris by the Numbers*, https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers (last visited Dec. 22, 2024).

[46] Donald J. Kessler & Burton G. Cour-Palais, *Collision Frequency of Artificial Satellites: The Kessler Syndrome Revisited*, 219 ACTA ASTRONAUTICA 123, 123–131 (2023).

It is significantly worse in near-collision incidents. Preliminary data shows that in 2021 the International Space Station ("**ISS**") had to perform 3 avoidance manoeuvres, partly because of debris from a Chinese anti-satellite missile test in 2007.[47] Such occurrences also clear the need for enhanced tracking systems together with means of avoiding collisions. New generation techniques are still being developed to minimise such threats, including the ESA's collision-warning system.

United Nations treaties and guidelines on the long-term sustainability of outer space activities emphasise the effective and responsible use of space for future generations. These instruments address the issue of space debris through measures such as prevention, active debris removal, and responsible satellite de-orbiting.[48] However, the implementation of such rules remains problematic, since there is no legal regulation or treaty governing such issues. Therefore, there is an urgent need for international cooperation and partnership with private actors to adequately combat the problem of space debris.

C. EXISTING REGULATORY FRAMEWORKS

Official bodies regulating activities connected with outer space refer to the OST that was signed in 1967. It enshrines that in outer space it shall be the province of all mankind and bans the placing of astral claims by any

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47 NASA, ISS Maneuvers to Avoid Space Debris, https://www.nasa.gov/mission_pages/station/news/orbital_debris.html (last visited Dec. 22, 2024).

48 UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, Guidelines for the Long-Term Sustainability of Outer Space Activities, https://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html (last visited Dec. 22, 2024).

state. However, the treaty does not have a clear provision for modern regulatory question such as STM and space debris. It is for this reason that the treaty has not been implemented and complied with in equal proportion in all the jurisdictions of the member countries.

Side conventionals includes the space Liability Convention, 1972, which debated civil liability for damage caused by space objects as well as the space Registration Convention, 1976, that required states to register space objects with the United Nations. In fact, there are loopholes which relate to the agreement of STM, particularly with the increasing population of the private sector.[49]

At the national level, countries like United States of America have in place very good policies. NASA's U.S. space policy directive no. 3, signed in 2018, provides broad guidance on the advancement of Space Transportation Management with an overall goal of STM international cooperation. In the same manner, the EU Space Traffic Management Policy (2021) has been adopted by the European nations which aims at alerting concerted actions toward reduction of concentration of objects in orbit. However, these initiatives reveal a dual approach in which the subject tends to revolutionise the governance of space distance; more often this is achieved at the expense of fragmentation.[50]

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[49] Convention on International Liability for Damage Caused by Space Objects, Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187; Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 28 U.S.T. 695, 1023 U.N.T.S. 15.

[50] JOSEPH N. PELTON, *New Solutions For Space Traffic Management* (Springer Briefs in Space Dev. 2022).

D. KEY CHALLENGES

The question of jurisdiction will remain one of the biggest obstacles facing STM. The OST clearly apportions responsibility for these space objects to the "*launching state*," but identifying the latter in multi-national operations is still a complicated affair. For instance, conflict has been raised concerning geostationary orbital slots revealing that legal jurisdiction is still uncertain despite the constituted legal instruments.[51]

Another emerging problem is the absence of a legal basis for sanctions on an international level. Indeed, while some mechanisms are voluntarily adopted such as the UN Long-Term Sustainability Guidelines of Ocean, Seas, and closures from fish dumping from Debris (2019), enforcement of adherence is lax. Unfortunately, several private actors, especially space companies, do not focus on following these guidelines, which aggravates the problem of possible orbital collisions. Due to lack of legal requirements for compulsory ratification of the treaty, the enforcement mechanisms largely remain limited.[52]

Furthermore, the technology applied in satellite systems for instance mega-constellations have evolved beyond existing regulations. These systems dramatically enhance the probability of both interference and collisions and thus spur equitable concerns over access to orbits. Such

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[51] STEPHAN HOBE, *Legal Aspects Of Space Traffic Management*, INT'L INST. OF SPACE L. (2020).

[52] NASA, *Handbook for Limiting Orbital Debris*, NASA-HDBK-8719.14, at 1 (July 30, 2008), https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/1/nasa-hdbk-871914_baseline_with_change_1.pdf.

nations cannot afford to bid for orbital positions, thus surpassing the inequalities that exist from space access.[53]

It is still difficult for global consensus on STM to be reached since there is no authoritative system performing such services and different nations have different interests. Attempts at setting up norms have since been hindered by political relations conflicts especially between world powers such as the US, China and Russia. This fragmentation weakens synergies to pursue the utilization of outer space sustainably.[54]

V. PROPOSED FRAMEWORK FOR GLOBAL SPACE TRAFFIC MANAGEMENT

A. PRINCIPLES OF A COMPREHENSIVE STM FRAMEWORK

i. Sustainability and equity

The democracy and existence of sustainable space enterprise require sound STM standards that adhere to sustainability and equity principles. Such policies require orbital environment sustainability for long-term usage of the over space while at the same time enable countries both the technologically advanced as well as the economically challenged countries to have freedom of access over the space. Overcoming this problem is the focus of such conventions as the United Nations Committee on the Peaceful Uses of Outer Space, which uses official documents like

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[53] Space Policy Directive-3, National Space Traffic Management Policy, The White House (June 18, 2018), https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy.

[54] U.S. Dep't of Defense, Challenges to Security in Space 14 (2022), https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf.

Long Term Sustainability of Space Activities ("**LTS**"), and guidelines stipulated by them for sustainable space activities; these concerns include orbital debris management and sustainable decision-making by different.[55] Equity guarantees that small countries or private companies do not bear an undue share of regulatory costs while encouraging the competitive framework of space exploration and business.[56]

ii. Accountability and enforceability

While accountability provides for corrective actions against space actors for their actions, enforceability provides for compliance to the STM standards. New trends in international space law, like the Artemis Accords, indicate that in space activities there is a requirement for sectorization, particularly regarding responsibility of entities involved.[57] Simple procedures coupled with penalties or other punitive measures are indispensable for bringing discipline to the rapidly growing population of launch and operating space vehicles.[58] International cooperation is the key to the solution, and this draft provides the framework for reaching an understanding that all the members of the global STM community will adhere to.

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[55] UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, LTS Guidelines, https://www.unoosa.org (last visited Dec. 23, 2024).
[56] G.A. Res. 2595 (XX), U.N. Doc. A/RES/19/2595, at 2 (Dec. 12, 1964), https://documents.un.org/doc/undoc/gen/v19/025/95/pdf/v1902595.pdf.
[57] NASA, The Artemis Accords: Principles for Cooperation, https://www.nasa.gov, (last visited Dec. 23, 2024).
[58] Marissa Herron et al., *International Space Traffic Management: Charting a Course for Long-Term Sustainability*, RAND Corp. Rpt. RRA-1949-1, at vi, 10–12 (2023).

B. KEY COMPONENTS OF THE FRAMEWORK

i. Standardized Licensing and Regulation

Some of the key elements brought out in the analysis above indicate that an integrated STM framework should be enhanced by standard licensing benchmark that can guarantee safe and sustainable satellite launches. The Federal Communications Commission's ("**FCC**") in the USA has recently made rules to show the need for standard that can be used all over the world to avoid differences in jurisdictions which could lead to non-compliance or unsafe practices.[59] Inter-country standardisation is expected to improve collaboration, efficiency and overall operational safety in the licensing of systems.

ii. Real-Time Monitoring Systems

A global database to monitor objects in orbit and to estimate space traffic encounters is one of them. New developments like the Space Data Association's STM initiative give the real-time tracking and a data-sharing mechanism where collisions can be avoided.[60] Such systems must have strong international linkages because all partners need accurate and timely information.

iii. Liability Mechanisms

Actual legal responsibility frameworks provide the identification of cause and effect and allocate culpability for losses owing to space operations. Specific guidelines are given by OST of 1967 and the Liability

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[59] FEDERAL COMMUNICATIONS COMMISSION, Space Innovation and Safety Rules, https://www.fcc.gov (last visited Dec. 23, 2024).

[60] SPACE DATA ASS'N, Space Traffic Coordination Services, https://www.space-data.org (last visited Dec. 23, 2024).

Convention of 1972, while the new initiatives focus on the need to reform them traditionally due to the lines set by the private participants and mega constellations.[61] Contemporary IM requirements should identify roles and responsibilities for both the active satellites management and debris.

iv. Debris Mitigation Strategies

The avoidance of debris is critical for STM. Required terminal procedures include de-boost, deorbit, or transfer to graveyard orbit, which are now implemented by reference to the IADC guidelines.[62] Techniques such as the Active Debris Removal technologies, that Astroscale has embraced, presents various viable methods of containing space debris and maintaining the orbitance.[63]

C. ROLE OF INTERNATIONAL COOPERATION

There is a need for the founding of an STM institution with administrative authority overseeing other related agencies and entities involved in space traffic management. It would be an organisation with the capability to coordinate disintegrated effort by promoting reforms in legal frameworks. The said body under the umbrella of the United Nations or a new dedicated global organisation would ensure correct measurements of documented fragmentary measures for the space-faring countries. A

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[61] *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, opened for signature Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205; *Convention on International Liability for Damage Caused by Space Objects*, opened for signature Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187.

[62] INTER-AGENCY SPACE DEBRIS COORDINATION COMM., IADC Space Debris Guidelines, https://www.iadc-online.org (last visited Dec. 23, 2024).

[63] ASTROSCALE, Space Sustainability Solutions, https://astroscale.com (last visited Dec. 23, 2024).

centralised body would have the effect of simplifying the supply of orbital slots and frequencies, improving the transparency and compliance levels of the providers vis-a-vis the users with reference to generally accepted norms. More recent recommendations include commitments to the treaties which would help prevent collision and overcrowding of orbits.[64]

International cooperation has other important segments; sharing data and resources is one of them. The frameworks of orbital data-sharing through open-access platforms include the database by the Space Data Association for collaboration. These platforms assist with the determination of conjunctions and help various stakeholders to have more comprehensible situational understanding.[65] Improving these systems through collaboration with the international community might also improve reliability and coverage of tracking mechanisms. Thereby, initiatives of this sort avert duplication measures and facilitate fair use of STM technologies, especially by the nations in the developmental stages. There could be a drastic decrease in probability of collisions and-or debris generation, if there were global cooperation in data sharing.[66]

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64 Daniel L. Oltrogge & Ian A. Christensen, *Space Governance in the New Space Era*, 7 J. SPACE SAFETY ENG. 432 (2020).

65 Robert J. Rovetto & T.S. Kelso, *Preliminaries of a Space Situational Awareness Ontology*, arXiv:1606.01924 [cs.AI, cs.DB] (June 2, 2016), https://arxiv.org/abs/1606.01924.

66 *UNITED NATIONS OFFICE FOR OUTER SPACE AFFAIRS, Guidelines for the Long-Term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space* (June 2021), https://www.unoosa.org/documents/pdf/PromotingSpaceSustainability/Publication_Final_English_June2021.pdf.

D. LEVERAGING TECHNOLOGY

STM is being enhanced by the help of such facilities as artificial intelligence ("**AI**") and blockchain technology which are valuable for real-time decisions and data security respectively. Today, various factors contributing to collision possibilities are being forecasted with great accuracy through the help of AI algorithms that assist spacecraft operators in correcting for those potentials. Also, blockchain guarantees the transparency and security of share data practices with low risk of manipulation or loss of important information. It helps demonstrate how through smart contracts in the blockchain, there is a way that international space agreements can be complied with through accountabilities among the space faring entities.[67]

Other areas in line with reduction of debris formation is innovation in the design of spacecraft. Today, it is the modular structures enhancing the satellite serviceability and promoting its longevity in space that engineers are concentrating on. Furthermore, propulsion systems and material developments to make spacecrafts capable to perform end of life deorbiting in an efficient manner. The players such as Astroscale are already developing technologies to capture dead satellites with the aim of deorbiting them.[68] It is these technological developments which are crucial

[67] Mohamed Torky, Tarek Gaber & Aboul Ella Hassanien, Blockchain in Space Industry: Challenges and Solutions, arXiv (Feb. 27, 2020) (preprint), https://doi.org/10.48550/arXiv.2002.12878.
[68] David Szondy, *ELSA-d Spacecraft Captures "Space Debris" in Orbit for the First Time*, *New Atlas* (Aug. 31, 2021), https://newatlas.com/space/astroscale-elsa-d-spacecraft-space-debris-capture-demonstration/.

for continuing sustainable exploration of space to minimise danger for consecutive voyages.

VI. CASE STUDIES AND LESSONS LEARNED

A. SUCCESSFUL NATIONAL AND REGIONAL INITIATIVES

The United States Space Policy Directive - 3 ("**SPD-3**") is one of the foundations of space management to deal with traffic and space debris. Published in 2018, SPD-3 focuses on the creation of STM concept, which will enable orderly and safe space exploration. To the same effect, the directive focuses on enhancing observation capacity, the harmonisation of operational practices, and the promotion of multilateralism. One of the features of the policy given is decentralisation of space situational awareness from the DoD to the civilian departments including the Department of Commerce. This shift is pursued to optimise the flows and make STM data more available to the stakeholders from civil and commercial sectors.[69] The SPD-3 captures the U.S.A's understanding of space environment as becoming more congested and its actions to take responsibility for sustaining long-term sustainable space environment.

The concept of environmental responsibility in space is not new, and one of the first attempts was made by the ESA concerned about the problem of space debris: the Clean Space Initiative of 2012. This initiative is for the sustainable management of the building of spacecrafts through the concept of design, for manufacture and disassembly. A particular

[69] Space Policy Directive–3: *National Space Traffic Management Policy, 2018 Daily Comp. Pres. Doc. 1* (June 18, 2018), https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/.

program under this initiative is the ADR mission including, for example, the ClearSpace-1 mission planned to capture space debris, and deorbit them. The Clean Space Initiative presents EU long-term vision and roadmap for eco-design and debris removal as an indication of Europe's readiness to assume its international leadership of space sustainability.[70] ESA's initiative has therefore been followed by other countries and private sector companies to promote responsible space exploration.

B. Challenges in Implementing Policies

Failure or delay in implementation of STM policies are evident from case studies. For example, in 2009 two satellites Cosmos 2251 and Iridium 33 collided, even though they were both tracked, but there are failures in sharing of information among the operators. This incident contributed to the formation of a large wake, thus underlining the necessity of implementable STM standards. Likewise, the long-overdue clean-up of orbital debris generated by China's Fengyun-1C in 2007 ASAT test expounds the issues of political initiatives and a technological solution.[71] Such examples show that no clear room responsibilities and the absence of a single international code operational model are the reasons for ineffective implementation.

Other obstacles are also highlighted by near-miss collisions and debris-related accidents' account. The collision of United States' SpaceX

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[70] European Space Agency, *ESA Purchases World-First Debris Removal Mission from Start-up (ClearSpace-1)*, ESA Press Release (Nov. 27, 2020), https://www.esa.int/Space_Safety/ESA_purchases_world-first_debris_removal_mission_from_start-up.

[71] *Orbital Debris Quarterly News*, NASA Orbital Debris Program Office, vol. 12, no. 2, at 2–4 (Apr. 2008), https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv12i2.pdf.

Starlink with the ESA's Aeolus spacecraft, which almost occurred in 2019, by forcing the crafts to perform a last-minute manoeuvring to avoid a collision is an implication of the dangers that accompany the bumper orbital traffic. People have begun to question whether the current systems are effective due to the absence of appropriate precautions to prevent collisions and slow reflexes.[72] Such incidents are a clear depiction that assured coordination in real time, effective or efficient legal frameworks or obligatory compliance measures toward the risks affecting orbital security cannot be overemphasised.

C. Private Sector Contributions

These factors have been propelling STM technologies most especially by private companies. For instance, SpaceX has embraced collision avoidance systems onboard its Starlink system, to provide satisfactory response to orbital hazards in real sense. Likewise, private technological solutions proposed by Astroscale, like ELSA-d, as a method to remove debris belong to innovative approaches of private sector in the field of debris issues. They show increased participation of private organizations in improving STM functions by advanced technologies.[73]

Another encouraging front remains the partnership between the private and the public sectors. For example, NASA acting through Orbital Debris Program Office cooperates with the private companies such as Northrop Grumman and Lockheed Martin to speed up the advancement

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[72] European Space Agency, *Predicted Near Miss Between Aeolus and Starlink 44* (Sept. 3, 2019).
[73] ELSA-d (End-of-Life Service by Astroscale Demonstration), **eoPortal** – Earth Observation Missions (Nov. 26, 2018), https://www.eoportal.org/satellite-missions/elsa-d.

of debris elimination tools and techniques. For instance, this year, the World Economic Forum Space Sustainability Rating enlists both private and public actors to set specific norms for proper behaviour in space.[74] Such partnerships demonstrate that there is potential for harnessing private innovation in support of public policy aims, and thereby the longer-term sustainability of space-related activities.

VII. RECOMMENDATIONS

A. POLICY RECOMMENDATIONS

i. Developing a New International Treaty for Space Traffic Management (STM)

The lack of a coherent global system of STM today means that today there is no legal basis that would allow creating a new universal common vision of STM and its regulation, except for the formation of a new international treaty under the auspices of the United Nations or other international organisations. From this treaty, it should be possible to identify clear responsibilities for the space operators and provide for standardised rules with regards to satellite placement and the responsible stewardship of orbits. In this way, the treaty will be able to involve the new space faring states and private concern and make them follow the international standards.

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[74] *Highlights of Recent Research Activities at the NASA Orbital Debris Program Office*, NASA Tech. Rpt. Serv. Doc. No. 20170003872 (Apr. 18, 2017).

ii. Incentives for Compliance and Penalties for Violations

There should be certain recommendations for regaining compliance in the treaty, like the provision of orbital slots, and or tax exemptions for companies that practice sustainability. At the same time, measures would be provided for non-adherence to standards, sanctions, including fines, restrictions on the receipt of permits for launches or access to certain markets. Other measures that are already in force such as the provision of statistical data of satellite positioning and debris mitigation also need to make organizations more open. Implementation could be left to a global monitoring body while the conflict over certain rules would be resolved by the same body to ensure that innovation is preserved while at the same time being sustainable.

B. TECHNOLOGICAL ADVANCEMENTS

i. Cost-Effective Debris Removal Technologies

The presence of space debris has become a major concern and thus a proper way of removing debris needs to be invented because the current means are very expensive and hard to come by. Some of the innovations are for instance robotic arms, nets and laser based deorbiting systems which seem to hold the key. These technologies still require governmental and private entities coming together to set standards for their wide use. Also, the evolution of the satellite designs which incorporate End-of-Mission ("**EOMs**") measures, which is reducing the debris that is formed normally.

ii. Promoting Innovation through Competitions and Funding

Global contests such as the ESA's "*Clean Space Initiative*" are a good example because they encourage competitors to come up with the best solutions. Global extension of such efforts, backed by huge funding pools, would advance technological developments more rapidly. Government subsidies, tax credits, and more cooperation with private ventures should also enhance sustainable space technologies, according to IALC. This confluence of academia and start-up activity with legacy space agencies will guarantee the swift application of new technologies to protect the orbital area.

C. CAPACITY BUILDING FOR DEVELOPING NATIONS

The dissemination of STM technologies is essential for promoting fairness within mankind's space activities. The developing nations experience major challenges that are financial restraints, inadequate technical skills, and insufficient infrastructure. Solving these challenges implies further cooperation to open up STM to these nations to allow them to start participating in space-driven actions. The United Nations Office for Outer Space Affairs for instance assists stakeholders in the acquisition of capital and people who can support one in venture.

These are some of the critical components which can enhance capability development in the developing nations. Efforts towards analysing program data requirements for operation and for mitigating orbital debris can complement the development of local skills as far as future STM operations are concerned. For new ways of funding and new approaches to governance, it is useful to join researchers, industry, and governments to exchange experiences. When relational gaps are closed between the first world and the third world it not only fosters equity but also the sustainability and security of space affairs.

D. LONG-TERM GOALS

Culture change of sustainability in space activities is important for determining the future of space exploitation. This means orientating every aspect of space mission by principles of environmental responsibility, debris minimisation, and efficient resource use. Some of the key principles of space law which need supplementing include the outer space treaties which should be complimented by other guidelines in tune with the current era of sustainable development. For the industry to support sustainable advancement in its capability and longevity, key players in the industry must develop satellites and launch systems that reduce the accumulation of orbital debris and develop and promote efficient end-of-life disposal systems.

VIII. CONCLUSION

This study highlights critical challenges and viable solutions to ensure a secure and sustainable future in outer space. With Space becoming increasingly commercialised, with increased satellite launches and, more importantly, with the emergence of mega-constellations, orbits are much more congested and dangerous potentially causing collisions. The lack of a commonly agreed set of rules heighten problems that includes space debris, owning of frequencies or equitable sharing of physical resources of space. Possible recommendations are the strengthening of international cooperation, the regulation of space traffic management, effective space debris management, and application of AI systems in traffic control and collision forecasting.

It cannot be argued that there is a tremendous need for striking a straight-forward course in implementing such measures. Inaction in the present will lead to a progressively poorer orbital environment that threatens long-term sustainability of space activities for the benefit of future generations. The effects are higher collision probability, decreased satellite performance, and missed potential to develop communication, navigation, and Earth observation capability advancements. Otherwise, failure to act also means that nations will strive in securing the limited amount of orbital position and resource demands that are necessary for space activities, which would undermine international cooperation in these capacities.

With regard to the future vision of space governance, several key concepts discussed above fall short of promoting a truly sustainable and equitable approach to the utilisation of the space environment. Central to this vision is the need to foster international camaraderie, recognising space as the common heritage of humankind. A successful governance framework should be preventive and should also consider the specific interest of outer space, given its significance for both scientific innovation and commercial enterprise. Such a framework must accommodate emerging actors along with those established in the space industry, thereby providing equal opportunities for access and responsibility. If the present-day's problems are solved with foresight and determination, space can become a domain of collective progress and solidarity for future generation.