Establishing Order in Orbit: Using AI to Manage Space Traffic and Facilitate State Compliance with International Space Obligations

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Abstract

The initial decades of the 21st century space exploration witnessed a dramatic surge in the number of objects orbiting the Earth. Barriers into the space industry have considerably fallen, opening the door to possibilities once reserved for that of science-fiction movies. The dramatic increase in space activities has caused overcrowding in critical areas of space, and outer space traffic congestion has soared to a level where the threat for in-space collisions is at an all-time high. This is all occurring in a domain where no system exists to facilitate orderly management of space traffic.

Amidst this evolving landscape, artificial intelligence offers a promising solution. Through pre-programmed algorithms and machine learning, artificially intelligent space systems can process vast amounts of data and make educated decisions about how to most effectively, efficiently, and safely manage space traffic. Artificial intelligence's ability to detect, track, and react to hazardous space conditions renders it a timely tool for addressing growing congestion in space. As artificial intelligence assists space-faring nations in managing space traffic, it will enhance the means by which states comply with existing obligations under international law.

Despite the imminent challenge posed by space congestion, there has been little progress in establishing order in the cosmos. The work herein proposes that an effective space traffic management system must be developed to keep space sustainable. A system of this nature must address three important objectives: 1) enhance space situational awareness, 2) reduce the impact of space debris, and 3) provide a regulatory framework to coordinate space traffic on an international basis. From its technical application to enhancing the means by which states meet existing international legal obligations, artificial intelligence presents a pathway for the international community to address current STM concerns.

Although the field of space law has been slow to evolve in response to the changing extraterrestrial landscape, and artificial intelligence law is still in its infancy, there are similar concepts within these two subject matters that can be harmonized to successfully fill the void of an international space traffic management framework.

Résumé

Les premières décennies du XXIe siècle ont été marquées par une augmentation spectaculaire du nombre d'objets en orbite autour de la Terre. Les barrières à l'entrée dans l'industrie spatiale ont considérablement baissé, ouvrant la voie à des possibilités autrefois réservées aux films de science-fiction. L'augmentation spectaculaire des activités spatiales a provoqué une surpopulation dans des zones critiques de l'espace, et la congestion du trafic spatial a atteint un niveau tel que la menace de collisions dans l'espace est à son plus haut niveau. Tout cela se produit dans un domaine où il n'existe aucun système permettant de faciliter une gestion ordonnée du trafic spatial.

Dans cet environnement changeant, l'intelligence artificielle offre une solution prometteuse. Grâce à des algorithmes préprogrammés et à l'apprentissage automatisé, les systèmes spatiaux artificiellement intelligents peuvent traiter de grandes quantités de données et prendre des décisions éclairées sur la manière de gérer le trafic spatial de manière plus efficace, efficiente et sécuritaire. L'intelligence artificielle est capable de détecter, monitorer et réagir aux conditions spatiales dangereuses, ce qui en fait un outil opportun pour faire face à la congestion croissante de l'espace. En aidant les nations spatiales à éviter des collisions désastreuses, l'intelligence artificielle améliorera les moyens par lesquels celles-ci se conforment à leurs obligations existantes en vertu du droit international

. Malgré le défi imminent posé par la congestion spatiale, peu de progrès ont été réalisés pour rétablir l'ordre dans le cosmos. Les travaux présentés ici suggèrent qu'un système efficace de gestion du trafic spatial doit être développé pour assurer la durabilité de l'espace. Un système de cette nature doit répondre à trois objectifs importants : 1) améliorer la connaissance de la situation spatiale, 2) réduire l'impact des débris spatiaux et 3) fournir un cadre

réglementaire pour coordonner le trafic spatial à l'échelle internationale. De son application technique à l'amélioration des moyens par lesquels les États respectent leurs obligations juridiques internationales existantes, l'intelligence artificielle offre à la communauté internationale une voie pour répondre aux préoccupations actuelles en matière de STM.

Bien que le domaine du droit spatial ait été lent à évoluer en réponse à l'évolution de l'environnement extraterrestre, et que le droit de l'intelligence artificielle en soit encore à ses débuts, il existe des concepts similaires dans ces deux domaines qui peuvent être harmonisés pour combler avec succès le vide d'un cadre international de gestion de la congestion spatiale.

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List of Acronyms and Abbreviations

ADR – Active Debris Removal

AI – Artificial Intelligence

AIAA – American Institute of Aeronautics and Astronautics

ASAT – Anti-Satellite Weapon

ATC – Air Traffic Control

COLREG – Convention on the International Regulations for Preventing Collisions at Sea

DoD – Department of Defense

FCC – Federal Communications Commission

GEO – Geosynchronous Orbit

IAA – International Academy of Astronautics

IADC – Inter Agency Space Debris Coordination Committee

ICAO – International Civil Aviation Organization

IMO – International Maritime Organization

ITU – International Telecommunications Union

JSpOC – Joint Space Operations Center

LEO – Lower Earth Orbit

NASA – National Aeronautics and Space Administration

NORAD – North American Aerospace Defense Command

OECD – Organization for Economic Cooperation and Development

OOS – On Orbit Servicing

SSA – Space Situational Awareness

SPD – Space Policy Directive

STM – Space Traffic Management

VTS – Vessell Traffic Service

UNCLOS – United Nations Convention on the Law of the Sea

UNCOPUOS – United Nations Committee for the Peaceful Use of Outer Space

UNESCO – United Nations Educational, Scientific, and Cultural Organization

UNGA – United Nations General Assembly

USSPACECOM – United States Space Command

Disclaimer

The arguments, opinions, and conclusions expressed herein are solely those of the author writing in his personal capacity. They do not and should not be considered as representations of official ideas, expressions, or policies of the United States Air Force or any other United States Government agency.

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Introduction

"For a place called space, it's getting mighty crowded up there."[1]

Consider this scenario: you are speeding down a roadway surrounded by thousands of other speeding cars traveling in every direction possible. There are no laws, police, traffic signs, or stop lights to organize the traffic, and the road is littered with random objects of all sizes. Such a system would prove disastrous in modern society where people rely on an organized transportation system to provide safe and (usually) efficient travel. While this hypothetical does not reflect vehicle traffic on Earth, it is precisely illustrative of the current outer space environment.

As thousands of satellites continuously orbit the Earth in support of nearly all aspects of daily life, significant growth in the space industry is leading to overcrowding in space and exponentially increasing the chances of a catastrophic cosmic collision. With no formalized system to regulate this space traffic, the risk for collisions in orbit is increasing as the space industry experiences unprecedented growth. Fortunately, technological developments in the field of artificial intelligence (AI) have emerged which can facilitate space traffic management (STM) and help foster safe navigation of this increasingly crowded environment.

In the nearly 70 years since space exploration began in 1957, the number of objects such as satellites, probes, rovers, space station elements, and crewed spacecraft orbiting the Earth has grown dramatically.[2] A decade into the space age, 159 objects were launched into space by five countries.[3] Fifty years later, this number jumped 2,664 objects launched by over 50 countries

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[1] Mark Wallace, "Traffic Ahead: Space is Becoming Too Crowded" (21 June 2024), online: <altaonline.com/dispatches/a61112622/traffic-ahead-space-is-becoming-too-crowded/>.
[2] UNOOSA, "Data Page: Annual number of objects launched into space" (last accessed 7 September 2024), online: <ourworldindata.org/grapher/yearly-number-of-objects-launched-into-outer-space>.
[3] *Ibid*.

and international organizations.[4] Today, there are over 10,000 active, or functioning, objects in space, accompanied by millions of inactive space objects, known as debris.[5] The past decade has seen unprecedented increases in space traffic. Between 2014 and 2020, the number of active space objects more than doubled.[6] The trend of exorbitant outer space growth is expected to continue for the foreseeable future. Researchers estimate that over 40,000 active objects will be in orbit by the year 2030.[7] The reality of this estimate remains to be seen; however, satellite operators have filed an astounding 100,000 applications to develop and launch new spacecraft within the next decade.[8]

The primary reason for this sharp increase in space activity is the rise in private, non-governmental investment in the space industry.[9] Space infrastructure has connected the world in ways that could have never been imagined in the days of Sputnik. They support nearly every aspect of daily life on Earth, including cellular communications, emergency response, global navigation, banking transactions, weather forecasting, and national defense.[10] As a result, private companies have joined governmental agencies in exploiting space for the resource it is. Whereas the notion of a "space economy" was unheard of decades ago, the space industry is forecasted to top one trillion USD by 2040.[11] Commercial investment in space exploration has

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4 UNOOSA, "Online Index of Objects Launched into Outer Space" (last accessed 7 September 2024), online: <unoosa.org/oosa/osoindex/search-ng.jspx>.
5 European Space Agency, "Space Environment Statistics" (last updated 15 August 2024), online: <sdup.esoc.esa.int/discosweb/statistics> [ESA, "Space Environment Statistics"].
6 Carmen Pardini & Luciano Anselmo, "Evaluating the impact of space activities in low earth orbit" (2021) 184 Acta Astronautica 11 at 11.
7 Cosmos, "Space traffic management - what happens when things collide?" (27 September 2022), online: <cosmosmagazine.com/space/space-traffic-management-collide/>.
8 Pardini, *supra* note 6 at 11.
9 Chiara Manfletti, Marta Guimaraes & Claudia Soares, "AI for space traffic management" (2023) 10:4 J Space Safety Engineering 495 at 495.
10 Salvador Llopis et al, "Cybersecurity Space Operations Center: Countering Cyber Threats in the Space Domain" in Kai-Uwe Schrogl, ed, Handbook of Space Security, 2d ed (Switzerland: Springer, 2020) at 923.
11 Manfletti, *supra* note 9 at 495.

resulted in more efficient manufacturing, launching, and operating of objects, and made it cheaper and easier for new entrants to reach for the stars.[12]

While the international community has declared space as open for free use, exploration, and scientific investigation by all countries,[13] these freedoms are becoming threatened by the ease of access just described. Much of the new space activity occurs in Lower Earth Orbit (LEO) which a highly valuable but exhaustible and non-excludable resource.[14] Outer space overcrowding, made worse with every rocket launch, inherently increases the odds that objects flying through this region will collide with one another. These collisions, also known as conjunctions, can disrupt, damage, or even destroy space objects due to the speeds at which they occur. Scientists have calculated that when an object five centimeters in size collides with another object in space, it transfers the same amount of energy as being struck by a large speeding bus.[15]

No matter the size, conjunctions pose a danger to space operations and threaten the lives of humans in space. While the number of people in space is relatively low, it is anticipated to increase in the near future as manned space exploration and space tourism become more prevalent.[16] Furthermore, conjunctions can be a source of international conflict as they may harmfully interfere with states' free use of space and result in disputes over liability for damage.[17] As will be argued throughout this thesis, a sound STM system reliant upon AI

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[12] John Coykendall et al, "Riding the exponential growth in space" (22 March 2023), online: <deloitte.com/us/en/insights/industry/aerospace-defense/future-of-space-economy.html>.
[13] *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, 27 January 1967, 610 UNTS 205 at art I [*Outer Space Treaty*].
[14] Keiko Nomura et al, "Tipping Points of Space Debris in Low Earth Orbit" (2024) 18:1 Intl J Commons 17 at 18.
[15] Aerospace, "Space Debris 101" (last accessed 4 September 2024), online: <aerospace.org/article/space-debris-101>.
[16] Zoe Hobbs, "How many people have gone to space?" (last updated 17 November 2023), online: <astronomy.com/space-exploration/how-many-people-have-gone-to-space>.
[17] Coykendall, *supra* note 12.

technologies can help avoid these conjunctions and facilitate compliance with international law to reduce conflict in space.

In its current form, managing space traffic has been described as an informal, ad hoc, and often ill-coordinated process.[18] Even that description is a bit generous. Despite growth in this 70-year-old field, there are no international agreements specifically tailored to STM or navigating space congestion.[19] There are two primary reasons for this. First, from a self-serving perspective, space actors enjoy their freedom of use and are reluctant to cede authority over their space activities.[20] While guidelines have been established recommending methods for reducing space debris and increasing space sustainability, these guidelines are voluntary, meaning that states can pick and choose those that meet their individual interests.[21] Second, geopolitical differences have hampered cooperation towards establishing a global STM regulatory regime. Heightened awareness of worsening orbital conditions has resulted in STM now being a regular topic within the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), and in particular, its legal subcommittee proceedings.[22] However, progress in governing this issue has stalled as states have failed to agree on what structure STM should take and how it might be enforced.[23]

a. An Argument for a Promising Solution

In light of these challenges, AI provides a strategic and effective solution for monitoring satellite orbital patterns, anticipating potential risks, navigating congestion, and preventing

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[18] Bruce McClintock et al, *The Time for International Space Traffic Management is Now* (Santa Monica, CA: RAND Corporation, 2023) at 3.
[19] Joseph N. Pelton, "A path forward to better space security: Finding new solutions to space debris, space situational awareness and space traffic management" (2019) 6:2 J Space Safety Engineering 92 at 95.
[20] Ahmad Kahn & Sufian Ullah, "Challenges to International Space Governance" in Schrogl, *supra* note 10 at 39.
[21] Pelton, *supra* note 19 at 95.
[22] McClintock, *supra* note 18 at 4.
[23] *Ibid.*

collisions in outer space as. Through pre-programmed algorithms and machine learning, AI's decision-making process can analyze larger volumes of data in a faster and more expansive manner than its human counterparts. By assisting with STM, AI will ensure the continued operational status of critical space infrastructure, thereby maintaining the uninterrupted support of life on Earth. Furthermore, AI has the flexibility to achieve this in situ, which is an advantage over the current method of transmitting data between space and human operators on Earth.

Private entities such as SpaceX have already started utilizing AI to assist with these objectives, however its use has been met with criticism from technical and legal perspectives.[24] As discussed *infra*, some legal scholars have expressed reservations about using AI in space; however, this thesis posits that AI can not only enhance STM measures, but also assist space actors in fulfilling their international legal obligations, provided it is deployed in an ethical manner. In so doing, using AI for STM can prove instrumental in averting the potential for legal, diplomatic, or military conflicts that could arise from space-related disputes.

b. Research Objectives and Roadmap

The goal of this thesis is to examine the legal implications of using a relatively new and attractive technology to resolve the problems associated with overcrowding in space. While the pillars of space law date back to the 1960s, and AI law is in its infancy, the urgency for effective STM requires that the two subject matters be harmonized in the context of the modern space environment. This thesis contends that AI technology, if legally and ethically employed, can be an invaluable asset to STM and change space from a congested and contested domain to an organized and safe environment. Furthermore, by introducing AI into STM operations, states, as the subject of international law, will be better poised to fulfill their duties of exercising

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[24] Jeff Foust, "Starlink's disruption of the space industry", *The Space Review* (28 May 2024), online: <thespacereview.com/article/4801>.

responsibility, control, supervision, and liability for their space objects.[25] The discussion herein also submits that internationally adopted principles of ethical AI use can align with space law principles to support a STM framework that is long overdue.

This thesis begins with Chapter 1 defining STM and its three critical components: 1) space situation awareness (SSA), 2) space debris remediation, and 3) a governance system for managing space traffic. Chapter 1 also reviews the origins of monitoring space traffic, expands on why space traffic is at a critical juncture, and compares STM with management systems used for aviation and maritime traffic. Chapter 2 conducts a comprehensive literature review of proposed resolutions for dealing with congestion in orbit, including the benefits and concerns associated with using AI for STM. Chapter 3 offers a brief primer about AI's recent evolution and legislating its ethical use. Chapter 4 presents a comprehensive analysis of the legal implications of utilizing AI to enhance SSA. It argues that the contemporary space environment necessitates a reinterpretation of terminology within the Outer Space Treaty and Liability Convention to address concerns about using AI for STM. Chapter 5 examines the potential of AI to mitigate and reduce space debris, thereby alleviating overcrowding in space and facilitating states' compliance with the due regard and control requirements established by the Outer Space Treaty. Furthermore, it examines criticisms that AI can be exploited for malicious space activities and makes the case that this concern can be alleviated by ensuring ethical tenets of AI use are integrated into future STM regulations. Finally, Chapter 6 analyzes two models for governing STM: an internationally led top-down approach, and a bottom-up approach based in domestic policies and international soft law. It argues that despite the former option being the optimal method for STM oversight, the latter option is more practical within today's geo-

[25] *Outer Space Treaty*, *supra* note 13 at arts VI – IX.

political climate and is therefore more likely to result in AI's immediate incorporation into STM governance.

c. Research Methodology

The study forming the basis of this thesis consisted of a qualitative doctrinal investigation into the legal issues associated with overcrowding in space and the use of AI in an outer space context. While the foundation of space law is based on five primary space treaties, none of them address the topic of STM. In fact, the most recent of these treaties was adopted in 1970's, well before space congestion was an issue, and decades before AI technology became popular. Therefore, the study of STM must go beyond the black letter law of these treaties. International soft law instruments have indirectly referenced STM; however, even those remain inadequate as they are only voluntary guidelines.

Despite AI's usefulness in assisting with STM, there has been a relative lack of attention paid to the legal and ethical complexities that arise from integrating these two technologically sophisticated domains. In addition to investigating space law's historical evolution in the context of STM, this thesis explores how the interpretation and application of longstanding principles of space law aligns with AI's integration into modern space operations. This research also examined the emergence of AI law, noting its alignment with space law principles. Ultimately, the analysis that follows examines two distinct legal areas and argues that they must be harmonized to address the challenges associated with making space safer and conflict free.

d. Research Parameters

Before proceeding with this thesis, it is important to establish the specific parameters within which its arguments will be advanced. While outer space is limitless, current technological limitations dictate that certain regions are more conducive to supporting critical space activities. It is not a coincidence that these regions are the most densely populated in terms of both active space objects and debris. This thesis will primarily focus on the region of Lower Earth Orbit which is generally defined as an altitude range of approximately 700 to 2,000 kilometers from the Earth's surface.[26] Satellites in this region take between 90 and 120 minutes to fully orbit of Earth, the equivalent of traveling approximately 18,000 miles per hour.[27] LEO offers the optimal altitude for space infrastructure that supports functions such as telecommunications and internet satellites, military operations such as missile defense, and remote sensing.[28] Additionally, LEO is locale of all non-lunar spaceflight and home to the International Space Station, which is continuously occupied by humans engaged in scientific research.[29] This region is of critical importance when discussing STM, as it is where the majority of all space objects and millions of pieces of space debris reside.[30] LEO's orbital characteristics underscore the necessity for effective STM, as the velocity at which space objects travel in this region creates a pressing need for data to be continuously collected and analyzed in order to facilitate swift responses to hazards that arise.

A second important orbital region is Geostationary Orbit (GEO), located considerably farther from the Earth's surface, approximately 36,000 kilometers into space.[31] The orbital period of objects in GEO is nearly synchronous with the Earth's rotational period, resulting them appearing to exist in a fixed position over specific regions of the Earth's surface.[32] However, in

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[26] William Ailor, "Evolution of Space Traffic and Space Traffic Management" in Schrogl, *supra* note 10 at 300.
[27] *Ibid*.
[28] Lisa Sodders, "LEO, MEO, or GEO? Diversifying orbits is not a one-size-fits-all mission (Part 2 of 3)" (20 July 2023), online: <ssc.spaceforce.mil/Newsroom/Article-Display/Article/3465697/leo-meo-or-geo-diversifying-orbits-is-not-a-one-size-fits-all-mission-part-2-of-3>.
[29] European Space Agency, "Types of orbits" (30 March 2020), online: <esa.int/Enabling_Support/Space_Transportation/Types_of_orbits#LEO> [ESA, "Types of orbits"].
[30] Ailor, *supra* note 26 at 304.
[31] ESA, "Types of orbits", *supra* note 26.
[32] *Ibid*.

terms of the number of active satellites and tracked debris, GEO constitutes only a small fraction of total space objects.[33] The International Telecommunications Union (ITU) exercises considerable control over GEO, allocating orbital slots and acting as a pseudo-STM facilitator.[34] Despite GEO also experiencing an increase in activity, the ITU has been largely effective in mitigating conflict, preventing collisions, and guaranteeing access and use by all, particularly developing states.[35] Accordingly, this thesis will concentrate on the issues of overcrowding and the absence of an STM system in the context of LEO.

Lastly, this thesis uses the term "space object(s)" which has been the subject of much legal discourse due to its inconsistent usage throughout the five major space treaties.[36] The Outer Space Treaty employs the term "objects launched into outer space,"[37] whereas the Liability[38] and Registration Conventions[39] explain that "space object includes component parts of a space object as well as its launch vehicle and parts thereof." The Moon Agreement, for its part, uses the phrase "man-made space objects,"[40] and the Rescue and Return Agreement refers to them as "space object or its component parts" in all but one article, where it utilizes the same terminology as the Outer Space Treaty.[41] Despite this inconsistent verbiage, the term "space

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[33] Ailor, *supra* note 26 at 302.
[34] Ram S. Jakhu, John Logsdon & Joseph N. Pelton, "Space Policy, Law and Security" in Joseph N. Pelton & Angelia Bukley, eds, *The Farthest Shore: A 21st Century Guide to Space* (Burlington, ON: Apogee Books Publication, 2010) at 202 [Jakhu, "Space Policy"].
[35] *Ibid.*
[36] Bin Cheng, "Definitional Issues in Space Law: 'Space Objects', 'Astronauts', and Related Expressions" in Bin Cheng, ed, *Studies in International Space Law*, 1st ed (Oxford: Oxford University Press, 1997) at 493 [Cheng, "Definitional Issues"].
[37] *Outer Space Treaty*, *supra* note 13 at art VIII.
[38] *Convention on International Liability for Damage Caused by Space Objects*, 29 March 1972, 961 UNTS 187 at art I(d) [*Liability Convention*].
[39] Convention on Registration of Objects Launched into Outer Space, 14 January 1975, 1023 UNTS 15 at art I(b) [*Registration Convention*].
[40] *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies,* 18 December 1979, 1363 UNTS 22 at art III(2) [*Moon Agreement*].
[41] *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space,* 22 April 1968, 672 UNTS 119 at art V [*Rescue Agreement*].

object" has generally been understood to mean objects launched into outer space; an interpretation that sufficiently encompasses the intent underlying the variations quoted above.[42] Notably, this includes space debris, which are inoperable space objects or fragments of space objects that remain in space and a major concern for STM.[43] The identify of debris as a space object is further explored in Chapter 5. Accordingly, as the term "space object" is used throughout this thesis, it should be read as any item launched into space including active satellites, spacecraft, space stations, landers, rovers, and debris. In instances where it is necessary to differentiate between types of space objects, this thesis will make explicit distinctions by referencing the specific type of space object under discussion.

Chapter 1: What is STM, and why is there a demand for it?

"There is no such thing as space traffic management… But now, all of a sudden, we really need it."[44]

a. Establishing a Baseline

Prior to analyzing the legal implications of using AI to address STM, it is necessary to frame the current state of space traffic and the existing void in its governance that drives concerns about overcrowded orbits. Doing so rationalizes the urgence need to address STM immediately and the eagerness to employ a new technology like AI to achieve this goal. Accordingly, this chapter defines the concept of STM, examines the history of monitoring space traffic, and argues that we have reached a critical stage that demands action now. Finally, this chapter compares space traffic with its air and sea counterparts to make the case that space's unique qualities render replicating these systems in the cosmos infeasible.

[42] Cheng, "Definitional Issues", *supra* note 36 at 495.
[43] *Ibid* at 506-507.
[44] Cosmo, *supra* note 7.

b. What is Space Traffic Management?

The first challenge in addressing STM is that there is unfortunately no singularly adopted definition of it.[45] In fact 19 different descriptions of STM can be found in various scholarly and scientific publications.[46] The concept is not referenced in any of United Nations outer space treaties, nor has UNCOPUOS established a meaning despite STM discussions annually appearing on their agenda.[47] Since the space community has failed to reach an agreed meaning of the concept, one's definition often reflects their own priorities in space. It is unsurprising then that some believe STM should consist of more technical rules specifically aimed at critically crowded orbits, space debris, and registration of space objects, while others think it should consist of broad international laws aimed at preventing conflict in outer space.[48]

The first official attempt at defining STM was in 2006 when the International Academy of Astronautics (IAA) described it as "the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space, and return from outer space to Earth, free from physical or radio-frequency interference."[49] This marked the first official contemplation that STM should address both technical aspects of space sustainability (STM measures) with institutional and regulatory governance (an STM regime).[50] In focusing on space actors' freedom to use space free from harmful interference, the IAA closely aligned their STM

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[45] Mark A. Skinner et al, "Results of the international association for the advancement of space safety space traffic management working group" (2019) 6:2 J Space Safety Engineering 88 at 88-89.
[46] Dan Oltrogge et al, *Recommendations of the IAF Space Traffic Management Terminology Working Group* (Dubai: International Aeronautical Foundation Technical Committee #26, 2021) at 2-3.
[47] *Report of the COPUOS*, UNCOPUOS, 67th Sess, UN Doc A/79/20 (2024), online(pdf): <unoosa.org/res/oosadoc/data/documents/2024/a/a7920_0_html/A_79_020E.pdf> at 29 [UNCOPUOS Report 67th Sess].
[48] Ram S. Jakhu & Joseph N. Pelton, "Space Traffic Management and Coordinated Controls for Near-space" in Ram S. Jakhu & Joseph N. Pelton, eds, *Global Space Governance: An International Study* (Cham: Springer International Publishing, 2017) at 305 [Jakhu, "STM for Near-space"].
[49] Quentin Verspieren, "Historical Evolution of the Concept of Space Traffic Management Since 1932: The Need for a Change of Terminology" (2021) 56:101412 Space Pol'y 1 at 2.
[50] *Ibid*.

objectives with principles of the Outer Space Treaty.[51] Others including Yvon Henry, the former chief of the ITU, have concurred that STM's primary objective should be to facilitate interference-free space activities, because in doing so, it facilitates the safe and free use of space in crowded areas where operations may face the largest risks.[52]

While the IAA's definition of STM characterized it as a both regulatory and technical issue, other agencies such as the United States' Defense Analyses Science and Technology Policy Institute have suggested that STM relates exclusively to oversight, coordination, and regulation of space activities.[53] This approach neglects the technical and operational details of monitoring, analyzing, and reacting to space activity, omissions that are detrimental to consistent and organized traffic management. Such a system would ultimately be ineffective at addressing space congestion as it merely reflects consultation obligations that already exist under Article IX of the Outer Space Treaty, but are rarely utilized.[54]

In 2018 the United States (US) government defined STM in its Space Policy Directive #3 (SPD-3) as "the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment."[55] This national policy narrowly focuses on operational activities and does not make reference to broader legal standards or an international regime for controlling orbital traffic.[56] Understanding that the US

[51] Corinne Contant-Jorgenson, Petr Lala & Kai-Uwe Schrogl, "The IAA Cosmic Study on space traffic management" (2006) 22:4 Space Pol'y 283 at 285-287.
[52] Yvon Henri, "Frequency Management and Space Traffic Management" (Delivered at the International Telecommunication Union Space Law Symposium, Geneva, 12 March 2015), online(pdf): <unoosa.org/pdf/pres/lsc2015/symp-04.pdf> at 19.
[53] Emily Nightingale et al, *Evaluating Options for Civil Space Situational Awareness (SSA)* (Washington, DC: Institute for Defense Analyses Sciences, 2016) at iv.
[54] P.J. Blount, "Renovating Space: The future of International Space Law" (2011) 40:1-3 Denv J Int'l L & Pol'y 515 at 526.
[55] US Presidential Memoranda, *Space Policy Directive - 3, National Space Traffic Management Policy* (18 June 2018), online: <trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy> [SPD-3] at s 2(b).
[56] *Ibid*.

cannot legislate global STM via domestic policy, defining STM in a way that ignores international governance of space traffic fails to address the global complexities of this issue. The importance of global governance in STM is significant given that space is open to all and not subject to national appropriation.[57] Nevertheless, from an international standpoint, SPD-3 has the potential to encourage other nations to develop their own technical solutions for improving space traffic. Considering the US' dominant role in the space community, SPD-3 can be a STM model that other nations can imitate, laying the foundation for future international STM law.

In 2020, the European Space Policy Institute asserted that STM is comprised of three complementary functions: 1) space traffic monitoring (or SSA), 2) regulation consisting of rules, principles, and guidelines, and 3) organized coordination among stakeholders.[58] This is a more comprehensive approach than SPD-3 and is closer aligned to the IAA's perspective of what STM should incorporate. This comprehensive model would benefit the space industry at large if adopted internationally, however within UNCOPUOS, a lack of clear agreement on defining STM has stalled debates on the issue and hampered progress toward resolving its associated concerns.[59]

Regardless of one's definition of STM, its underlying logic is straightforward. If one space object is in a specific location, another cannot occupy that same spot simultaneously without causing damage, destruction, or conflict. To prevent conjunctions, space operators must maneuver their objects out of harm's way. This has multiple consequences, including the undesired expenditure of valuable fuel which can shorten an object's lifespan; interruption of

[57] *Outer Space Treaty, supra* note 13 at art II.
[58] European Space Policy Institute, *ESPI Report 71 - Towards A European Approach to Space Traffic Management - Full Report* (Vienna: European Space Policy Institute, 2020) [ESPI, "Report 71"] at s 2.2.
[59] McClintock, *supra* note 18 at 4.

satellite coverage, thereby impacting its supported systems on Earth; and impeding the trajectory of other space objects.[60] STM's fundamental objective is to avoid these destructive and assuredly costly consequences. Achieving this requires a system that can establish and ensure compliance with "rules of the road" to facilitate safe on-orbit operations.[61]

For an STM system to succeed, it is essential to have both a regulatory component and a focus on technical solutions that allow states to freely explore space with minimal risks for collisions. The remainder of this thesis will utilize a STM definition that incorporates both of these aspects. To achieve success, an STM system must prioritize three key areas: 1) enhanced SSA, characterized by widespread data sharing, 2) debris remediation through meaningful active debris removal and mitigation measures, and 3) international governance that utilizes space traffic control rules to facilitate navigation in congested orbits.[62] Each of these aspects plays a vital role in maintaining safe and conflict-free space operations, as the extraterrestrial environment continues to be populated and exploited.

c. The Evolution of Managing Traffic in Space

In the years following the Soviet Union's launch of Sputnik, there were little, if any, concerns that space objects might collide into one another.[63] The early space age saw the USSR and US emerge as two superpowers, each striving to prove itself as the superior space nation by reaching into the unknown in bigger, faster, and mightier ways than the other. Though some early exploration focused on scientific exploration, the bulk of initial space developments were aimed at enhancing military capabilities such as observation (e.g. spy) satellites and missile

[60] *Ibid* at 2.
[61] Hjalte O. Frandsen, "Looking for the Rules-of-the-Road of Outer Space: A search for basic traffic rules in treaties, guidelines and standards" (2022) 9:2 J Space Safety Engineering 231 at 232.
[62] Jamie Morin, "Four steps to global management of space traffic" (2019) 567:7746 Nature 25 at 26-27.
[63] Loretta Hall, "The History of Space Debris" (Delivered at the Space Traffic Management Conference, Daytona Beach, FL, 6 November 2014), online(pdf): <commons.erau.edu/cgi/viewcontent.cgi?article=1000&context=stm> at 2.

warning systems.[64] As these military systems continued to be launched into orbit, it became strategically important for the two superpowers to closely monitor both their own and each other's space objects.[65]

In 1958, the U.S. Department of Defense (DoD) created the North American Aerospace Defense Command (NORAD), whose mission included space surveillance and the tracking of objects in orbit.[66] In the 1960's and 1970's, NORAD's database, which came to be known as a satellite catalog, became a critical resource for monitoring space objects and providing conjunction assessments, or predictions of potential collisions.[67] These efforts were largely beneficial for the Cold War objectives of monitoring the adversary's space objects for purposes of ballistic-missile defense and anti-satellite (ASAT) weapon deployment. Consequently, observing and tracking the movement of the superpowers' orbital assets was crucial in pursuit of their national strategic activities.

As the competition for space superiority raged on, dead satellites, spent rockets, and other non-functional hardware were frequently discarded into space.[68] At the time, scientists adopted the "big sky theory" which held that because space is so vast, discarded debris could float away without interfering with ongoing operations.[69] However, this theory became increasingly untenable as more objects accumulated in the environment. As the number of space objects increased steadily throughout the Cold War, so too did the amount of space debris.[70] In 1978,

[64] James Clay Moltz, "The Changing Dynamics of Twenty First Century Space Power" (2019) 12:1 J Strategic Security 15 at 18-20.
[65] *Ibid*.
[66] Rick W. Sturdevant, "From Satellite Tracking to Space Situational Awareness: The USAF and Space Surveillance, 1957-2007" (2008) 55:4 Air Power History 4 at 8.
[67] *Ibid*.
[68] *Ibid* at 15.
[69] Brittany Sauser, "Anticipating Collisions between Spacecraft and Space Junk" (10 December 2010), online: <technologyreview.com/2010/12/10/198507/anticipating-collisions-between-spacecraft-and-space-junk>.
[70] *Ibid*.

Donald Kessler expressed a concern that the continued production of space debris could result in a cascading chain reaction of space collisions, thereby increasing the amount of space debris exponentially until safe space operations are rendered impossible.[71] This "Kessler Syndrome" has been widely acknowledged as a threat to outer space activity as even the smallest debris particles can cause damage or destruction when colliding with a space object at over 18,000 miles per hour.[72]

In the wake of the Space Shuttle Challenger tragedy, the National Aeronautics and Space Administration (NASA) joined forces with the DoD with the objective of enhancing its capacity to track space objects.[73] The intent was to facilitate astronaut safety by optimizing collision avoidance capabilities for piloted spacecraft.[74] By relying on the information gathered by US Strategic Command (now the US Space Command (USSPACECOM)), NASA enhanced its ability to predict the trajectory of space objects and maneuver the space shuttle to safety when necessary. In the following years, USSPACECOM data was also instrumental in helping the International Space Station avoid collisions in orbit.[75]

In 1999, the American Institute of Aeronautics and Astronautics (AIAA) held an International Space Cooperation workshop with the objective of addressing key issues related to orbital management, collision avoidance, orbital debris, and the possibility of a regulatory framework on these issues from an international perspective.[76] The workshop concluded that

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[71] Donald J. Keesler & Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt" (1978) 83:6 J Geophysical Research 2637 at 2642.

[72] *Ibid*.

[73] US, NASA, *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook, (*NASA/SP-20205011318, December 2020) at 7.

[74] *Ibid.*

[75] *Ibid.*

[76] Graham Gibbs & Ian Pryke, "International cooperation in space: the AIAA–IAC workshops" (2003) 19:1 Space Pol'y 53 at 53-54.

while the situation was not yet critical, issues related to space debris needed immediate attention in order to avoid becoming unmanageable.[77]

Near the turn of the century, UNCOPUOS took notice of space traffic hazards and began discussing safety measures including regulating access to space, "rules of the road" in orbit, and how to integrate atmospheric launch and re-entry traffic with air traffic.[78] The Inter Agency Space Debris Coordination Committee (IADC) was formed (independent from UNCOPUOS) as a forum for national space agencies to exchange information and develop strategies to mitigate the impact of space debris.[79] In 2002, the IADC proposed Space Debris Mitigation Guidelines, which were designed assist states in reducing the threats posed by debris in outer space.[80] Following a period of refinement, these mitigation guidelines were recognized by UNCOPUOS and endorsed by the UN General Assembly (UNGA).[81] Although these guidelines focused on space debris as opposed to STM at large, they share similar goals in that the guidelines aim to minimize the long-term presence of debris in LEO and reduce the probability of collisions in orbit.[82]

Throughout the 2010's, UNCOPUOS continued assessing the impact of debris and the rapidly changing landscape of space, namely the development of large satellite constellations.[83] The growing number of space objects and increased risk for collisions led to the adoption of the

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[77] *Ibid* at 59.
[78] Stijn Lemmens & Francesca Letizia, "Space Traffic Management Through Environment Capacity" in Schrogl, *supra* note 10 at 846.
[79] Theresa Hitchens, "Debris, Traffic Management, and Weaponization: Opportunities for and Challenges to Cooperation in Space" (2008) 14:1 Brown J World Affairs 173 at 174-175.
[80] *IADC Space Debris Mitigation Guidelines*, June 2021, IADC-02-01 Rev. 3, online(pdf): <iadc-home.org/documents_public/file_down/id/5249>.
[81] UNOOSA, *Space Debris Mitigation Guidelines of COPUOS*, (Vienna: 2010), online(pdf): <unoosa.org/pdf/publications/st_space_49E.pdf> [Debris Mitigation Guidelines].
[82] *Ibid.*
[83] *Report of the COPUOS*, UNCOPUOS, 62d Sess, UN Doc A//74/20 (2019), online(pdf): <unoosa.org/res/oosadoc/data/documents/2019/a/a7420_0_html/V1906077.pdf>.

Guidelines for the Long-Term Sustainability of Outer Space Activities (LTS Guidelines) in 2018.[84] The LTS Guidelines comprise 21 broad recommendations for states to mitigate risks associated with operating in a crowded space environment.[85] Relevant to STM, the guidelines encourage states to[86]:

- Provide updated contact information and share information on space objects and orbital events (Guideline B.1)
- Share and disseminate space debris monitoring information (Guideline B.3)
- Perform conjunction assessment during *all* orbital phases of controlled flight (Guideline B.4)
- Develop practical approaches for pre-launch conjunction assessment (Guideline B.5)
- Design and operate space objects in a way that increases their trackability (Guideline B.8)
- Design measures to address risks associated with uncontrolled re-entry of space objects (Guideline B.9)

Although the LTS Guidelines do not explicitly reference STM, the aforementioned provisions indicate that space traffic was a primary consideration during the drafting process.[87]

The IADC Debris Mitigation Guidelines and the LTS Guidelines demonstrate ambition and good intentions. Nevertheless, their voluntary nature allows states to select and implement practices that align with their specific needs. Additionally, the guidelines are quite broad, allowing individual states to determine how to interpret and implement them, potentially at the expense of the greater good. This allows states to use the guidelines in ways that best advance their space programs; however, different forms of implementation can lead to inconsistencies in

[84] *Ibid* at Annex II [LTS Guidelines].
[85] *Ibid*.
[86] *Ibid*.
[87] *Ibid* at 31.

space policies and disagreements over how the guidelines should be prioritized and interpreted.[88] Therefore, while they highlight important aspects of STM, both sets of guidelines are insufficient for truly managing or regulating traffic in space.

d. Why Space Traffic Management Now?

Throughout the first part of the 21st century, two major factors transformed the outer space landscape and brought space traffic to the critical juncture anticipated by the 1999 AIAA workshop. First, between 2007 and 2009, the quantity of debris skyrocketed as a result of multiple outer space collisions.[89] In 2007, China launched an ASAT missile that struck one of their own defunct weather satellites in LEO.[90] This incident created the largest cloud of space debris in history, polluting LEO with over 3,000 trackable (10 centimeters or larger) and an estimated 35,000 smaller pieces of debris, many of which remain in orbit today.[91] This was closely followed in 2009 by an unintentional collision between the US Iridium 33 (560 kg) and the Russian Cosmos 2251 (900 kg) satellites.[92] The active US communications satellite and the non-functional Russian satellite slammed into one another at over 10,000 miles per hour in a highly concentrated region of LEO, resulting in over 1,800 pieces of trackable space debris.[93] The debris cloud from this event prompted multiple satellites to take evasive action in order to avoid potential damage, and it is projected that remnants from this collision will remain in LEO through the end of this century.[94] These events are relevant to the STM discussion for two

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[88] Peter Martinez, "The development and implementation of international UN guidelines for the long-term sustainability of outer space activities" (2023) 72:7 Advances Space Research 2597 at 2604.
[89] Col John W. Wagner, "Beware the situation: how JSpOC tracks space debris" *Room The Space Journal of Asgardia* (2014) online: <room.eu.com/article/Beware_the_situation_how_JSpOC_tracks_space_debris>.
[90] Brian Weeden, "2007 Chinese Anti-Satellite Test Fact Sheet" (23 November 2010), online(pdf): <swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf>.
[91] *Ibid*.
[92] Brian Weeden, "2009 Iridium-Cosmos Collision Fact Sheet" (10 November 2010), online(pdf): <swfound.org/media/6575/swf_iridium_cosmos_collision_fact_sheet_updated_2012.pdf>.
[93] *Ibid*.
[94] *Ibid*.

reasons. First, they more than tripled the amount of uncontrollable space debris in Earth's orbit.[95] Second, they marked the beginning of USSPACECOM's practice of sharing its SSA data with space operators to warn them of impending collisions.[96]

The second factor that has significantly altered the outer space landscape and is fueling the demand for a comprehensive STM system is the rapid expansion of stakeholders in outer space exploration and exploitation. From the beginning of the space age through the early 1990's, space objects were generally unique, custom-built items designed for specific missions, and each launch generally ushered no more than a few objects into orbit.[97] In the past decade, technological advancements have driven a reduction in launch costs and resulted in a bustling space industry. Former US astronaut Edward Lu characterized current growth trajectory of the space industry as following the path of Moore's law – which states that the low cost of an object or activity can enable its existence to double on an annual basis for an undetermined period of time.[98]

Dubbed the "second space race"[99] or "NewSpace"[100], today's space industry is replete with for-profit companies pursuing faster and cheaper ways to access the cosmos. SpaceX, Amazon, and OneWeb have led the way in developing large constellations consisting of satellites that are smaller and cheaper than traditional government and military satellites.[101] As of May 2024, SpaceX has launched more than 6,500 satellites as part of its Starlink constellation, which

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95 Ray A. Williamson, "Assuring the sustainability of space activities" (2012) 28:3 Space Pol'y 154 at 156.
96 *Ibid.* USSPACECOM's SSA sharing practices are further explored in Chapter 4.
97 Ailor, *supra* note 26 at 308.
98 Edward Lu, "A Moore's Law for space" (29 January 2024), online: <spacenews.com/moores-law-space/>.
99 Namrata Goswami, "The Second Space Race: Democratic Outcomes for the Future of Space" (25 January 2022), online: <gjia.georgetown.edu/2022/01/25/the-second-space-race-democratic-outcomes-for-the-future-of-space>.
100 Theodore J. Muelhaupt et al, "Space traffic management in the new space era" (2019) 6:2 J Space Safety Engineering 80 at 80.
101 *Ibid* at 81. Some fully functional satellites, known as "cubsesats," can be as small as 10 centimeters in size.

constitutes a majority of all operational satellites in orbit today.[102] Similarly, the launch market, once characterized by exorbitant spending on large and powerful rockets, has been revolutionized by SpaceX's developments in reusable rocketry by redesigning their supply chain and incorporating commonality of design.[103] Whereas NASA spent roughly $152 million USD per launch in the early 2020's, SpaceX's Falcon 9 launch in 2022 cost $62 million, a price that CEO Elon Musk expects to further decrease.[104] The combination of large-scale investments and technological advances in propulsion, sensors, and materials has enabled the space economy to take off to unchartered levels.[105] This will continue as private entities look to capitalize on all aspects of the space industry from space settlements to space mining, and everything in between.[106] Between debris aggregation and new entrants into space activity, the continuous accumulation of objects in useful regions of space such as LEO threatens its sustainability and demands corrective action now. The international community at large must intervene to manage this issue and facilitate safe and organized space operations.

e. Contemporary Comparisons

The fundamental premise of STM is neither novel nor groundbreaking. The concept of "traffic management" has been implemented in all other modes of transportation such as land, sea, and air for centuries. As space is considered an international common,[107] scholars often look to how other international commons are governed as comparisons for managing traffic in space. This section examines the systems of airspace and maritime traffic management as potential framework models for STM.

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[102] Foust, *supra* note 28.
[103] Michael Vlismas, *Elon Musk: Risking it All* (London: Jonathan Ball Publishers, 2022) at 151.
[104] *Ibid* at 152.
[105] Muelhaupt, *supra* note 100 at 80 and 86.
[106] Vlismas, *supra* note 103 at 132.
[107] George D. Kyriakopoulos, "Security Issues with Respect to Celestial Bodies" in Schrogl, *supra* note 10 at 344 [Kyriakopoulos, "Security Issues"].

1. *Air Traffic Management*

Although airspace is not regarded as an international common due to sovereign appropriation of territorial airspace,[108] aviation exhibits many functional similarities to space operations. The Earth's skies are wide and expansive, and certain flight paths resemble highly congested orbits, such as LEO. To illustrate, the world's busiest airport in 2023 was Hartsfield-Jackson International Airport in Atlanta, Georgia, which orchestrated approximately 3,000 daily flights from the airport's control towers.[109] This amount of air traffic and the dangers it poses if it were not organized can be analogized to highly trafficked LEO orbits. Air traffic controllers facilitate safe air transport by effectively coordinating with pilots on the ground and in the sky.[110] They accomplish this by following technical procedures that guide aircraft along their designated flight paths, ensure they avoid hazardous flight paths, and mitigate collisions when traffic is heavy in a particular airspace.[111]

This system of international air traffic control is well-established and governed by internationally developed standards and recommended practices born out of the widely adopted Chicago Convention and its subsequent legal instruments.[112] The Convention charges the International Civil Aviation Organization (ICAO) with the international coordination and development of safe air navigation techniques and all other aspects of international civil aviation.[113] Notwithstanding the fact that individual national governments are responsible for establishing air traffic control (ATC) rules, the Chicago Convention and its creation of ICAO

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[108] *Convention on International Civil Aviation*, 7 December 1944, 15 UNTS 295 at art 1 [*Chicago Convention*].
[109] Noah Bovenizer, "The top 10 busiest airports in the world" (13 March 2024), online: <airport-technology.com/features/the-top-10-busiest-airports-in-the-world/>.
[110] NATCA, "What is an Air Traffic Controller?" (last accessed 1 September 2024), online: <natca.org/education/what-is-an-air-traffic-controller/>.
[111] Francis Schubert, "Air Traffic Management" in Pablo Mendes De Leon, ed, *Elgar Concise Encyclopedia of Aviation Law,* (Northampton, MA: Edward Elgar Publishing, 2023) 43 at 43-45.
[112] *Ibid.* at 43.
[113] *Chicago Convention, supra* note 108 at art 37.

paved the way for international collaboration towards an effective and well-integrated ATC system.[114] Even in international airspace, which is more akin to outer space given the prohibition against nationally appropriating space[115], ICAO has established methods for ATC operations via Flight Information Regions in order to ensure safe passage.[116] As a result, air traffic can be managed and controlled in a safe and effective manner at any location on Earth due to the consistent recognition of globally standardized procedures.

The ICAO and Chicago Convention models provide a gold-standard reference for a top-down STM regime. However, as discussed below, direct replication of this structure, or ICAO's absorption of STM is not feasible due to the vastly different characteristics between air and space domains and differences in the traffic conditions therein.

2. *Maritime Traffic Management*

Similar to the system of air navigation, the world's oceans, while vast and expansive, function via a system that manages maritime traffic. Maritime traffic management is more fragmented than air traffic; however, in 1948, the UN established the International Maritime Organization (IMO) to serve as a specialized agency responsible for regulating maritime transport.[117] The IMO has best achieved its mission by adopting the 1972 Convention on International Regulations for Preventing Collisions at Sea (COLREGs), and the 1982 UN Convention on the Law of the Sea (UNCLOS). COLREGs is specific to maritime traffic coordination and establishes minimum standards for avoiding collisions at sea.[118] It provides 41

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[114] Ermanno Napolitano, "The Chicago Convention as a Self-Contained Regime" (2018) 43 Ann Air & Sp L 55 at 83.
[115] *Outer Space Treaty*, *supra* note 13 at art II.
[116] Napolitano, *supra* note 114 at 90.
[117] IMO, "Brief History of IMO" (last accessed 4 September 2024), online: <imo.org/en/About/HistoryOfIMO/Pages/Default.aspx>.
[118] *Convention on the International Regulations for Preventing Collisions at Sea*, 20 October 1972, 1050 UNTS 16 [*COLREGs*].

different technical provisions aimed at ensuring maritime safety as ships interact with Vessel Traffic Services (VTS) which help them navigate the seas, and in particular, areas of sensitive, hazardous, or high-density maritime traffic.[119] Furthermore, Rule 1 of the COLREGs states that its provisions apply in the high seas, thereby ensuing traffic is managed on international waters in areas where no state can assert its jurisdiction or sovereignty.[120] Accordingly, as with the Flight Information Regions in aviation, COLREGs ensures global application of its sea traffic scheme. Currently, there are over 500 VTS locations worldwide that operate subject to the implementation of COLREGs provisions at the national level.[121] However, there is discussion within the IMO to centralize VTS services worldwide.[122] In contrast, UNCLOS is a more comprehensive instrument akin to the Outer Space Treaty that addresses a range of issues related to maritime navigation including protection of the marine environment during seafaring operations.[123] As with the Chicago Convention, COLREGs and UNCLOS leave it to states to enact domestic laws and enforcement procedures to meet their requirements. Nevertheless, the cooperative efforts in establishing rules for the seas have proven quite successful—a model which draws analogies to space.

3. *Distinguishing STM from the Air and Sea*

Despite these highly functional systems governing Earth's air and sea traffic, no analogous structure exists to manage the increasing amount of space objects, even though space exploration is approaching its 75th anniversary. While many have sought STM models based on

[119] *Ibid.*
[120] *Ibid* at rule 1.
[121] Fulko van Westrenen & Gesa Praetorius, "Maritime traffic management: a need for central coordination?" (2014) 16:1 Cognition, Technology & Work 59.
[122] *Ibid* at 59-69.
[123] *United Nations Convention on the Law of the Sea*, 10 December 1982, 1833 UNTS 3 at part VII [*UNCLOS*].

ATC and VTS systems, translating these to the extraterrestrial realm is not so simple for multiple reasons.

First, spacecraft operate at substantially faster speeds than aircraft, and certainly ships. It takes a satellite in LEO anywhere from 90-120 minutes to orbit the Earth, equating to approximately 25 times the speed of a jet aircraft.[124] While air and sea traffic typically have time to identify or be notified of nearby traffic, space objects do not share that same luxury. As discussed in Chapter 4, the DoD's collision avoidance monitors aim to identify potential conjunctions up to 72 hours in advance of a near approach, but this is not always possible, especially in the case of space debris or objects too small to be detected by ground-based SSA capabilities.[125]

Second, planes and ships have the benefit of on-board operators who can visually observe approaching hazards and responsively execute avoidance maneuvers. Although accidents still occur in aviation and on the sea, the benefit of having an onboard pilot who can observe and react to dangerous or unexpected situations cannot be underestimated. Except for the few crewed spacecraft, space objects do not have humans onboard that can maintain visual awareness of their surrounding environment. Even then, avoiding collisions with undetectable space objects is extremely difficult for space pilots as evidenced by the 177 impact features found on the space shuttle throughout its lifespan.[126] The process for responding to hazardous situations in space takes time as it requires operators to first be notified of a pending threat, and then react to

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[124] Sanat Kaul, "Integrating Air and Near Space Traffic Management for aviation and near space" (2019) 6:2 J Space Safety Engineering 150 at 151.
[125] *Ibid.*
[126] Hall, *supra* note 63 at 3.

it by remotely maneuvering the object out of danger.[127] This thesis argues that AI can assist with this process, assuming the proper legal and ethical parameters are in place.

Third, as Chapter 5 will discuss, outer space is occupied with millions of pieces of uncontrollable space debris, only a fraction of which are large enough to be detected and tracked by SSA radars.[128] This is not a variable that ships or planes must contend with. In the event of damage or destruction, aircraft and ships do not typically linger in the airspace or shipping lanes for extended periods, posing a hazard to other traffic. Even in the rare cases of unpredictable conditions that aircraft and ships may encounter, such as severe storms and wildlife, these are relatively small in number and far less threatening than the massive amount of space debris polluting outer space.

Finally, history after the 1970's has demonstrated that reaching a binding international agreement on matters pertaining to space operations is difficult from a geopolitical standpoint.[129] A primary reason for this is the dual-use nature of space objects, which are capable of performing both military and civilian functions from the same space object, or even simultaneously.[130] The potential for dual-use capabilities to erode trust and impede cooperation in space is a significant concern that hinders progress in resolving critical issues such as orbital congestion, which has a detrimental impact on all space actors.[131] This is exacerbated by increasing ideological diversity in the space environment as there are more space-capable and space-interested states than ever before.[132] Making the distinction between civilian and military

[127] Morin, *supra* note 62 at 26.
[128] ESA, "Space Environment Statistics", *supra* note 5.
[129] Ram S. Jakhu & Joseph N. Pelton, "Introduction to the Study of Space Governance" in Jakhu, *supra* note 48 at 3-4.
[130] Kyriakopoulos, "Security Issues", *supra* note 107 at 346.
[131] Brian Weeden, "Overview of the legal and policy challenges of orbital debris removal" (2011) 27:1 Space Pol'y 38 at 42 [Weeden, "Debris Removal"].
[132] Jack Wright Nelson, "The Artemis Accords and the Future of International Space Law" (10 December 2020) 24:31 Am Society Intl L Insights 1 at 5.

functions is far easier when it comes to air and maritime activities. Ultimately, the treatment of space as a military domain has contributed to strategic competition and mistrust among nations, hindering consensus and the political will to establish a cooperative space traffic management system.[133]

f. Conclusion

Although space traffic has been monitored since the beginning of space exploration, the necessity for its management is largely a 21st century development that is becoming increasingly urgent. The risk of space collisions presents a significant potential for disruption on Earth, as well as the possibility of sparking international conflict. Given the increasing amount of space activity and society's reliance on space infrastructure, it is no longer feasible to maintain a void in STM in the context of the NewSpace age. Just as there is no single entity that is responsible for this problem, there will be no single solution, and the debate for the most effective way to alleviate this problem continues.[134]

Chapter 2: Comprehensive Literature Review

While the air and sea benefit from robust international regulatory frameworks that have evolved to keep pace with technological advancements in those domains, space law has not developed in similar fashion. The distinctive nature of space makes it considerably challenging to simply copy-and-paste traffic management systems from the air and sea. In light of these considerations, a significant debate has emerged within academic and scientific circles regarding potential technical and legal mechanisms to manage space traffic. Furthermore, if such mechanisms exist, the question then becomes how to organize a system that promotes safe and

[133] Brian G. Chow, "Space Traffic Management in the New Space Age" (2020) 14:4 Strategic Studies Q 74-109 at 86-90.
[134] Muelhaupt, *supra* note 100 at 86.

efficient STM without unduly infringing upon the freedoms within Article I of the Outer Space Treaty.

As the STM problem is multifaceted, so too are the solutions proposed to address it. These solutions may be technical, legal, or a combination of both. This chapter presents a review of the literature surrounding various proposals, illustrating a wide array of possibilities that could contribute to the development of a productive STM regime.

a. Defining STM

As discussed in Chapter 1, there is no consensus among international stakeholders on the precise definition of STM, complicating efforts to formulate global policies towards it. Jakhu and Pelton suggest that various levels of altitude present different traffic concerns, therefore what STM means depends on the area of airspace, near space, or outer space that one is discussing.[135] In a sense, congestion experienced in LEO consists entirely of space objects, whereas in the sub-orbital "Protozone," many space objects (including debris) might burn up, but high-altitude aircraft, including unmanned aerial vehicles, weather balloons, and some supersonic planes operate without issue.[136] The authors recognize that the absence of a clearly delineated boundary between airspace and outer space complicates assigning different STM parameters, as different entities may have varying interest in regulating activity at varying altitudes.[137] This is a point well made. As the sky ascends into space, the characteristics of various altitudes should be treated differently. It is prudent that extra caution be exercised in areas where humans may be frequently present, especially as upper atmospheric flight and space tourism become more popular in the coming years. At a point in the future where these activities are frequent, traffic

[135] Jakhu, "STM for Near-space", *supra* note 48 at 315.
[136] *Ibid* at 324.
[137] *Ibid*.

management may have to address prioritizing space vehicles in these altitudes. Similarly, since LEO is highly polluted with space debris, such pollution should be accounted for when considering STM measures in the region, whereas STM procedures in other less polluted areas of space may place consider less of a priority. This thesis acknowledges these distinctions and that various concerns evolve over time, however, focuses its analysis on STM in LEO because it is the most utilized and congested area of space at this juncture.

Pelton subsequently presents the argument that defining STM not only recognizes the necessity for different approaches at varying altitudes, but also a clear distinction between space traffic control and debris mitigation.[138] He argues that inherent in "management" is the ability for space objects to be controlled or managed, therefore STM should apply only to active space debris, and omit space debris which cannot be controlled.[139] Therefore, he suggests that discussions on STM focus on developing global SSA programs and mechanisms for exchanging SSA data on active space objects between relevant stakeholders.[140] Pelton proposes that the issue of space debris be addressed as a distinct matter due to its inert nature and the inability to maneuver it from Earth.[141] He maintains that debris removal and on-orbit servicing initiatives are still in their infancy, insinuating that they and should be addressed separately from SSA, which has been a long-standing practice and simply requires enhancement.[142] While he may be correct on the timing of technological developments, given that STM's objective is to avoid collisions, tracking, monitoring, and mitigating space debris is as equally important within an STM system as SSA for active objects. Because both debris and active space objects present a

[138] Pelton, *supra* note 19 at 96.
[139] *Ibid* at 97.
[140] *Ibid*.
[141] *Ibid*.
[142] *Ibid.*

risk of collision in space, this thesis argues that a comprehensive STM system *must* address both types of space objects in order to be truly effective in making the space environment safe and sustainable.

Verspieren is unequivocal in his criticism of the term STM, particularly the "management" component, and makes a case for its complete elimination.[143] He asserts that the majority of initiatives aimed at developing an STM solution concentrate on voluntary coordination and the promotion of non-binding behavioral norms.[144] He argues that these approaches do not align with the conventional definition of "management" which insinuates submission to an authority.[145] He observes that the title of SPD-3, "National Space Traffic Management Policy," is deceptive in that SPD-3, like the majority of STM proposals, is primarily concerned with SSA and safety coordination rather than the actual management of space.[146] Sensing his level of frustration over the lack of true "management" of space, the resolution should not be to simply re-label current efforts, but to advocate for their conversion from mere coordination to an actual system of operational management. Coordination is undoubtedly one aspect of STM, however there must be acceptance of rules that actually manage space (colloquially referred to as "rules for the road") to maximize the ability for space objects to continue functioning in crowded orbits. A set of rules that address parameters such as deciding who must move when two items are headed towards collision; or the maintenance of minimum distance between satellites; or limiting the ability of large constellations to intersect with crowded regions of space, is interdependent with tracking and safety operations. Accordingly, an

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143 Verspieren, *supra* note 49 at 4.
144 *Ibid.*
145 *Ibid*.
146 *Ibid*.

STM system must actually serve to manage traffic as opposed to simply encouraging parties to coordinate about it so as to adequately address the problem and create a safer space environment.

The international community's failure to adopt definitions for a variety of important space terms is well documented.[147] That STM is one of these terms is unfortunate as it contributes to the lack of meaningful action towards managing space congestion on a cooperative global scale. Even the LTS Guidelines, which are clearly oriented at fostering safe traffic in orbit, failed to use the term or give it a definitive meaning that would motivate space actors to implement behaviors and norms in the name of STM.

b. Technical Resolutions for STM

Various authors have investigated potential solutions for managing space traffic with the objective of reducing the probability of collisions. Two categories of technical resolutions have emerged to meet this objective: enhancing the ability of active objects to safely navigate through space, and reducing the impact of debris in orbit. This thesis posits that AI represents the optimal solution for facilitating these processes. However, it is beneficial to examine the alternatives that have been put forth in order to gain insight into the rationale behind the assertion that AI is the most effective approach. It is also relevant to consider these alternatives and the legal difficulties they present.

1. *Keep Out Zones*

One proposed method for avoiding conjunctions is the establishment of safety zones and/or designated traffic zones in crowded or high-value orbits. Muelhapt et al. proffer that mandating a safe distance between satellites, particularly large satellite constellations, and neighboring objects will minimize opportunities for collision.[148] They also advocate for

[147] See, Cheng, "Definitional Issues", *supra* note 36.
[148] Muelhaupt, *supra* note 100 at 86.

establishing a "human flight zone," which would be a special region that is most optimal for spacecraft operations from which other space objects would be specifically excluded.[149] The authors model the idea of safety zones after the airspace near airports wherein, stringent regulations are implemented due to the heightened risk of collision near airports as compared to the open sky.[150] The concept of establishing a safety zone to avoid harmful interference was adopted in the 2020 Artemis Accords, an agreement between the US and other like-minded nations designed to establish norms of responsible behavior in space.[151] To date, the implementation of space safety zones has yet to occur, and their practical applications remain untested.

Logically, the notion of safety zones would be effective if adhered to as preventing space objects from getting too close to one another is an optimal solution for avoiding collisions, at least between active space objects. From a legal perspective, these safety zones present a challenge when juxtaposed against states right to freely use space. Harrington recognizes this concern, noting that if safety zones were to be treated as "keep out" zones, it could potentially contravene the freedom of access to, and use of space enshrined in Article I of the Outer Space Treaty.[152] The question that must be considered in this debate is what type of limitations, if any, spacefaring nations believe may be placed on Article I's provisions. This debate that will not be addressed in this thesis, however similar considerations are raised by Muelhapt et al. who propose that an appropriate STM authority similar to the ITU could dictate the application of

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[149] *Ibid*.
[150] *Ibid*.
[151] *The Artemis Accords: Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroids for Peaceful Purposes*, NASA, 13 October 2020, online(pdf): <nasa.gov/specials/artemis-accords/img/Artemis-Accords-signed-13Oct2020.pdf>.
[152] Andrea J. Harrington, "Due Regard as the Prime Directive for Responsible Behavior in Space" (2023) 20:1 Loy U Chicago Intl L Rev 57 at 79.

such safety zones if such a practice received consensus of the international community.[153] Moreover, safety zones do not take into account the potential danger posed by space debris, which lacks the capacity to evade entry into a designated safe space.

2. <u>*Transponders*</u>

Kaul proposes licensing requirements for LEO-bound space objects that mandate they carry transponders to continuously report the object's location to space traffic controllers who can then carry out ATC like functions.[154] He notes that technologies of this nature have been tested and were successfully detected from LEO, yet acknowledges that they increase launching costs and operating expenses of space objects.[155] As Article VI of the Outer Space Treaty ascribes authorization for space activities to launching states, an effort to make licensing contingent on transponder use would require development and implementation at the domestic level which could lead to inconsistent practices and incompatible methods of data collection. For example, technological inequalities among spacefaring nations would likely result in states developing and using different levels of transponder technologies and data security measures so as to protect sensitive tracking information from bad actors or adversaries. Similarly, states could refuse to place transponders on sensitive security or defense space objects out of fears that adversaries might gain access to the tracking information. If these types of space objects were excepted from transponder requirements, it would breed further distrust and discord within the space community. Nevertheless, Kaul suggests that the installation of transponders on space objects will enhance their capacity for being tracked while in orbit and in integration with air traffic during launch and re-entry phases of space missions.[156]

[153] Muelhaupt, *supra* note 100 at 86.
[154] Kaul, *supra* note 124 at 151.
[155] *Ibid* at 153.
[156] *Ibid*.

3. *Debris Clean-up*

The subject of space debris as it pertains to STM has received widespread attention among scholars. Chapter 5 comprehensively examines space debris as a component of STM. However, for the purposes of this literature review, it is important to highlight two primary means that have developed for dealing with space debris. These include debris removal and debris mitigation. Carns posits that active debris removal (ADR), which entails the physical removal of a state's object from orbit, presents significant legal challenges in that under the existing space law framework states retain jurisdiction and control over their space objects through eternity.[157] Accordingly, it would be unlawful for states to remove others' debris without their consent. However, even if a state were only focused on its own debris, identifying the owner of space debris is extremely difficult, if not impossible, for fragments smaller than 10 centimeters in size. Carns therefore proposes that as private enterprises develop the capability to remove these tiny debris fragments from orbit, it should become instant international customary law that this removal can be done without requiring consent from the launching states.[158] The effect of such a practice, though unlikely, would be the quick and large-scale cleanup of space. Ailor emphasizes the benefits of removing larger debris, proposing that expelling one large piece of debris from space can reduce the risk of future collisions as much as decades of mitigation practices.[159] Locke et al. argue that the financial incentive for deorbiting space debris is cost-effective when compared with the alternative of having to pay liability damages in the event of a conjunction decades after the object is no longer functional.[160] This is logical, as the longer

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[157] Marc G. Carns, "Consent Not Required: Making the Case That Consent Is Not Required under Customary International Law for Removal of Outer Space Debris Smaller than 10CM" (2017) 77 AFL Rev 173 at 175 [Carns, "Consent Not Required"].
[158] *Ibid* at 225-228.
[159] Ailor, *supra* note 26 at 316.
[160] Jericho Locke et al, *Cost and Benefit Analysis of Mitigating, Tracking, and Remediating Orbital Debris* (Washington, DC: NASA Office of Technology, Policy, and Strategy, May 2024) at 53.

debris remains in orbit, the greater the probability that it may collide with another space object, resulting in damage or destruction. Even in the absence of a conjunction, space operators must expend costly fuel to maneuver around space debris, which is estimated to cost millions of dollars over the life of a satellite.[161] Aside from ADR activities, Nassisi et al. advocate for the implementation of more rigorous debris mitigation regulations during the development phase of space objects.[162] They argue that "eco-designed" satellites composed of compostable materials will facilitate space sustainability by minimizing how much debris the satellites generate once in orbit or at the end of their operational lives.[163]

c. Legal Framework for STM

The development of a legal framework to oversee an STM system has been a topic of considerable discussion among space scholars. Hitchens examines the idea of adopting a universal code of rules for STM.[164] While there are various international agreements promoting peripheral STM concepts such as the IADC Debris Mitigation Guidelines and UNCOPUOS' LTS Guidelines, there is no agreement or set of guidelines that encourage space faring nations to work towards a comprehensively organized STM system. She suggests that UNCOPUOS might be an appropriate leader for constructing an STM system modeled off of the ITU's management of GEO, but is not optimistic that states would agree on methods to enforce an STM code of conduct.[165] She instead recommends that space faring nations form an international task force to build off of the IAA's work and develop a robust code of conduct focused on space navigation and traffic management.[166] Upon completion of this framework, the task force would present a

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[161] *Ibid* at 54.
[162] Annamaria Nassisi et al, "Space Debris Mitigation Systems: Policy Perspectives" in Schrogl, *supra* note 10 at 1084.
[163] *Ibid*.
[164] Hitchens, "Debris, Traffic Management, and Weaponization", *supra* note 82.
[165] *Ibid at 178.*
[166] *Ibid*.

plan to UNCOPUOS for adoption of a global STM policy.[167] Her roadmap for a STM code of conduct is a theoretical step in the right direction; however, any agreement on a truly comprehensive STM system will require buy in from the dominant space powers: the US, Russia, and China. Unfortunately, these nations divergent ideologies and national space strategies might limit how willing they are to cooperate with each other and/or submit to a code of conduct that limits how they can use valuable orbits. With this in mind, Hitchens recognizes that any form of STM regime would, to some extent, restrict the free use of space; something that those seeking to assert space superiority are unlikely to receive favorably.[168] Pic et al. suggest that a new multilateral agreement on STM will defend against power asymmetry from the superpowers and make it more difficult for one or more of them to unilaterally impose their will upon other smaller or developing space actors.[169]

Others such as Kaul and Sadat[170] recommend that ICAO assume a more active role in this area by collaborating with UNCOPUOS to assume responsibility for STM. Kaul proposes that an ICAO could establish a new annex for LEO and modify existing air policy to include standards and recommended practices for LEO traffic management.[171] Despite the fact that ICAO and UNCOPUOS have engaged in joint discussions on the subject of near-space traffic, the notion that the ICAO would extend its authority to LEO, which is well beyond the limits of "airspace," is difficult to imagine. Not only does the Chicago Convention not authorize ICAO to oversee space activity, ICAO does not have the resources or expertise to meet the demands of

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[167] *Ibid*.
[168] *Ibid*.
[169] Pauline Pic, Philippe Evoy & Jean-Frederic Morin, "Outer Space as a Global Commons: An Empirical Study of Space Arrangements" (2023) 17:1 Intl J Commons 288 at 297.
[170] Sadat & Mir Sadat & Julia Siegel, Space Traffic Management: A Time for Action, (Washington, DC: Atlantic Council, August 2022) 1 at 7.
[171] Kaul, *supra* note 124.

today's space age.[172] While ICAO may have some interest in space traffic management, it is more prudent to treat ICAO as a starting point for an independent space traffic control agency, rather than force it to assume responsibility for a subject matter beyond of its area of expertise.

Dodge predicts that private organizations may assume a primary role in the administration of STM.[173] He believes this would prove beneficial for the space environment as non-governmental entities could represent all stakeholders without being subject to bureaucratic or political barriers that often hinder progress.[174] Private STM oversight raises interesting questions from an international law perspective, particularly when considering that states are the subjects of international law and space is regarded as an international common. Assigning STM oversight to a non-governmental entity would require that states submit to this entity's authority, which could include limitations on when and where they can conduct certain space activities. Furthermore, concerns over the non-governmental entity's impartiality and prioritization of space behaviors might create reluctance among major space faring nations to willingly enter into such a system.

d. AI as an STM Solution

Lastly, since this thesis proposes AI as the optimal solution to STM, it is important to review recent literature discussing its employment in space. Martin and Freeland recognize the benefits that AI can provide for functions such as remote sensing which is crucial in studying environmental change, enhancing national intelligence and security, and tracking aircraft tracking.[175] They note the potential of AI to assist with STM, particularly in the areas of

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[172] Jakhu, "STM for Near-space", *supra* note 48 at 321.
[173] Michael Dodge, "The Divergent and Evolving Legal Pathways of Future Space Traffic Management Collaboration" (Delivered at the Space Traffic Management Conference, Daytona Beach, FL, 13 November 2015), online(pdf): <commons.erau.edu/cgi/viewcontent.cgi?article=1082&context=stm>.
[174] *Ibid* at 14.
[175] Anne-Sophie Martin & Steven Freeland, "The Advent of Artificial Intelligence in Space Activities: New Legal Challenges" (2021) 55:101408 Space Pol'y 1 at 4.

collision avoidance, management of large satellite constellations, and processing conjunction alerts in LEO.[176] From a legal perspective, they caution that AI used for space activities must remain subject to the series of outer space treaties, and international law at large; therefore, it falls upon states to ensure that AI operates in accordance with legal standards.[177] Gonzalo and Colombo assert that AI is a "remarkable" tool for addressing the increasing demand for data analysis to prevent collisions in space.[178]

Others are quick to share concerns about using AI for STM. Nag et al. question how non-AI participants will fit into an AI-dependent STM system.[179] They points out that while international law grants free use to all states, it does not demand that all countries operate in space in the same manner; therefore, STM systems must accommodate both AI-enabled spacecraft and those operated by humans on Earth.[180] This is a legitimate point. Given that many active space objects pre-date the AI boom, an STM system must account for non-AI objects whose remote operation requires humans to receive, interpret, and react to space data. In the event of a potential conjunction, this could take time, whereas in situ AI might act autonomously in real-time, leading to issues over whether human operators are making decisions based on outdated data. The resolution is that any STM framework must not solely be focused on AI, but incorporate provisions for both autonomous and human operated space objects.

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[176] *Ibid* at 5.
[177] *Ibid* at 7.
[178] Juan Luis Gonzalo & Camilla Colombo, "Collision Avoidance Algorithms for Space Traffic Management applications" (Delivered at the 71st Astronautical Congress, Dubai, 12 October 2020), online(pdf): <re.public.polimi.it/bitstream/11311/1148386/1/GONZJ02-20.pdf> at 8.
[179] Sreeja Nag et al, "System Autonomy for Space Traffic Management" (Delivered at the 37th Digital Avionics Systems Conference, London, 23 September 2018), online(pdf): <ieeexplore.ieee.org/document/8569343> at 1.
[180] *Ibid*.

Kyriakopoulous et al. focus on a separate concern, namely the question of liability for activities conducted by AI in space.[181] He argues that AI-based space operations raise complex liability concerns, particularly when the Liability Convention is juxtaposed against domestic legislation pertaining to liability for AI-based activities.[182] For example, he recalls that the EU favors strict liability in cases where using AI technology has a significant potential to cause harm.[183] In contrast, the Liability Convention only applies a strict liability standard when a space event results in damage on Earth, and otherwise apportions liability based on fault.[184] These divergent approaches are problematic in that they hold AI systems to different degrees of liability, which will inevitably lead to confusion and conflict unless addressed by the international community. Long also expresses concerns about AI's interplay with the Liability Convention for incidents in space, noting that attributing fault, and in particular, evaluating the elements of foreseeability and proximate cause is a difficult task that will be made only more challenging when space objects are capable of autonomous action.[185]

Massingham observes an even more serious consequence of AI autonomy, namely that the actions of an AI-enabled space system such as an unanticipated maneuver or interference with another space object, could potentially be regarded as a use of force under the law of war, and drag relevant states into international conflict.[186]

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[181] George D. Kyriakopoulos et al, "Artificial Intelligence and Space Situational Awareness: Data Processing and Sharing in Debris-Crowded Areas" (Delivered at the 8th European Conference on Space Debris, Darmstadt, GE, 20 April 2021), online: <conference.sdo.esoc.esa.int/proceedings/sdc8/paper/118> at 7-8 [Kyriakopoulos, "AI and SSA"].
[182] *Ibid*.
[183] *Ibid* at 7.
[184] *Liability Convention, supra* note 38 at arts II and III.
[185] George Anthony Long, "Artificial Intelligence and State Responsibility under the Outer Space Treaty" (2018) 61 Proceedings Intl Inst Space L 709 at 718.
[186] Eve Massingham & Dale Stephens, "Autonomous Systems, Private Actors Outer Space and War: Lessons for Addressing Accountability Concerns in Uncertain Legal Environments" (2022) 22:3 Melbourne J Intl L 276 at 295.

Chapter 3: AI as a Space Traffic Solution

"Data is the new oil, but just like crude, but if unrefined it cannot really be used…"[187]

Artificial intelligence offers a promising solution to assist with STM while simultaneously enabling spacefaring nations to fulfill their existing international legal obligations. This chapter provides a brief overview of AI and examines international legal frameworks dedicated to AI and their relevance to outer space.

a. What is AI?

Understanding AI begins by first understanding the definition of intelligence.[188] The Oxford English Dictionary defines intelligence as "the faculty of understanding."[189] To understand something, one must acquire knowledge and then apply said knowledge; as obtaining knowledge without actually using it is merely data collection.[190] Once this process is complete, it can be asserted that a person has gained an understanding, or learned something, and therefore has intelligence about a particular thing.[191] Artificial intelligence involves enabling machines to undergo that learning process, and then generate a conclusion or make a decision.[192] The term AI encapsulates machine learning, a technique where computers use algorithms to transform data they are given, or have acquired, into rules for action, similar to how humans use knowledge to govern our decisions.[193] Through this process, AI-enabled machines interact with the world to collect data and formulate courses of action to best achieve a pre-programmed and desired

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[187] Charles Arthur, "Tech giants may be huge, but nothing matches big data" *The Guardian* (23 August 2013), online: <theguardian.com/technology/2013/aug/23/tech-giants-data> *quoting* Clive Humby, mathematician (2006).
[188] Juan M. Lavista Ferres, William Weeks & Brad Smith, *AI for Good*, (Indianapolis: John Wiley and Sons, 2023) at ch 1.
[189] Oxford English Dictionary, "Intelligence" (last accessed 29 August 2024), online: <oed.com/dictionary/intelligence_n?tl=true>.
[190] Ferres, *supra* note 188 at ch 1.
[191] *Ibid*.
[192] Charlotte Hu, "A simple guide to the expansive world of artificial intelligence" (5 Feb 2023), online: <popsci.com/technology/artificial-intelligence-definition>.
[193] Ferres, *supra* note 188 at ch 1.

objective.[194] This constitutes machine autonomy, which means that AI systems can modify their inner states without external stimuli and exert control over their own actions without any direct intervention from humans (often referred to as "keeping humans out-of-the-loop").[195] When computerized, the learning cycle can effectively, efficiently, and objectively use data in ways that benefit human life.[196] It is important to note the difference between autonomous machines, as just described, and automated machines, which merely react in accordance with strict pre-programmed commands and do not have the ability to learn and adapt based on new data.[197]

As humans progress through the learning cycle, the brain filters out a majority of the data we experience throughout the day. If our brains retained every smell, sound, and optical perception made all day, every day, it would be quickly overwhelmed, despite the brain being considered the most complex object in the universe.[198] Instead, the brain selectively retains only the small portion of data that is beneficial, and the rest is subconsciously purged. Machines, however, can facilitate data collection, categorization, and analysis much quicker than humans and in a replicable, consistent fashion without the need to purge.[199]

b. The AI Boom

The term "AI" was coined in 1956 by researchers from Dartmouth University seeking to demonstrate that machines programmed with complex algorithms could learn in a manner similar to humans.[200] Despite its conception nearly 70 years ago, AI's current boom is attributable to two critical developments. First, the quantity of existing data and the capacity to store it have

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[194] Long, *supra* note 185 at 711.
[195] Ugo Pagallo, Eleonora Bassi & Massimo Durante, "The Normative Challenges of AI in Outer Space: Law, Ethics, and the Realignment of Terrestrial Standards" (2023) 36:23 Philosophy & Tech 1 at 7.
[196] Ferres, *supra* note 188 at ch 1.
[197] Kathiravan Thangavel et al, "Artificial Intelligence for Trusted Autonomous Satellite Operations" (1 January 2024) 144:100960 Progress Aerospace Sciences 1 at 8.
[198] Ferres, *supra* note 188 at ch 1.
[199] *Ibid*.
[200] *Ibid*.

reached an all-time high, while costs associated with doing so have remained relatively low.[201] Secondly, processing power has reached unprecedented levels.[202] Within the space realm, AI has the potential to enable better traffic management as it can be used both onboard satellites and in ground systems for practical applications such as object recognition and tracking, collision detection, maneuver and avoidance, and even debris cleanup.

c. AI Concerns and Criticisms

AI's rapid data collection and analysis capabilities can be used to free up human resources, allowing people to focus more efficiently and effectively on high value tasks.[203] However, AI does not come free from controversy or challenges from practical and legal perspectives. Hollywood has dramatized AI concerns through depictions of robots taking over the world, or even more worrisome, killer robots bent on human extinction.[204] The reality of AI's current state is much less threatening. Nevertheless, it is vital that certain concerns are explored when implementing AI into space operations as even minor errors in its deployment could result in detrimental consequences.

The success of machine learning is contingent upon the quality of the initial code and data programmed into the machine.[205] These form the foundation upon which the machine will learn.[206] Incorrect or biased baseline data can lead the machine to produce a biased and undesirable result, which could have serious practical and legal consequences. For instance, if AI were trained to manage collision avoidance for a US satellite system but the underlying code

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201 *Ibid*.
202 *Ibid*. Nowhere is this more evident than the cell phones we carry in our pockets, which can process and store more data quicker and cheaper than the entire Apollo spacecraft could in the 1960s.
203 *Ibid*.
204 Janet Vertest, "NASA's Mars rovers could inspire a more ethical future for AI" *The Space Review* (9 October 2023), online: <thespacereview.com/article/4666/1%3E>.
205 Chapman University AI Hub, "Bias in AI" (last accessed 4 September 2024), online: <chapman.edu/ai/bias-in-ai.aspx>.
206 *Ibid*

only included data from the US space registry, the satellite would be effective at avoiding other US objects but remain highly vulnerable to colliding with space objects from other countries. This illustrates how AI bias can complicate STM instead of managing it (and highlights the need for global SSA sharing as discussed in Chapter 4). It is therefore essential that AI be developed, programmed, and trained based on thorough and accurate data so as to prevent errors in machine learning and avoid biases in the AI's decision-making process. In terms of STM applications, AI bias is a significant concern as it could easily lead to conjunctions and associated legal ramifications for causing damage in space. The following chapter provides a more detailed analysis of the legal issues that AI may generate regarding the Liability Convention.

Additionally, AI systems can learn undesirable shortcuts or discriminate if the underlying programming is biased, or if improper outcomes are not remediated by human intervention.[207] To illustrate, in 2024, scientists employed AI in a simulated wargame to learn how machines might be useful for military objectives.[208] Alarmingly, each of the five distinct AI models used in this experiment aggressively escalated to nuclear force.[209] From a human perspective, nuclear war is an unacceptable solution to a conflict. However, this experiment shows how machines, if not pre-programed with appropriate constraints, may find undesirable shortcuts as valid, rapid, and effective means to meet the objectives they are assigned. In an STM situation, AI seeking to mitigate the congestion of outer space could, if not properly developed or monitored, decide to de-orbit large functional satellites as a means of reducing overcrowding in space. This would be highly problematic and highlights the need for space-based AI to be carefully developed,

[207] Ferres & Weeks, *supra* note 188 at ch 1.
[208] Oceane Duboust, "AI models chose violence and escalated to nuclear strikes in simulated wargames" (last updated 23 February 2024), online: <euronews.com/next/2024/02/22/ai-models-chose-violence-and-escalated-to-nuclear-strikes-in-simulated-wargames>.
[209] *Ibid*.

narrowly trained, and closely monitored to ensure its actions reflect the desired goals and needs of outer space.

d. Promoting Ethical AI Use

In view of AI's emergence and the aforementioned concerns regarding machine learning, various countries and international organizations have begun establishing frameworks and guidelines to address the ethical, legal, and societal implications of AI. AI law is similar to space law in that it has not developed at the same pace as the technological aspects of the industry. The fear among some is that if AI is not regulated from the start, it will become too embedded in society that regulating it becomes nearly impossible.[210] Therefore, AI technology must immediately become a focal point in every area of law as developers are increasingly investigating ways to incorporate the technology into all aspects of society.

One of the first major initiatives to promote responsible AI use was the Montreal Declaration of 2018 wherein experts solicited input from over 500 citizens of all backgrounds on the social issues that may arise with AI's use.[211] The result was ten ethical principles to be considered by AI developers and users. Although the Montreal Declaration has only been opened for signature by individual citizens and private organizations, it has served as a model for future international AI frameworks by highlighting important aspects of ethical AI use.

2019 marked the first wide-scale international agreement on AI as the Organization for Economic Cooperation and Development (OECD) established AI principles that were later adopted by the G20.[212] These principles emphasize responsible stewardship of trustworthy AI

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[210] Vlismas, *supra* note 103 at 132.
[211] Université de Montréal, "Montreal Declaration for a Responsible Development of Artificial Intelligence" (last accessed 8 September 2024), online(pdf): <declarationmontreal-iaresponsable.com/wp-content/uploads/2023/04/UdeM_Decl_IA-Resp_LA-Declaration-ENG_WEB_09-07-19.pdf>.
[212] OECD, *Council Recommendation on Artificial Intelligence*, OECD/LEGAL/0449 (2024), online: <legalinstruments.oecd.org/fr/instruments/oecd-legal-0449#committees>.

including respecting human rights and ensuring fairness, transparency, robustness, and accountability in AI systems.[213] While the OECD principles are not specifically tailored to outer space, several of them are relevant to the legal obligations discussed in the Outer Space Treaty and Liability Convention, which are covered in Chapters 4-6.

A 2019 US Executive Order outlined several principles that the US federal government must adhere to when using AI.[214] Codified into law as the National AI Initiative Act, these principles include transparency, fairness, and non-discrimination, which are designed to foster public trust in AI technologies.[215] This order directed national defense leaders and NASA to prioritize the allocation of high-performance computing resources to AI-enabled applications.[216] In 2022, the Biden administration published an AI Bill of Rights which established out non-binding guidelines for American developers to follow when using AI.[217] These broad principles can be applied to AI's use in space; however, their primary focus is on protecting humans from potential AI-related harm.[218] Nevertheless, issues such as data privacy and discrimination are very relevant to outer space technologies employing AI for tasks like Earth observation and surveillance. Though these activities are not directly relevant to this thesis, it is worth noting them as an illustration of AI's versatility space.

In 2021, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) adopted recommendations on the ethics of AI, addressing issues such as data

[213] *Ibid*.
[214] *Maintaining American Leadership in Artificial Intelligence,* 84 Fed Reg 3967 (2019).
[215] US, HR 6216, *National Artificial Intelligence Initiative Act of 2020*, 116th Congress (enacted).
[216] *Ibid*.
[217] The White House, "Blueprint for an AI Bill of Rights: Making Automated Systems Work for the American People" (October 2022), online(pdf): <whitehouse.gov/wp-content/uploads/2022/10/Blueprint-for-an-AI-Bill-of-Rights.pdf>.
[218] *Ibid*.

governance, environmental impact, and sustainable development.[219] This represents the primary UN-associated framework focused on AI. UNESCO's guidelines are predominantly aimed at fostering ethical AI here on Earth; however, they do reference AI's use in space when discussing the importance of transparency and explainability in AI systems.[220] These particular principles encourage thorough scrutiny of AI technologies, thereby fostering the public's trust in its output. This is quite similar to a push within the space community to implement transparency and confidence building measures in space activities to ensure the domain is used exclusively for peaceful purposes.[221] Both AI technologies and space activities are often depicted in popular culture as mysterious and inaccessible to the common person. The lack of understanding in these areas can breed mistrust, which emphasizes the need for transparency in decision making processes. UNCOPUOS has asserted that enhanced transparency will build confidence between nations that space objects and space activities are being used for good, or perhaps more importantly, dissuade them from assuming space is being used nefariously.[222] The same logic applies to AI systems. UNESCO's guidelines also emphasize that member states should, in accordance with international law, assume legal responsibility for their AI systems, noting that responsibility and liability for decisions and actions of AI systems should always be attributable to the AI system's operator.[223] Like the OECD AI principles discussed above, these concepts of responsibility and liability reflect similar concepts in the international space law framework.

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[219] *Recommendation on the Ethics of Artificial Intelligence,* UNESCO, 41st Sess, UN Doc SHS/BIO/PI/2021/1 (2021), online(pdf): <unesdoc.unesco.org/ark:/48223/pf0000381137>.
[220] *Ibid* at 30.
[221] *Transparency and confidence-building measures in outer space activities,* UNGA, 72nd Sess, UN Doc A/76/65 (16 February 2017), online(pdf): <unoosa.org/res/oosadoc/data/documents/2017/a/a7265_0_html/A_72_065E.pdf>.
[222] See *Ibid*. See also Artemis Accords, *supra* note 152.
[223] UNESCO ethical AI guidelines, *supra* note 219.

Also in 2021, the European Union introduced the Artificial Intelligence Act which establishes a risk-based approach to govern how AI can be used.[224] The EU's approach categorizes the risk associated with AI use into three levels: unacceptable, high-risk, and applications not explicitly banned.[225] This approach prohibits unmonitored AI from being used in critical services that could endanger human livelihoods or encourage destructive behavior.[226] However, it enables AI's use in other areas that can provide benefit to human lives.[227] Among high-risk activities are aviation and the operation of critical infrastructure.[228] The Act defines "critical infrastructure" as an asset, equipment, a network, or a system necessary to support vital societal functions, economic activities, public health and safety, and so on.[229] Although the Act does not explicitly mention outer space, it could be confidently argued that AI-based STM systems are critical to EU infrastructure, and therefore, may be subject to stricter EU regulation. This could complicate establishing a global STM framework that incorporates AI technology. If the EU has more stringent limitations than other states on how AI can be used within critical infrastructure, a la functions supported by space activities, there could be significant discord in the levels of autonomy and human oversight proposed by various parties at the negotiating table.

To date, UNCOPUOS has not adopted any policy, guidelines, or legal framework on using AI in space.[230] In this context, it is essential to incorporate specific AI regulatory concerns such as transparency and data governance into frameworks concerning the sustainable use and

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224 EU, *Regulation 2021/0106 of the European Parliament and of the Council of 21 April 2021 laying down harmonized rules on artificial intelligence*, (2021) COM/2021/206 final. The Act was officially adopted on 13 June 2024 and codified as OJ, L 2024/1689 on 12 July 2024 [EU AI Act].
225 White & Case, "AI Watch: Global regulatory Tracker - European Union" (last updated 16 July 2024), online: <whitecase.com/insight-our-thinking/ai-watch-global-regulatory-tracker-european-union>.
226 *Ibid.*
227 *Ibid.*
228 European Parliament, "EU AI Act: first regulation on artificial intelligence" (last updated 18 June 2024), online: <europarl.europa.eu/topics/en/article/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence>.
229 EU AI Act, *supra* note 224 at annex III.
230 White & Case, *supra* note 225 at United Nations.

accessibility of outer space.[231] Nevertheless, as will be illustrated in the following chapters, there is a strong alignment between AI's ethical principles and the existing tenets of existing space law.

Chapter 4: STM Dissected [Part 1] – Enhanced Space Situational Awareness

"It's not enough to know the exact location of your satellites if you don't know where the rest are."[232]

Briefly returning to the idea of automobiles, if the local authority responsible for building roads was ignorant of traffic patterns, the resulting traffic system would be quite inefficient and incompatible with societal needs. Such a system would increase the risk of collisions and endanger vehicle occupants. This logic is analogous to space traffic. If spacefaring nations lack awareness of the presence, location, and trajectory of space objects, attempts at navigating and managing the densely populated orbital regions will be futile. Managing STM demands that space actors be able to detect and track space objects in order to avoid collisions or other harmful interference with ongoing space activities.

Space Situational Awareness refers to the ability to ascertain the location of a specific space object at any given moment in time.[233] Knowing the location of space objects is the foundation upon which any traffic system can be built. Tracking a space object enables operators to predict its future trajectory and avoid collisions. For a single object, SSA is relatively straightforward, as it involves collecting data on the object's speed and trajectory in order to anticipate its future position. However, it would be short-sighted for a space operator to limit their SSA to a single object's location considering that LEO contains thousands of active space

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[231] Kyriakopoulos, "AI and SSA", *supra* note 181 at 8.
[232] Swedish Space Corporation, "Debris and congestion – a future challenge in Space" (13 December 2022), online: <sscspace.com/debris-and-congestion-a-future-challenge-in-space/>.
[233] Nightingale, *supra* note 53 at 11.

objects, in addition to millions of pieces of uncontrollable debris. Consequently, gathering and analyzing SSA data necessitates that operators anticipate and predict potential conjunctions from any and all directions at all times. In light of this massive workload, NewSpace operators are developing methods for AI to monitor space traffic and manage the increasing burden posed by SSA and collision avoidance.[234]

From a legal perspective, using SSA to avoid conjunctions allows states to meet various obligations imposed by the Outer Space Treaty such as preserving the free use of space for all, avoiding harmful interference, and facilitating international responsibility for space activities through continuous supervision.[235] Furthermore, while SSA data is crucial for preventing collisions, it can also be used to determine liability for damage in orbit should it occur.[236]

a. Knowing the Space Environment

Tracking outer space activity is not a new practice. It has simply grown far more complex than early space pioneers could have ever imagined. Beginning with Sputnik's launch in 1957, spacefaring nations focused on monitoring the space capabilities of adversarial nations, largely out of concerns for national security.[237] As the Cold War drew to a close in the 1990s, and the volume of space traffic began to increase, the US Air Force developed a robust system for monitoring and cataloging space objects.[238]

Current SSA is largely derived from sensors and radars located in various locations around the world that monitor the skies and detect various space objects passing over their observable areas.[239] The US is the global leader in this field, with approximately 25 sensors

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[234] Muelhaupt, *supra* note 100 at 85.
[235] *Outer Space Treaty, supra* note 13 at arts I, VI, VIII, and IX.
[236] *Ibid* at art VII, and *Liability Convention, supra* note 38.
[237] Nightingale, *supra* note 53 at 11.
[238] Sturdevant, *supra* note 66 at 6.
[239] Nightingale, *supra* note 53 at 12.

distributed globally, including the powerful system called the "Space Fence" which processes over approximately 130,000 observations per day in LEO.[240] The data gathered by Space Fence sensors is fed into a catalog where it is used to calculate information about individual space objects' position, size, speed, emissions, etc.[241] Cataloging this data as space objects are detected by various sensors around the Earth at different times and locations allows observers to learn about an object's trajectory, and more important for STM purposes, predict where it is headed. As sensors have become more sophisticated over time, data collection, cataloging, and processing have become increasingly challenging, particularly in light of the growing volume of space activities over the past decade.

The US has traditionally managed this massive workload at its Joint Space Operations Center (JSpOC).[242] At the JSpOC, military personnel are tasked with analyzing satellite trajectories, detecting potential close approaches between space objects, and issuing collision warnings, otherwise known as alerts, to the objects' operators.[243] JSpOC's parameters for what qualifies as a "close approach" in LEO is when objects are forecast to pass within 1 kilometer of one another.[244] Assuming the requisite information is available, JSpOC typically alerts a space object's operator within 72 hours of the time of closest approach, providing information such as the size and speed of objects likely to collide in the near future, as well as a predicted time of encounter.[245] Despite JSpOC's critical role in tracking space traffic, it can only warn operators of potential collisions and has no authority over whether the operators take due considerations of

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[240] Sadat, *supra* note 170 at 9.
[241] Roger Mola, "How things work: Space Fence" Smithsonian Magazine, (February 2016), online: <smithsonianmag.com/air-space-magazine/how-things-work-space-fence-180957776/>.
[242] Wagner, *supra* note 89.
[243] *Ibid.*
[244] *Ibid.*
[245] *Ibid.*

the warnings, or react to them by maneuvering their objects out of harm's way. In effect, JSpOC serves the role of space traffic warning provider, rather than that of a manager.

Recent exponential growth within the space industry means that the amount of SSA data to be collected and analyzed has grown dramatically. For instance, in 2021, the Starlink constellation alone generated over 1,600 collision alerts per week.[246] In light of the fact that a large majority of the alerts issued by JSpOC relate to non-military space objects, SPD-3 directed that the military transfer these duties to a civilian agency within the Department of Commerce.[247] Other nations such as Russia and China have their own sources of SSA gathering, however there is no system for large scale data sharing between the world's leading SSA nations.[248] Ideally, the US shift away from treating SSA as a military function will pave the way for a more internationally cooperative approach to sharing SSA data. By de-emphasizing the military nature of SSA, and STM at large, it will build confidence that states are monitoring space objects for the benefit of all, instead of targeting adversary assets. In turn, better sharing of SSA data will help the international community hold accountable those who do use space for non-peaceful purposes, as all parties will have visibility on how others are using the cosmos.[249]

Private actors have also entered the SSA scene.[250] For example, the Space Data Association is a commercial entity that collects information on satellites, including their positional data and maneuver plans when shared by the object's operators.[251] Despite more

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[246] Tereza Pultarova, "Orbiting debris trackers could be a game changer in space junk monitoring" (6 September 2023), online: <space.com/orbiting-space-junk-trackers-to-prevent-satellite-damage>.
[247] P.J. Blount, "Space Traffic Management: Standardizing On-Orbit Behavior" (2019) 113 AJIL Unbound 120 at 124 [Blount, "STM"].
[248] *Ibid* at 122.
[249] Daniel A. Porras, "PAROS and STM in the UN: more than just acronym soup" (Delivered at 5th Annual Space Traffic Management Conference, Austin, TX, 27 February 2019), online: <commons.erau.edu/stm/2019/presentations/22/>.
[250] Nightingale, *supra* note 53 at 6.
[251] *Ibid* at 7.

entrants into the SSA field, there are currently no integrated systems that provide the same level of comprehensive situational awareness as those found in the air and maritime domains.[252] Moving forward, an international STM program that mandates SSA information sharing will be imperative due to the anticipated growth in the number of objects in space and the corresponding increase of SSA data. As with terrestrial vehicle traffic, the safest way to navigate space is for actors to be fully aware of the environmental conditions in which they are operating.

b. How Can AI Help?

1. *Detecting Objects in Space*

In 2016, a piece of space junk approximately 3 centimeters long collided with the solar panel of a European satellite, resulting in a 40 centimeter hole.[253] Fortunately, this did not impact the satellite's functionality, however engineers predict that if the debris had struck the satellite's main body, it would have been rendered useless.[254] This event highlights the fact that what we cannot see in outer space can still harmfully interfere with space activities as the speed at which objects travel through space renders even tiny items destructive. It also demonstrates the importance of detecting space objects as a foundational element of effective SSA.

AI can assist with this by performing observation tasks based on images collected from sensors located both on Earth and in orbit. AI is already being used to "look" for a variety of things such as individuals (via facial recognition software), cancer cells within human tissue,[255] and geological aspects of Earth from satellite images.[256] In turning AI's eyes to the skies,

[252] Sadat, *supra* note 170 at 8.
[253] Pultarova, *supra* note 246.
[254] *Ibid.*
[255] Mary Kekatos, "How artificial intelligence is being used to detect, treat cancer -- and the potential risks for patients" (21 June 2023), online: <abcnews.go.com/Health/ai-detect-treat-cancer-potential-risks-patients/story?id=101431628>.
[256] Thomas Graham & Kathiravan Thangavel, "Artificial Intelligence in Space: An Analysis of Responsible AI Principles for the Space Domain" (Delivered at the 74th International Astronautical Conference, Baku, 2 October 2023), online: <researchgate.net/publication/374419104> at 1.

scientists are sharpening the ability for AI technologies to comb through SSA data and detect space objects based on things like changes in energy levels and emissions that are otherwise extremely difficult to analyze.[257] Similarly, proposals have been made to equip satellites with sensors that can provide reviewable images to AI systems looking for small objects in orbit.[258] Morin likens these space-based sensors to those located on an aircraft that measure atmospheric conditions as planes traverse the sky.[259] Once an AI system identifies a space object, it can compare this data with existing space catalogs to enhance an operator's knowledge about the traffic their objects may encounter as they navigate in orbit.[260]

As outlined in Chapter 3, it is important to recognize that AI can be biased based on the information it is initially programmed with. In such instances, the output is less impactful or potentially distorted, which may lead to misleading results for AI-reliant operations. One notable limitation of current tracking systems is their inability to observe, track, and gather data on items, smaller than 10 centimeters, approximately the size of a softball.[261] Thus, despite extensive catalogs of space objects, such as the one maintained by JSpOC, millions of fragments remain undetectable and untraceable, yet still carry enough speed to damage or destroy larger space objects.[262] It is therefore essential that AI systems are carefully programmed and monitored to ensure they seek out small, yet dangerous objects beyond the current catalogs in order to truly enhance SSA and facilitate safe navigation of congested orbits.

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[257] Federica Massimi et al, "Deep learning-based space debris detection for space situational awareness: A feasibility study applied to the radar processing" (April 2024) 18:4 IET Radar, Sonar & Navigation 635 at 647.
[258] Morin, *supra* note 62 at 26.
[259] *Ibid.*
[260] Sandra Erwin, "Slingshot unveils AI that spots satellite anomalies and potential bad actors" (5 June 2024) online: <spacenews.com/slingshot-unveils-ai-that-spots-satellite-anomalies-and-potential-bad-actors/>.
[261] Pultarova, *supra* note 246.
[262] *Ibid.*

2. *Tracking the Trajectory of Space Objects*

In the first half of 2023, satellites within SpaceX's Starlink constellation were forced to maneuver over 25,000 times to avoid other spacecraft and debris.[263] In turn, this created 25,000 datapoints that other space-faring entities should have been cognizant of, all from one space actor within a six-month period. This amount of activity demonstrates that in view of the projected expansion of space operations, SSA analysis will soon become overwhelming. As tens of thousands of objects orbit the Earth at approximately 18,000 mph, the task of analyzing orbital trajectories in order to execute mission related maneuvers and/or collision avoidance events will be insurmountable for humans. One US General referred to the aggregation of data associated the drastic growth of space activity as "the tyranny of volume."[264] Incorporating AI into these processes can assist in relieving the workload of humans and facilitate reliable, consistent, and comprehensive tracking of space objects.

Within the last decade, scientists have developed machine learning aimed at constantly tracking space objects and calculating the probability of collisions in orbits.[265] These projects have trained AI systems to analyze previously conducted satellite maneuvers with the goal of predicting future maneuvers and then generating avoidance protocols based on the anticipated future maneuvers.[266] This thesis will not examine the mathematical intricacies of such projects. However, the relevant takeaway is that AI is in the beginning stages of being used to predict the trajectory of space objects, assess the likelihood of conjunctions, and recommend the optimal

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[263] *Ibid*.
[264] The Space Report, "How artificial intelligence in space will play key roles for the US Space Force" (last accessed 21 August 2024), online: <thespacereport.org/resources/artificial-intelligence-to-play-key-roles-for-space-force>, *quoting* USSF Lt Gen John Shaw.
[265] Luis Sanchez et al, "An Intelligent System for Robust Decision-Making in the All-vs-All Conjunction Screening Problem" (Delivered at the 3rd IAA Conference on SSA, Madrid, 4 April 2022), online(pdf): <strathprints.strath.ac.uk/88523/> at 1-2.
[266] *Ibid*.

course of action to mitigate the hazard.[267] In some cases, AI, if authorized, can also autonomously steer a satellite out of harm's way.[268]

Comprehensive SSA data about the space environment is critical for enabling AI to conduct these STM measures. This requirement for complete and informed data underscores the need for an STM regime that emphasizes openness and transparency with SSA data collection and sharing. While there are some data-sharing agreements between Western nations,[269] a comprehensive STM system needs data to be shared on a global scale in order to establish the most accurate portrait of the space environment. Consider how commercial air traffic data (routes, flight numbers, times and dates of travel, etc.) is shared on a global scale so that states can facilitate international aviation. To achieve optimal space navigation, a similar approach is required. However, even if this sharing were to occur, it would be a monumental task to organize and analyze the data. AI systems would be able to process the data and standardize it, so that tracking of space objects and collision avoidance could be uniformly and consistently conducted worldwide. Ailor suggests that this form of standardization could result in the establishment of "rules of the road" for satellite maneuvers with the aim of preventing interference and predicting close approaches, conjunctions, and other STM concerns.[270] AI's ability to transpose SSA data, no matter the source, into actionable information makes it ripe for processing large scale data sharing.

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[267] Nag, *supra* note 179 at 9.
[268] *Ibid.*
[269] USSPACECOM operates an up-to-date website (space-track.org) where SSA data is made publicly available free of charge in an effort to promote transparency in the space domain along with safety of space flight for satellite operators. Space-track.org grants basic users access to their satellite catalog which includes probabilities for conjunctions as objects traverse space. Registered satellite operators receive enhanced services including conjunction data messages and close approach notifications. Despite granting open access to this wealth of information, the satellite catalog remains limited to data only received from the US space surveillance network. Space Track.org, "Frequently asked questions" (last accessed 11 September 2024), online: <space-track.org/documentation#/faq/>.
[270] Hitchens, *supra* note 79 at 176.

3. *Issuing, Evaluating, and Responding to Collision Alerts*

The US space surveillance system generally issues a collision warning if multiple objects are anticipated to cross within 1 km of one another in LEO,[271] or if the probability of a collision reaches or exceeds 1 in 1,000.[272] Under these parameters, hundreds of alerts (officially known as conjunction data messages) are issued on a weekly basis.[273] However, as noted, the alerts merely inform operators of a hazardous situation, but there is no authority to mandate that they change the trajectory of the object at risk. While this system has proven effective, the anticipated growth in space activity will result in a significant increase in the number of alerts, likely exceeding the capacity of operators to evaluate and respond to them in an appropriate manner or timeframe.

The anticipated volume of alerts has the potential to negatively impact the space environment in multiple ways. First, operators may become desensitized to alerts, or experience alert fatigue, which could result in dangerous oversights, disbelief, or even disregard. Following the Iridium/Cosmos collision, it was reported that the Iridium constellation had been receiving over 400 alerts per week prior to the conjunction.[274] On the day they collided, that particular conjunction was not even in the top ten of collisions most likely to occur based on prior probability calculations.[275] This illustrates the level of attention and detail required for SSA at all times, and even then, the potential for catastrophic conjunctions can still be missed by human operators.

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[271] Wagner, *supra* note 89.

[272] Moribah Jah, "The sky is falling: Lets reduce the false positives in conjunction data messages" (January 2024), online: <aerospaceamerica.aiaa.org/departments/the-sky-is-falling-lets-reduce-the-false-positives-in-conjunction-data-messages/>.

[273] Space Track.org, *supra* note 269 at "Conjunctions".

[274] Brian Weeden, "Billiards in Space" *The Space Review* (23 February 2009), online: <thespacereview.com/article/1314/2>.

[275] *Ibid.* And this was in 2009, when the amount of space objects in orbit was significant less than today's space environment.

Alternatively, a zealous space operator who treats every alert as an imminent threat would quickly be overwhelmed by the need to thoroughly analyze thousands of potential collisions that never come to fruition. This would result in the expenditure of considerable time, energy, money, and disrupt the satellite's services if they were needlessly maneuvered on a frequent basis.[276]

AI is less susceptible to these concerns and assuming it has the requisite data to analyze, it can be employed to filter alerts and identify those that genuinely pose a threat and necessitate a response.[277] As the space community improves upon its ability to detect smaller space objects, the workload required to track, predict, and avoid collisions with these smaller, yet dangerous objects, will skyrocket. The ability to detect and track hundreds of thousands of additional items in space will assist in making space operations safer, yet the analysis required to actually navigate around these objects will become unmanageable. It is therefore imperative that machine learning be employed to assist humans in discerning which close calls pose legitimate threats to space activities and the systems they support on Earth.

As AI models become more sophisticated at evaluating and responding to conjunction alerts, particularly by recommending maneuvers and trajectory alterations, the risk of collisions will decrease, and space will become safer. These capabilities will become invaluable as existing collision avoidance processes are constrained by limitations of SSA sensing and processing, which are slow to record and have difficulty keeping up with frequent or continuous maneuvers.[278] Moreover, the 72-hour advance notice JSpOC aims to provide can be helpful, however loses its usefulness if the tracked space object unexpectedly and materially alters

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[276] Jah, *supra* note 272.
[277] Nag, *supra* note 179 at 9.
[278] Phillip A Slann, "Anticipating uncertainty: The security of European critical outer space infrastructures" (2016) 35 Space Policy 6–14.

course. For instance, in 2019, a European satellite executed an emergency maneuver to avoid colliding with Starlink satellite.[279] A collateral effect of this maneuver was that the European satellite navigated into the path of a different satellite, missing it by only 58 meters.[280] In a terrestrial traffic analogy, satellites must frequently avoid collisions but have no signals or flashers to warn others of their impending moves.

The use of satellites with autonomous maneuvering capabilities, or those dependent on AI SSA processing, reduces the risk of potential damage to surrounding space objects. Nevertheless, a vast majority of satellites in orbit lack autonomous maneuvering capabilities, relying instead upon operators on Earth who may not be as quick to react to consistent alerts and unanticipated maneuvers. Some have argued against implementing AI for STM purposes for this very concern, expressing that autonomous satellites could maneuver without warning, creating unexpected and problematic situations for non-AI-enabled objects.[281] This is a valid concern, as operators on Earth could possibly be making decisions based on SSA data that becomes outdated due to an autonomous maneuver unbeknownst to them. This underscores the necessity for caution when employing AI for STM. It is vital to ensure that AI-enabled space objects remain subject to human control and oversight and share their own SSA data to mitigate potential misunderstandings or accidents.

c. Legal Ramifications of Using AI for SSA

While AI can drastically improve SSA in a variety of technical ways, those seeking to enhance STM on a larger scale must consider the legal implications of utilizing AI to monitor and track space objects. One of the most basic concepts in international law is *pacta sunt*

[279] Beichao Wang et al, "Research Advancements in Key Technologies for Space-Based Situational Awareness" (2022) 2022 Space: Science & Tech 1 at 1-2.
[280] *Ibid*.
[281] Nag, *supra* note 179 at 10.

servanda, the concept that, "every treaty in force is binding upon the parties to it and must be performed by them in good faith."[282] Key to this concept is the role of "good faith" which, if exhibited, can lead to trust and confidence between states and their counterparts.[283] If done ethically, employing AI in the means described above provides transparency to states' good faith efforts to make space safer and comply with international legal obligations.

1. *State Responsibility and Supervision of Outer Space Activities*

Even prior to the drafting of the Outer Space Treaty, the international community viewed space as a global commons, accessible for exploration by all states on an equal footing.[284] Accordingly, space-faring states must assume the duty of exercising international responsibility for their national activities in the domain, even when those activities are conducted by non-governmental entities.[285] In international law, responsibility is a fundamental principle that holds states accountable for adhering to their legal obligations, and for any violations thereof.[286] As the focal point of Article VI of the Outer Space Treaty, states are responsible for ensuring that their space activities align with the treaty's overarching objective of peaceful and free use for all.[287] To put this notion of responsibility into practice, Article VI mandates that states 1) authorize and 2) continuously supervise the space activities of their own non-governmental entities.[288] This author submits that authorization is the administrative means for effectuating responsibility, while continuous supervision is the operational aspect of Article VI responsibility.

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[282] *Vienna Convention on the Law of Treaties*, 23 May 1969, 1155 UNTS 331 at art 26 [*VCLT*].
[283] Harrington, *supra* note 152 at 66.
[284] *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space*, UNGA, 18th Sess, UN Doc A/RES/1962(XVIII) (1963).
[285] *Outer Space Treaty, supra* note 13 at art VI.
[286] Bin Cheng, "Article VI of the 1967 Space Treaty Revisited: 'International Responsibility', 'National Activities', and the 'Appropriate State'" (1998) 26:1 J Space L 7 at 14 [Cheng, "Article VI"].
[287] *Outer Space Treaty, supra* note 13 at art I and VI.
[288] "The activities of non-governmental entities in outer space… shall require authorization and continuing supervision…" *Ibid* at art VI.

Generally speaking, authorization equates to the process of giving one access to a resource, or permission to do something. In this instance, authorization effectively means granting a non-governmental entity permission to conduct space activities, which is typically accomplished through licensing and other means. Supervision, on the other hand, is a duty to be exercised once the party is in space (given that the language of this sentence within Article VI begins with "The activities of non-governmental entities *in outer space*…"[289] emphasis added).[290] Moreover, the need to continuously supervise space activities is inherently codependent on authorization of access to space initially. Stated differently, if a state authorizes some amount of space activities for a non-governmental party, then the state must continuously supervise these activities to ensure the party refrains from unsanctioned activities. Understanding a non-governmental entity could unforeseeably elect to engage in unauthorized activities once they are in space, the assurance of continuous supervision is the means by which the state can address such actions. In this circumstance, the first clause of Article VI requiring states to bear international responsibility (i.e. blame) for their actors' space activities is activated. As continuous supervision is the operational aspect of Article VI's responsibility obligation, the remainder of this section will focus on that aspect as using AI for SSA is an operational measure to accomplish STM.

Supervising one's own space activities was relatively simple in 1967 when there were only a few hundred active objects in orbit, and most, if not all, space activities were under government control.[291] In these circumstances, requiring continuous state supervision was

[289] *Ibid.*
[290] Cheng appears to support this position, as he likens authorization to control from Article VIII, and language in the Registration Convention, both of which impose administrative taskings on space actors. Cheng, "Article VI", *supra* note 286 at 26-27.
[291] Verspieren, *supra* note 49 at 2.

almost an unnecessary redundancy. However, today's space landscape is substantially different and given the millions of objects in space, the question therefore becomes: what constitutes continuous supervision in today's space environment, and how do states continue to meet Article VI's obligations?

An optimist may suggest the drafters anticipated the advent of the NewSpace Age and still expected that states would maintain constant supervision of their objects. After all, they drafted articles concerning installations on celestial bodies,[292] and the rendering of assistance to astronauts in distress, neither of which were developed technologies at the time.[293] This author believes it is more likely that the drafters did not anticipate the current state of space exploration when writing about continuous supervision, otherwise they would have also included language about space debris (which existed in 1967) and/or STM. Regardless of the position taken, the distinction between the level of supervision required in the 1960s and levels required today necessitates an updated interpretation and application of the concept. In the absence of explicit clarification on what constitutes continuous supervision, we refer to guidelines on how to interpret treaties.

According to Article 31 of the Vienna Convention on the Law of Treaties, a treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in light of its object and purpose.[294] First, we must understand what constitutes the ordinary meaning of these terms. Merriam-Webster Dictionary defines continuous as "marked by uninterrupted extension in space, time, or sequence"[295] and

[292] *Outer Space Treaty, supra* note 13 at art XII.
[293] *Outer Space Treaty, supra* note 13 at art V.
[294] *VCLT*, *supra* note 282 at art 31(1).
[295] Merriam-Webster Dictionary, "Continuous" (last accessed 29 August 2024), online: <merriam-webster.com/dictionary/continuous>.

supervision as "the act, process, or occupation of supervising [meaning to oversee]."[296] Accordingly, the literal definition of continuous supervision is uninterrupted oversight.

Next, we consider these terms in the overall context of the treaty's overall object and purpose.[297] In the context of Article VI, this uninterrupted oversight applies to space activities attributable to the state. It is hardly debatable that the navigation of space objects through orbit constitutes "space activities." Therefore, in applying this concept to the treaty's overall objective, it can be reasonably argued that the drafters expected states to have uninterrupted oversight over their space objects in order to guarantee that space exploration is conducted in a peaceful, cooperative, and interference free manner, and in compliance with international law.[298]

In theory this is a logical interpretation of the obligations for space faring nations. However, given the tremendous growth in space activity over the past decade, it is becoming increasingly challenging to maintain uninterrupted oversight and ensure a conflict-free space environment. The AI capabilities discussed above can provide some relief, but the lack of an international framework for STM or guidelines on the use of AI in space is unhelpful any attempts at re-interpreting what continuous supervision looks like in the modern space age.

It is often suggested that it is up to individual states to determine the frequency that satisfies "continuous" and the level of oversight sufficient to constitute "supervision."[299] This includes the UNGA which passed a resolution urging states to implement national legislation providing for continuous supervision of space activities under their jurisdiction.[300] However, this

[296] *Ibid* at "Supervision" (last accessed 29 August 2024), online: <merriam-webster.com/dictionary/supervision>.
[297] *VCLT*, *supra* note 282 at art 31(2).
[298] *Outer Space Treaty*, *supra* note 13 at preamble.
[299] See Laura Montgomery, "US Regulators May Not Prevent Private Space Activity on the Basis of Article VI of the Outer Space Treaty" (2018) Meractus Working Paper, Mercatus Center at George Mason University, online: <mercatus.org/publications/regulating-private-space-activity-outer-space-treaty> arguing that Article VI is not self - executing and therefore states must enact national law in order to regulate private actors.
[300] *Application of the concept of the "launching state",* UNGA, 59th Sess, UN DOC A/RES/59/115 (2004).

resolution provides no guidance on the specifics of this supervision.[301] Hobe proposes that by enacting domestic legislation governing procedures such as licensing, certification, and registration of spacecraft, states can fulfill their continuous supervision obligations.[302] However, these functions are administrative and more reflective of authorization than continuing supervision. The concept of continuing supervision should extend beyond mere administrative functions of licensing, registration, and certification. Article VI does not restrict continuous supervision to these pre-launch activities, and if the ultimate objective is to avoid harmful interference and facilitate cooperation *in outer space*, then the practical impact of continuous supervision requirements must extend beyond the Earth's atmosphere and into orbit where interference and conflict have the potential to occur. Enhanced SSA, particularly through use of AI, is the means by which states can fulfill this legal obligation.

The space industry is more active than it was in the 1960's and even early 2000's. Furthermore, Earth relies more on space infrastructure than ever before. As the number of private actors in this field increases, it becomes increasingly important for the state to maintain continuous supervision of these entities in order to comply with Article VI and other international obligations. Accordingly, applying the continuous supervision obligation to modern space operations requires that states not only keep track of their space objects, but also monitor how their space objects interact with others in orbit. This constitutes monitoring their own activities, in addition to being aware of the congestion on valuable orbits, so as to avoid collisions and sparking space conflicts. However, in the NewSpace environment, it is insufficient to merely watch objects in space. Instead, states should understand "continuous supervision" to include forward-leaning analysis of potential conjunctions and adequate

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[301] *Ibid.*
[302] Stephan Hobe, "Legal Aspects of Tourism" (2007) 86:2 Neb L Rev 439 at 445.

measures for avoiding them. It is critical to engrain this practice as part of Article VI "continuing supervision" so that all states will feel an obligation to assist with the hazards posed by overcrowding in space.

It can be argued that JSpOC (and now the FCC due to SPD-3) fulfills this obligation by monitoring for conjunctions and warning other; however, this the product of the US government, which is but one of 115 state parties to the treaty.[303] The fact that one state can exercise continuous supervision for many is insufficient from an Article VI perspective, as all states remain responsible for their own activities in space, not just those with the best tracking capabilities.[304] This concept is increasingly crucial and eminent as commercial space activities continue to increase. With more non-state actors operating in space, it is important to remember that Article VI places the onus on states to ensure these private entities adhere to international law.

AI-facilitated SSA programs offer exceptional awareness of outer space activities by detecting, tracking, and avoiding collisions in space. In doing so, they facilitate the ultimate state assumption of responsibility and continuous supervision in real-time application. By consistently observing, tracking, analyzing space data, and making predictions to avoid collisions in orbit, AI is a highly effective tool to effectuate state oversight. AI can achieve this at a much greater quantity, quality, and pace than humans. However, in accordance with the guidelines for ethical AI use, humans must maintain ultimate decision accountability for space objects, including those that have on-board AI systems. By leveraging AI and machine learning to

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[303] *Status of International Agreements relating to activities in Outer Space as of 1 January 2024*, COPUOS, 62nd Sess, UN Doc A/AC.105/C.2/2024/CRP.3 (2024)

[304] Cheng, *supra* note 286, at 27. There have been scholarly disagreements among what constitutes an "appropriate" state, however for purposes of this thesis, the assumption is that the appropriate state is that state engaged in a particular space activity.

enhance their SSA systems and ensure the safe operations of space-based infrastructure, states can confidently and effectively fulfill their obligatory responsibilities as outlined in Article VI.

2. *<u>Due Regard</u>*

While Article VI addresses the responsibility of states to oversee their own space activities, Article IX of the Outer Space Treaty governs how states should interact with other entities operating in space. Article IX obligates states to exercise due regard towards the corresponding interests of other signatories pursuing their own space activities.[305] Article IX does not further specify what constitutes "due regard," however scholars have suggested it implies granting a level of consideration or attention that is reasonable under the circumstances.[306] While this may be difficult to quantify in the abstract, in an SSA, and broader STM, context it seems evident that due regard entails exercising diligence to avoid collisions in space. Moreover, Article IX requires that states consult with others when their activities may harmfully interfere with those of other states.[307] When considering STM, a comprehensive reading of Article IX can reasonably lead to the conclusion that states exercise due regard by making good faith efforts to avoid collisions or other harmfully interfere with other's space activities as a result of crowding in orbit.[308]

Using AI and machine learning to track space objects and avoid collisions is a critical component in exercising due regard because it facilitates the safe navigation of crowded orbits. Advanced AI that can analyze potential conjunctions, alert operators to the hazard, provide recommendations for overt action, or autonomously move a satellite out of harm's way, provides

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[305] *Outer Space Treaty, supra* note 13 at art IX.
[306] Harrington, *supra* note 152 at 69.
[307] *Outer Space Treaty, supra* note 13 at art IX.
[308] Harrington, *supra* note 152 at 67.

space operators the necessary data and tools to collaborate and consult with one another to avoid harmful interference.

As increased growth within the space industry edges LEO towards a critical capacity, the international community faces the reality that orbital congestion will permanently pose a risk of harmful interference. Accordingly, any new launches into or maneuvers within this congested area may soon require consultation in accordance with Article IX. In these circumstances, it will become increasingly important to exercise adherence to the due regard requirement, but it could also become quite difficult given the quantity of consultations and due regard analyses that must be conducted. Nevertheless, AI generated courses of action for collision avoidance presents an opportunity to create norms of conduct that can themselves eventually lead to binding law.[309] Given the lack of an international STM system, if AI can successfully facilitate SSA and help states meet their due regard and consultation obligations, it could serve as a foundation for future international STM agreements.

In demanding that states exercise due regard towards one another, Article IX simultaneously limits and protect a state's freedom of action as it both prevents them from encroaching on other's activities while also stopping others from doing the same.[310] To that end, using AI to fulfill Article IX requirements aligns with the UN's ethical AI principle of sustainability which requires that AI be used to promote environmental, economic, and social sustainability.[311] In focusing on preventing harmful contamination of the space environment and harmful interference in others space activities, Article IX effectively aspires to keep space

[309] *Ibid.*
[310] John S. Goehring, "Can We Address Orbital Debris with the International Law We Already Have? An Examination of Treaty Interpretation and the Due Regard Principle" (2020) 85:2 J Air L Commer 309–317.
[311] *Principles for Ethical Use of Artificial Intelligence in the United Nations System,* Inter-Agency Working Group on Artificial Intelligence, 20 September 2022, online(pdf): <unsceb.org/sites/default/files/2022-09/> at 4 [UN Principles for ethical AI].

sustainable for future exploration. In this case, AI ethics and space law obligations align, allowing for the harmonization of AI use for SSA purposes with international law.

3. *Liability for AI-facilitated activities*

As referenced in Chapters 2 and 3, one frequent criticism of AI is that for all of the benefits it can provide towards enhancing SSA, and by extension STM, there is always the possibility that something can go wrong and that an AI-enabled system might cause destruction, damage, or other harmful interference to another state's space objects. The unpredictable nature of AI and machine learning systems raises important questions about liability for damage caused by AI systems in space. Liability for activities in outer space is addressed by both the Outer Space Treaty (Article VII) and the Liability Convention, as well as general international law (e.g. Responsibility of States for Internationally Wrongful Acts [312]). As the *lex specialis* for liability in space, the Liability Convention builds on aspects of these other agreements and will therefore be the focus of this section.

Articles II and III of the Liability Convention outline a two-tiered liability regime contingent on the location of the damage in question.[313] Relevant to in-space operations is Article III which establishes that a launching state is liable for damage caused outside the surface of the Earth, provided that the damage is caused by a space object of another state *and* that the damage is attributable to the fault of the "state or persons for whom it is responsible."[314] However, given that AI is neither a person, nor a state actor, several questions loom as to how the

[312] *Draft articles on Responsibility of States for Internationally Wrongful Acts*, ILC, 53rd Sess, UN Doc A/56/10 (2001).
[313] *Liability Convention, supra* note 38 at arts II-III.
[314] *Ibid*. Article II attributes strict liability for damage on the Earth's surface caused by another state's space activities, however as the subject of this thesis is in-orbit space traffic, the focus for this liability discussion will be on Article III's provisions.

actions of this autonomous technology should be treated in the event that it causes damage in space.

First, questions have been raised as to whether AI technology can even be considered a space object for purposes of the Liability Convention, or whether its unique nature places it beyond the Convention's scope together.[315] Article III stipulates that states are liable for damage caused by their space objects to the space objects of other states (in addition to a demonstration of fault, as discussed below).[316] Consequently, if AI systems are not considered space objects, they would fall outside of the Liability Convention. Article I defines a space object as "includ[ing] component parts of a space object as well as its launch vehicle and parts thereof."[317] While the Liability Convention does not address whether computing software constitutes a "component part," many argue that the term "component parts" refers to items that are physically attached to a space object.[318] This interpretation omits non-tangible aspects of space systems, such as AI programming.[319] As AI becomes more prevalent and integral to SSA and other operations, this perspective must be re-considered. AI's role in orchestrating the functionality of a space object makes the AI programming a crucial element of the object's operations. The fact that AI cannot be held in one's hand, or affixed to a space object, is immaterial when considering its influence on the object's actions. Ultimately, if the objective of the Liability Convention is to facilitate effective rules for establishing liability,[320] it must be interpreted in a way that addresses AI's presence in space. The necessity to consider AI as a component part of a space object is underscored by contemplating the alternative. If AI were excluded from being a "component

[315] Thomas Graham, Kathiravan Thangavel & Anne-Sophie Martin, "Navigating AI-lien Terrain: Legal liability for artificial intelligence in outer space" (2024) 217 Acta Astronautica 197 at 200 ["Navigating AI"].
[316] *Liability Convention, supra* note 38 at art III.
[317] *Ibid* at art I.
[318] Graham, "Navigating AI", *supra* note 315 at 200.
[319] *Ibid.*
[320] *Liability Convention, supra* note 38 at preamble.

part," it would fall outside of the definition of a space object, and outside the scope of the Liability Convention entirely. Consequently, there would be a massive void in holding space actors accountable for damage caused by autonomous objects in space. This lack of accountability for autonomous space objects would not only disregard the ethical principles of AI use, but also propagate lax standards for using AI in space if states knew there were no ramifications to damage it caused in orbit. Accordingly, it is imperative that the Liability Convention be interpreted in a way that enables AI space technologies to fall under its purview.

Assuming that AI is in fact a component part of a space object, the question still remains as to how to apportion fault for the decision-making of an autonomous object. Given that states are the subjects of liability under the convention, it seems logical that liability for damage caused by AI activity would be attributed to the state that launched or procured launching of the AI technology.[321] In practice, this approach may be perceived as unfair due to the introduction of an additional independent link in the chain of fault resulting from AI's autonomous decision-making process.[322] For example, if the launching state can demonstrate that it took all reasonable measures to avoid negative outcomes when developing, training, and deploying the AI system, yet the AI decision-making still resulted in an undesirable outcome, it may be challenging to attribute fault to the launching state.[323] In such a scenario, attributing liability could have a negative impact on the use of AI in space, and deter states from implementing it into their SSA systems as they would be held accountable for actions beyond their control due to determinations autonomously made by the AI system.

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[321] *Ibid* at art I(c).
[322] Alex S. Li, "Autonomizing Outer Space: Updating the Liability Convention for the Rise of Artificial Intelligence (AI)" (2024) 15:1 UC Irvine L Rev [forthcoming in 2024] at 42.
[323] *Ibid*.

Nevertheless, on the international stage, a rationale of "the AI did not perform as expected" should not be acceptable when examining liability under the Liability Convention for AI based actions. This is emphasized by the UN principles for ethical AI use, which recommend that humans retain oversight and control over AI systems to enable intervention over an AI's decision if necessary.[324] The principles also strongly suggest that states implement appropriate governance structures to attribute legal and ethical accountability for AI based decisions to human entities.[325] Accordingly, while AI offers substantial benefits for SSA activities, it is imperative for states employing it to maintain oversight. In the absence of specific agreements targeted at liability for AI systems, the most effective way to ascertain a state's fault for AI-based actions is to assess the level of human oversight and supervision exercised over the AI decision-making process. Additionally, an assessment of fault should also examine efforts, if any, made by humans to intervene and stop or mitigate damage caused by the AI system in time period close in proximity to when the damage occurred. In light of these considerations, and despite criticisms to the alternative, it is possible for the Liability Convention to be effectively applied to AI systems by holding operators accountable for ensuring that the technology functions in accordance with international law. By taking this approach, the international community will not only protect victims of space damage, but also ensure that states adhere to legal and ethical standards for AI use.

d. Conclusion

On the global stage, UNCOPUOS has acknowledged that SSA capabilities are essential to safe and sustainable space operations in the face of a boom in space activities.[326] It is

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[324] UN Principles for ethical AI, *supra* note 311 at 5.
[325] *Ibid* at 6.
[326] UNCOPUOS Report 67th Sess, *supra* note 47 at 9.

therefore crucial to gather and share data on space activities, but the sheer volume of information is becoming increasingly challenging to manage. Machines have demonstrated the capacity to not only process vast quantities of data, but also to learn from it and anticipate and project potential conflicts. However, the current SSA remains imperfect as AI can only learn from data that it is provided. The current inability to track objects under 10 centimeters is problematic and could introduce bias in AI-based SSA systems if not properly accounted for. Furthermore, questions over liability for AI activities will grow more pressing as AI's usage in space becomes more prevalent. Nevertheless, as means to detect and track smaller objects are developed, AI's value to the space industry is set to increase substantially as it will enable states to better comply with international obligations.

Chapter 5: STM Dissected [Part 2] – Cleaning Up Space Debris

"Clear with a chance of space debris"[327]

Despite the vastness of space, Earth's valuable orbits are finite in nature. Increasing congestion in these areas means that when space objects are interfered with or forced to navigate around dead, non-functional, and other forms of space debris, the entire system of space traffic is impacted. In combination with the amount of debris dispelled into space, the growing quantity and diversity of space actors sparks concern about whether the orbital environment will remain suitable for use by future generations.[328] Concerns about the orbital capacity of vital space regions such as LEO, demand that debris remediation is equally as important in managing space traffic as SSA. Some argue that STM should focus primarily on SSA and collision avoidance,

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[327] This quote, from the blockbuster movie *Gravity*, was spoken by the actress Sandra Bullock as she portrayed an astronaut on a spacewalk. Immediately after uttering the quote, her character experienced a debris cloud rip through the objects she was working on, causing mass destruction to the object and her spacecraft and leaving her stranded in space. While this is a Hollywood dramatization, the notion of "a chance of space debris" is a reality in today's congested space environment. DVD: *Gravity* (London: Warner Brothers Pictures, 2013).

[328] LTS Guidelines, *supra* note 84 at Guideline A.4.

thereby leaving space debris a distinct matter subject to a separate regulatory scheme, however this perspective is short-sighted.[329] Collision avoidance is a critical tool for ensuring space objects remain clear of space debris, but if the amount of debris continually increases, collision avoidance will grow more difficult as space objects will be forced to consistently zig-zag their way through the cosmos in order to avoid space junk. Even then, smaller pieces of debris may not be able to be detected and avoided in a timely manner. It therefore becomes obvious that SSA alone is not enough to truly manage space traffic.

A comprehensive STM resolution requires devoting attention to reducing the impact of space debris on space traffic. There are two main strategies for achieving this: actively removing it from orbit and mitigating the amount of debris introduction into space.[330] This chapter will examine these two options, and the hurdles existing space law presents with implementing said options. Ultimately, this section argues that AI can play a crucial role in facilitating both of these strategies while simultaneously assisting states in complying with international law.

a. The Debris Situation

Kypraios and Carpanelli described space debris as the most direct consequence of human exploration of outer space.[331] They identify it as is one of, if not the greatest threats to space traffic moving forward.[332] Not only are remnants from recent disasters such as the Iridium/Cosmos collision still orbiting the Earth, but byproducts of space missions dating back to the 1950's serve as hazards to current objects and are expected to continue lingering in orbit for

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[329] Pelton, *supra* note 19 at 96.
[330] Daniel Lambach & Luca Wesel, "Tackling the Space Debris Problem: A Global Commons Perspective" (Delivered at 8th European Conference on Space Debris, Darmstadt, 20 April 2023), online(pdf): <conference.sdo.esoc.esa.int/proceedings/sdc8/paper/230/SDC8-paper230.pdf> at 2.
[331] Christos Kypraios & Elena Carpanelli, "Space Debris" in Anne Peters, ed, *Max Planck Encyclopedia of International Law* (Oxford: Oxford University Press, 2023) at s A(1).
[332] *Ibid.*

decades to come.[333] As a result of approximately 6,640 space missions undertaken since 1957, it is estimated that currently there are more than 40,500 pieces of space debris in orbit that are larger than 10 centimeters in diameter, about 1,100,000 debris measuring between 1 and 10 centimeters in diameter, and hundreds of millions debris fragments smaller than 1 centimeter, most of which are undetectable yet capable of causing mission-ending damage.[334] Of the approximately 25,000 tracked and cataloged space objects, over 90% of them are debris.[335] In fact, ever since the beginning of the space age, the amount of space debris has outnumbered active satellites.[336]

The concerning aspect of these numbers is that even the smallest pieces of debris are capable of causing damage. The International Space Station, which is equipped with some of the best impact protection in history, can only withstand the hypervelocity impact of debris approximately 1.4 centimeters in size or smaller.[337] Post-flight damage inspections of the US space shuttle frequently showed centimeter sized holes or cracks in the shuttle's components resulting from millimeter sized debris particles that struck the large spacecraft during its missions.[338] In 1986 a .2 millimeter sized paint chip hit a window pane of the space shuttle Challenger, creating enough damage that the window had to be replaced (an approximately $50,000 USD repair) upon its safe return to Earth.[339] Fortunately for the humans inside the space

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[333] Hall, *supra* note 63 at 4. For example, Vanguard 1, a satellite launched by the US in 1958, only remained active for six years before malfunctioning, however it is expected to remain in orbit for another 200 years. *Ibid.*
[334] ESA, "Space Environment Statistics", *supra* note 5.
[335] Ram S. Jakhu, Yaw Otu Nyampong & Tommaso Sgobba, "Regulatory framework and organization for space debris removal and on orbit servicing of satellites" (2017) 4:3 J Space Safety Engineering 129 at 129-130 [Jakhu, "Regulatory Framework"].
[336] ESA, "Space Environment Statistics", *supra* note 5
[337] Jer-Chyi Liou, "Engineering and Technology Challenges for Active Debris Removal" (Delivered at 4th European Conference for Aerospace Sciences, St. Petersburg, 4 July 2011), online: <ntrs.nasa.gov/citations/20110013011> at 2.
[338] Hall, *supra* note 63 at 3.
[339] *Ibid.*

shuttle, it was fortified with thick layers of protection over its windows. However, most space objects are not as strongly defended against space debris, and a strike by even a small fragment could turn an otherwise functioning object into an inoperable and uncontrollable piece of debris plunging through space.

Aside from the general inability to track most debris, the fact that it cannot be controlled contributes to its dangerous nature. The inability to communicate or remotely maneuver objects tearing through space leaves active objects at the mercy of SSA detection, reactive avoidance maneuvers (assuming they capable of them), and a little bit of luck. Even then, operators that can detect debris and have the ability to dodge it via avoidance maneuvers must do so on an ad hoc basis making it difficult to anticipate and react to. This is inefficient and taxing on Earthly resources from temporal, financial, and personnel perspectives and impacts space objects through consumption of fuel which shortens their life span.

Some analysts believe that LEO has reached a critical density, suggesting that the debris problem is likely to grow faster than it can be reduced *even if* no further objects are added to the region.[340] Another study suggests that even without any new launches, the growth in the amount of space debris could result in as many as nine more Iridium/Cosmos level collisions by 2050.[341] The risk posed by space debris renders its continuous increase unacceptable – a notion that is widely recognized in the space field.

b. Regulating Debris

Despite the widespread concerns over space debris' presence and growth, there is no internationally binding set of rules that establish uniform prevention or mitigation strategies.[342]

[340] *Ibid* at 10.
[341] Jakhu, "Regulatory Framework", *supra* note 335 at 130.
[342] Lambach, *supra* note 330 at 1.

While aforementioned soft law instruments provide voluntary recommendations for mitigating future debris, no major space treaty directly discusses the issue, thereby leaving the legal and technical aspects of regulating it at an international scale up for debate. Lambach and Wesel note the difficulties in regulating space debris are multifaceted including legal, technical, economic, and political challenges.[343] Their analysis indicates the obvious, that dealing with space debris is not easy despite the seemingly universal acknowledgement that it constitutes an ever-growing problem. However, challenges in resolving the issue should not stand in the way of progress to rid space of harmful debris.

There are aspects of the Outer Space Treaty and Liability Convention that create pathways for addressing the issue. Article IX of the Outer Space Treaty calls for the avoidance of harmful contamination of space but does not define "harmful contamination" as a concept.[344] Furthermore, Article IX leaves it to individual states to adopt "appropriate" measures for this purpose.[345] Space debris should undoubtedly be considered "harmful contamination" considering the hazard it presents to space traffic. Examining other articles within the Outer Space Treaty and Liability Convention provides support for this position. Articles VII and VII of the Outer Space Treaty discuss a state's liability and jurisdiction/control over its space objects, with both articles including "component parts of objects launched into space" terminology.[346] Similarly, the Liability Convention does not specifically reference space debris, however Article I define a space object to include its component parts, as well as its "launching vehicle and parts thereof."[347] Accordingly, states are responsible and liable for the component parts of their space

[343] *Ibid* at 3.
[344] *Outer Space Treaty*, *supra* note 13 at art IX.
[345] *Ibid.*
[346] *Ibid* at arts VII and VIII.
[347] *Liability Convention, supra* note 38 at art I.

objects, which should be understood to include parts that break off of, or are separated from the primary payload but remain in orbit. In the NewSpace age, dispelling objects into LEO that are not active and cannot de-orbit themselves or respond to external commands constitutes a contamination of orbit that should be perceived as harmful. Even if the debris does not immediately collide with other space objects, its potential to do so in a congested area of space renders it of a harmful nature. Perhaps this was not the case in the early space age, however given the concentration of space debris and overcrowding in LEO, the harmful nature of newly created debris is a modern reality.

The formulation of soft law instruments such as the IADC Debris Mitigation Guidelines serve as an international request to individual states that they take the problem seriously and act now to prevent debris from overwhelming the finite capacity of valuable orbits. In its 2007 adoption of Space Debris Mitigation Guidelines, UNCOPUOS established their own definition of space debris as being "non-functional man-made objects and parts thereof in Earth's orbit."[348] Soon after, additional international instruments of a similar nature emerged including the LTS Guidelines. However, these instruments lack a binding effect to manage space traffic on an international basis. If STM is to be effective, there must be a system that holds all states accountable for reducing space clutter and increasing safe operations. Therefore, something greater is needed as competition for space within LEO intensifies. As Kaul suggests, a permanent space debris control and elimination system must be an integral part of STM operations in order for them to be effective.[349]

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[348] Debris Mitigation Guidelines, *supra* note 81 at 1.
[349] Kaul, *supra* note 124 at 151.

c. How Can AI Help?

An obvious but substantial difficulty when it comes to space debris is that even if a robust STM system existed, space traffic controllers cannot send commands to inert space objects that direct them away from collisions or into less dangerous orbits. Ground based options are therefore largely limited to mitigation policies, which are generally enforced before objects are launched and can be effective in stemming the addition of new debris into space, but are rather limited when it comes to actually removing dead objects from orbit. Likewise, pieces of space debris are unable to safely direct themselves out of harm's way. This would require the debris to not only have awareness of their orbital characteristics and neighboring hazards, but also an ability to maneuver safely to a different area of space. AI can help. One of the core tenets of ethical AI use is ensuring that it is employed to make the environment more sustainable, and it can serve that exact purpose in space. Creative minds have generated several ideas for using the technology to both minimize the production of new debris and methods for removing existing pieces from debris space entirely.

1. *Active Debris Removal*

Due to gravitational forces, all objects in orbit are falling towards Earth.[350] While active space objects us high orbital velocities and station keeping maneuvers to remain on their designated trajectory, inactive space objects no longer have such capabilities and will steadily succumb to the Earth's gravitational pull until they re-enter the atmosphere where it can burn up.[351] Through this process debris are is eventually "removed" from space. However, this

[350] Thomas Cheney, "The rising flood of space junk is a risk to us on Earth" (6 May 2024), online: <thespacereview.com/article/4787/1>.

[351] *Ibid.* There are concerns that re-entering debris poses a substantial risk to humans and structures on the Earth's surface if said debris fails to burn up in the atmosphere. While these types of events have occurred, they are in the minority but could grow more prevalent as debris is removed from space at an increased rate. Noting this hazard, this thesis will only focus on space debris in orbit for purposes of STM and will not further investigate debris threat towards the surface of the Earth.

process is slow as gravitational forces in space are weak, meaning debris can take decades or centuries before re-entering the atmosphere. In light of the overcrowding in space, this process must be accelerated. ADR constitutes closely approaching a piece of debris and exerting physical force upon it to remove it from orbit.[352] Looking to the future, this capability must be employed to both protect and clean up the space environment.

Recognizing the importance of ADR, several international efforts have pursued technologies to see its execution.[353] While we have yet to see mainstream employment of ADR, rapid advances in AI are making ADR capabilities increasingly feasible. One example is Astroscale's deployment of AI-enabled space objects that can distinguish debris from active space objects and then, using a robotic appendage or grappling claw, push the item out of LEO and back towards the Earth's atmosphere, or into less cluttered areas of space.[354] A different, but similar concept being explored involves teaching AI-guided robots to detect, capture, and contain debris by using a special type of net to stop the object's free fall through space.[355] In trapping a piece of debris, a net (or catcher's mitt type apparatus being developed in Japan) can then drag the debris out of LEO, or at minimum, reduce its velocity enough for the Earth's gravity to more quickly pull it into the atmosphere.[356] Other ADR proposals contemplate AI-driven spacecraft that can approach larger pieces of debris and attach a "de-orbiting aid," such as thruster, which would then boost the debris back towards Earth, or out into deep space.[357]

From a technical perspective, implementing any of these ADR concepts would require various levels of AI technology as the in-space execution would have to be timely, precise, and

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[352] Liou, *supra* note 337 at 3.
[353] Marc G. Carns, Orbital Debris Prevention and Mitigation Efforts Among Major Space Actors (Leiden: Brill Nijhoff, 2023) at 320.
[354] *Ibid* at 325.
[355] *Ibid* at 326.
[356] Carns, "Consent Not Required", *supra* note 157 at 210.
[357] Weeden, "Debris Removal", *supra* note 131 at 39.

adaptive to the debris' characteristics and trajectory. Using humans to conduct these types of operations seems far too dangerous, inefficient, and expensive, leaving AI as the only alternative. Successful ADR operations will be contingent upon machine's ability to learn safe motor skills so as to prevent the creation of additional breakup and debris during the process. AI would prove especially valuable in the removal of debris that is untrackable by terrestrial SSA systems, as these objects would otherwise remain unnoticed in space for years. In removing debris from congested orbits, AI will not only create room for the safe passage of active space objects, but also reduce the workload for SSA applications tracking debris, enabling them to focus on active space objects.

2. *ADR Concerns*

While offering substantial benefits for STM, AI-enabled ADR is not without controversy as it raises concerns from legal and policy perspectives. From a security standpoint, states are weary of space objects that can be used to alter the trajectory of another's space object as they could also be used for nefarious purposes.[358] ADR technology can, if in the wrong hands, be employed for ASAT-like purposes to destroy or dispel active objects from space.[359] Therefore, on a global stage, ADR could lead to distrust and instability if there is not sufficient transparency to assure participating states that it is not being used to disrupt active space capabilities, particularly those of a military nature. This highlights the importance of eliminating AI bias when it comes to developing how the machine identifies and distinguishes debris from active space objects. Failure to make this distinction could result in harmful interference with critical space activities, lead to military conflict, and create legal disputes over responsibility, accountability, and liability for objects in space.

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[358] *Ibid* at 42.
[359] *Ibid.*

A key component present in all AI frameworks, both domestic and international, is the notion that AI must be used for good.[360] A variation of this appears within UN principles for ethical AI use which state that AI systems should "do no harm" and should operate in accordance with the purposes, principles, and commitments of the UN Charter.[361] These notions resemble several longstanding provisions within the Outer Space Treaty including its preamble (peaceful purposes), Article I (benefit for all countries), Article III (activities must be in accordance with the UN Charter), and Article IX (cautions about harmful interference).[362] As AI employed ADR becomes more prevalent, an international STM framework marks the perfect opportunity to harmonize the "do no harm" principle and its related Outer Space Treaty provisions in binding form. In so doing, the international community will be put on notice that states will be held accountable, responsible, and, if necessary, liable for AI systems that cause or exacerbate harm in outer space.

Notably, the UN's ethical principles of AI do not establish an element of intent when it comes to harm, as proving AI's intent would be difficult in the event it caused harm. Thus, regardless of whether the harm caused by AI in orbit was accidental or intentional, it would violate the principle of "do no harm." This aligns with the Outer Space Treaty and Liability Convention, neither of which inserts an element of intent into determining fault for damage, harmful interference, or the failure to use space for peaceful purposes. Based on this precedent, it *should* be agreeable that adjudicating responsibility, accountability, and liability for harm caused by AI would be solely based on whether harm occurred, independent of intent.

[360] See generally White, *supra* note 225.
[361] UN Principles for ethical AI, *supra* note 311 at 4.
[362] *Outer Space Treaty, supra* note 13 at preamble and art I, III, and IX.

This is not to say that all harm, once established, should all be considered the same. From a strictly policy standpoint, accidental or unintentional harm should be investigated to improve AI functions in space and prevent future occurrences. However, nefariously caused harm should be strongly condemned and the subject of international ridicule. Other AI principles such as transparency, human-in-the-loop, and proportionality will be important in making the difficult determination of whether harm was accidental or nefarious. For example, proportionality would require that AI systems be programmed to *only* remove actual debris from orbit, and no more. To the extent that an AI ADR satellite "decides" that an active satellite (perhaps one from an adversarial country) is a target for removal, humans must be able to intervene and not only prevent harmful interference of the other's space activities, but also repair any bias or error in algorithms that led to such a conclusion. This ties in closely with Article VI's obligations to continuously supervise space objects. While AI can excel in providing continuous supervision as discussed in Chapter 4, humans must retain the ability to continuously supervise AI-enabled space objects from causing harm, damage, or interference.

It should also be acknowledged that AI-enabled ADR requires the placement of more objects into the space environment that may engage in frequent maneuvers. As a result, there will be an increase in space congestion and complication of SSA in the short term in order to de-congest space in the long term. In order to quickly reduce debris in orbit, multiple ADR systems will likely need to be deployed, which from an economic perspective will be an expensive endeavor.[363] In 2011, the International Interdisciplinary Congress on Space Debris Remediation

[363] Lambach, *supra* note 330 at 3.

issued a declaration urging the establishment of a public-private partnership to conduct ADR and on orbit servicing (OOS, discussed *infra*) that would be internationally funded.[364] \

Despite logistical and legal concerns over its implementation, AI promises to be an effective means for removing debris from orbit. Short of waiting for the Earth's gravity to pull debris back into the atmosphere, ADR is the only method by which critical regions of space can quickly become de-congested and therefore is critical in STM operations.

3. *Debris Mitigation*

A second means of reducing space debris' threat towards active space objects entails thwarting its creation. This solution is akin to the often-used phrase of "stopping the bleeding" which, while it does not necessarily reduce the quantity of already debris in space, keeps that number from growing. As a result, the space environment can better accommodate active space objects and their collision avoidance maneuvers.

On orbit servicing (OOS) is a mitigation measure that addresses both current and future debris. Similar to ADR, OOS involves using satellites with robotic appendages to approach and interact with debris, however instead of pushing it out of LEO, OOS robots will repair dead or damaged objects and return them to service.[365] Not only does OOS revive lifeless debris, but it also obviates the need to launch replacement objects into an already crowded orbit. OOS requires a high level of AI sophistication as it would require the "repair robot" to not only identify, track, and engage a dead or malfunctioning space object, but also decipher what is wrong and be able to repair it without colliding or causing further damage. In some instances, this may be as simple as refueling or attaching new energy sources to space objects; however,

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[364] Ram S. Jakhu, "McGill Declaration on Active Space Debris Removal and On-Orbit Satellite Servicing" (2011) 37:3 Air & Space L 277 at 280.
[365] Jakhu, "Regulatory Framework", *supra* note 335 at 130.

other OOS operations such as satellite repair may prove more tedious and increase the risk that something will go wrong. The requirement for OOS satellites to rendezvous closely with other space objects raises concerns similar to ADR that it can be used for nefarious purposes to disable, degrade, or destroy other's space capabilities. Such concerns re-emphasize that agreements regarding STM must incorporate the AI confidence building principles discussed above.

Other methods in which AI can be used to help with debris mitigation involve reusable rocketry. Typically, launch vehicles dismember at various points of a payload's ascension, leaving debris in LEO for as short as a few days or long as decades.[366] SpaceX has led the way in developing reusable rocketry whereby AI-driven technology guides a space objects component parts back to the Earth's surface, landing softly at a designated target to be reused in future missions.[367] During this process, the AI monitors the rocket's trajectory and considers factors such as wind speed and atmospheric conditions to control it towards a safe landing.[368]

AI is also being employed to de-orbit space objects at the end of their lifetime.[369] The IADC guidelines suggest that satellites should be deorbited within 25 years of their mission's completion.[370] Many space faring nations have implemented this guideline via domestic legislation, including the US which in 2022, reduced the timeline from 25 years to 5 years.[371] This decision was based on concerns that 25 years was too long of a time period to truly mitigate debris congestion, and an awareness that modern space technologies can enable quicker de-

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[366] Hall, *supra* note 63 at 3.
[367] Saitata, "How SpaceX Accelerates Space Exploration Using Artificial Intelligence" (1 September 2023), online: <medium.com/teamcalai/how-spacex-accelerates-space-exploration-using-artificial-intelligence-a4f82692fbdc>.
[368] *Ibid*.
[369] Pelton, *supra* note 19 at 96-97.
[370] IADC, *supra* note 80 at s 5.3.2.
[371] US, FCC, *In the Matter of Space Innovation Mitigation of Orbital Debris in the New Space Age* (FCC 22-74, IB Docket No. 22-271) (Washington, DC: 30 September 2022), online(pdf): <docs.fcc.gov/public/attachments/FCC-22-74A1.pdf> at 2.

orbiting.[372] This change will increase the relevance and prevalence of AI in space as objects will need to be capable of recognizing when they are near the end of their life and initiate a return to Earth in an appropriate time and manner.

The technical side of using AI to address space debris is promisingly evolving. However, there remain substantial legal questions towards dealing with space debris such as the ADR concerns discussed above. Fortunately, by helping states reduce and mitigate debris, AI can also further their compliance with other aspects of international space law.

d. Legal Ramifications of Using AI for Space Debris

From a legal perspective, the fact that space debris is not covered within the five primary outer space treaties may be thought to leave a massive void in international law on the topic and STM at large. However, multiple provisions within the Outer Space Treaty open the door for considerations on regulating space debris. Additionally, widely recognized soft law instruments have been adopted directly addressing debris due to global consensus that the issue is at a critical stage.[373] Employing AI to remove and mitigate debris can assist states in attacking congestion on orbit and generally help facilitate compliance with the Outer Space Treaty. This is important because states are obligated to comply with treaties in which they enter,[374] but more compliance with international agreements breeds good faith and trust, thereby increasing states' willingness to entertain new agreements.

[372] *Ibid*.
[373] Hamza Hameed, "Access Alert: Takeaways from the 61st UN COPUOS Scientific and Technical Subcommittee" (5 March 2024), online: <accesspartnership.com/takeaways-61st-session-un-copuos-stfc/>.
[374] VCLT, *supra* note 282 at art 26.

1. *Exercise of Jurisdiction and Control Over Both Debris and AI Space Systems*

Article VIII of the Outer Space Treaty mandates that states who launch an object into space "retain jurisdiction and control over such object…while in outer space."[375] Similar to the previously discussed Article VI, Article VIII emphasizes state responsibility (and accountability) for their private acters under international law.[376] Notably, neither the text of Article VI nor VIII makes a distinction between active and non-functional objects. Both Articles simply assign states responsibility, jurisdiction, and control as long as the object remains in space.[377] As a component part of a space object, debris should be subject to Article VIII's provisions so long as it remains in space.[378] Control in an Article VIII sense, should be read to denote legal control, meaning a state of registry, as the participating party within international law, retains some amount of authority over private entities who have registered their space objects within that state.[379] Notably, there are no mechanisms for unregistering or transferring registration, control, or jurisdiction of space objects under international law.[380] This means that states retain control over their objects, even when said objects become debris. AI-enabled ADR and OOS allows states to actively exercise control over their debris for the benefit and in the interest of all countries. Particularly in the case of large space actors responsible for large amounts of debris such as the US, China, and Russia, AI can assist these states in being more accountable on the world stage by exhibiting active control over the mess they have created in orbit. This is a win for all involved.

[375] *Outer Space Treaty, supra* note 13 at art VIII.
[376] *Ibid* at art VIII.
[377] Cheng, "Definitional Issues", *supra* note 36 at 506.
[378] Ive Ramus Cvetkovic & Marko Drobnjak, "As Above so Below: The Use of International Space Law as an Inspiration for Terrestrial AI Regulation to Maximize Harm Prevention" in, Ales Zavrsnik & Katja Simoncic, eds, *Artificial Intelligence, Social Harms and Human Rights* (Cham: Palgrave Macmillan, 2023) 207 at 223.
[379] Carns, "Consent Not Required", *supra* note 157 at 191.
[380] See generally *Outer Space Treaty, supra* note 13 and *Registration Convention, supra* note 39.

The ability of an object to learn and act autonomously is critical for ADR and OOS and significantly enhances space sustainability. While AI can assist states in exercising jurisdiction and control over their space debris, some have raised concerns over how states can retain jurisdiction and control over the AI-enabled space object itself.[381] Therefore, the question of whether a state can exercise control over an autonomous satellite must be examined.

Article VIII of the Outer Space Treaty requires states to exercise control over the "object launched into outer space… and any personnel thereof."[382] Given that AI is a machine mimicking human activity, it is not a "person." Nevertheless, considering that the space treaties define a space object as inclusive of its component parts, AI technology, as an element within a space object as previously discussed should fall under Article VIII's purview. Therefore, the AI system guiding a particular space object is subject to Article VIII jurisdiction and control. By comparison, if an AI guided object were to rouge, it would, in theory, be no different from a human operator doing the same. Under either circumstance, Article VIII comprehensively requires that states exercise control over both humans and objects in space. In this sense, the state of registry should be expected to exercise legal control over an autonomous system to prevent undesirable outcomes. In practice, this control would be strict legislation or regulations that borrow from AI's ethical use principles related to human oversight and the ability to override, repair, or decommission AI systems that risk undue harm or exhibit undesired behaviors.[383] Accordingly, any STM regime must contemplate these principles and merge them with Article VIII concepts to ensure AI is fully regulated and controlled while in orbit.

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[381] Long, *supra* note 185 at s V.
[382] *Outer Space Treaty, supra* note 13 at art VII.
[383] UNESCO ethical AI guidelines, *supra* note 219 at 22.

2. <u>*Facilitating Mutual Assistance and Due Regard*</u>

AI's impact on helping states exercise due regard in space activities were discussed at length in Chapter 4, however remain relevant in the case of using AI to remediate space debris. This chapter has focused in depth on the notion that AI can reduce space debris as a harmful contaminant in the outer space environment as called for in Article IX of the Outer Space Treaty. Moreover, Article IX mandates that states be guided by the concepts of "cooperation and mutual assistance" in their exploration and use of space.[384] In using AI-enabled removal and mitigation techniques, states are able to not just clean up their own debris, but also offer these services to other nations that might not have the technology or funding to achieve it themselves. This level of collaboration to reduce debris is illustrative of exercising due regard as debris cleanup will afford all states better access to and use of critical regions of space. States can further practice due regard by facilitating commercial development of debris remediation techniques. By encouraging private investment and competition in the AI-enabled debris removal and mitigation markets, states can assist in driving down the cost of producing these services and incentivize more space faring entities to take an active role in solving this problem.

e. Conclusion

If a heavily used highway was littered with old tires, dispelled car parts, and other garbage, drivers would expect their local government to address the issue. Such is the case with debris in LEO. It is time that stakeholders within the space industry jump into action so that traffic in space, both now and in the future, can operate in a safe manner. AI technologies are the primary means by which both removal and mitigation of space debris can be accomplished,

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[384] *Outer Space Treaty, supra* note 13 at art IX.

however it must be well regulated and controlled in order to prevent undesirable outcomes. The most effective way for seeing this through is via a comprehensive STM framework.

Chapter 6: STM Dissected [Part 3] – A Framework to Regulate STM

"*The stars may be the limit, but without sound legal frameworks, our reach for them will fall into chaos*."[385]

With an understanding of AI's ability to enhance the technical aspects of STM and facilitate compliance with existing space treaties, we must now shift gears towards expanding the current space law landscape to directly address traffic congestion in orbit. In light of ongoing efforts to mitigate congestion in space, a substantial looming question is *who should have the authority to exercise STM oversight and ensure that it is conducted in a safe and equitable manner*? In addressing this question, two potential methods for STM governance have emerged. The first is a top-down approach, whereby an international organization would be responsible for comprehensive oversight and management of space traffic. This proposal finds support in Article I of the Outer Space Treaty which declares space as free for exploration and use "by all states, without discrimination of any kind, on a basis of equality and in accordance with international law."[386] In emphasizing equality among space-faring nations and compliance under international law, Article I supports the position that an international body is the most appropriate source to govern space traffic. An alternative approach is to leave STM to individual states which, through Articles VI and VIII of the Outer Space Treaty, are charged with governing their own space activities so long as they operate in compliance with international law. This bottom-up approach would see states develop STM norms and practices suitable to their own needs and space capabilities, either individually or through multilateral agreements that could eventually

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[385] Roger Quinland, "Galactic governance: From the Outer Space Treaty to modern regulations" *The Space Review* (19 August 2024), online: <thespacereview.com/article/4843/1>.
[386] *Outer Space Treaty, supra* note 13 at art I.

evolve into binding international law. This chapter examines both options and explains why a single international organization is the optimal solution, but an unlikely one given the current state of global affairs. It concludes by arguing that the most viable option to manage space traffic in the short term is for states to implement STM measures at domestic levels.

a. The Preferred Option – A Top-Down International Harmony

The ideal scenario for a regulatory framework focused on STM is a sweeping top-down international initiative with a governing body, technical standards that include on-orbit traffic rules binding on all space actors. These rules would address several vital aspects of STM such as: methods for standardizing SSA, requirements for data sharing, criteria for determining rights to certain crowded orbits, minimum distance rules between large constellations, and right-of-way protocols to structure procedures for close approaches and determine who should have priority versus who should maneuver when two objects are headed for a collision.[387] The rules would also address means for executing debris mitigation and removal as discussed in Chapter 5. The most effective iteration of this top-down system should incorporate the commercial sector and leverage AI technology to keep pace with the volume of data required to manage international space traffic. Similar to the Chicago Convention, this treaty should empower an international body with the responsibility of providing oversight and coordination within the STM system in a manner analogous to ICAO's role in the aviation sector.

A treaty, or an annex to an existing space treaty, is the optimal solution because it conveys the gravity of STM's importance. The absence of territorial borders in space necessitates that its rules be observed equally by all space actors. The 2006 Cosmic Study on STM identified the need for cooperation and political will to implement this type of

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[387] Frandsen, *supra* note 61 at 233.

framework.[388] The study estimated it will take at least 15 years to implement such as system.[389] Seventeen years later, with no international STM framework developed, McClintock, et al. reiterated the urgency of establishing an international organization to maintain STM expertise and facilitate collaboration towards comprehensive rulemaking.[390]

One of the key challenges in adopting an international approach to STM is determining who should be responsible for regulating space traffic and how this responsibility should be allocated. As discussed in Chapter 2, a number of scholars have proposed the establishment of an ICAO-like organization to oversee space traffic. In 1999, the AIAA recommended that an International Orbital Coordination Center be created.[391] Others have suggested that ICAO itself expand its scope to encompass the space realm, arguing that STM is merely an extension of air traffic management.[392] However, argued in response, replicating the ICAO or IMO model without modification will not adequately address the unique dynamics of space. Moreover, handing STM duties to ICAO would encroach upon UNCOPUOS' longstanding expertise in the field of space. Even with UNCOPUOS maintaining its position as the best forum to discuss STM, creating a new STM system or body would require a consensus among spacefaring nations, which is a challenging achievement in the current global context. Current adversarial relationships among the US, China, and Russia – the three nations that would be the most significant contributors to and beneficiaries from an international STM system – represents an insurmountable challenge towards the establishment of such a system.[393] Nevertheless, certain

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[388] Contant-Jorgenson, *supra* note 51 at 286.
[389] *Ibid*.
[390] McClintock, *supra* note 18 at 8.
[391] Gibs, *supra* note 76 at 59.
[392] See Kaul, *supra* note 124.
[393] Blount, *supra* note 247 at 122.

aspects of the contemporary space sector offer grounds for optimism regarding the future establishment of an international STM framework.

1. *States' Commitment to Addressing STM*

First, there is evidence of a desire to mitigate the harmful threat of overcrowding. Several states including the US, Russia, China, France, Australia, Japan, India, the Republic of Korea, and the United Kingdom are working to implement their own STM programs.[394] Many of these programs reflect principles set forth in the IADC debris mitigation guidelines and the UNCOPUOS LTS guidelines. This shared commitment to addressing STM is a step in the right direction and is in the best interests of spacefaring nations from both an internationally cooperative and self-preservation perspective. By committing to managing traffic in orbit, these nations can ensure that their own space missions are less susceptible to collisions or close calls. Furthermore, a collective effort to implement these guidelines, even if done on an individual basis, can establish consistent standards of on-orbit behavior. Setting standards for STM through consistent practice makes it difficult for outlier states to engage in controversial or even illegal space activities. Additionally, consistent implementation of domestic or soft law practices, if successful, can lead other nations to implement the same practices. In turn, this can eventually lead to the soft law becoming codified into binding law, or even accepted as international customary law.

2. *Private Interest in International STM*

Second, commercial actors' emergence into all areas of the space industry, including STM, is a positive development for those who advocate for a global STM regime. The motivation and interests of private entities are often different from those of the public sector. For

[394] Brian Weeden & Victoria Samson, *Global Counterspace Capabilities an Open-Source Assessment* (Broomfield, CO: Secure World Foundation, 2023) at xvi-xxvi.

instance, private entities are primarily motivated by the pursuit of profit, which frequently entails reducing costs and prioritizing market competitiveness and product superiority over considerations of national politics or international diplomacy. Additionally, private enterprises are not accountable to taxpayers and are therefore subject to significantly fewer regulatory constraints. From an economic, administrative, and temporal standpoint, collaborating with a single, global STM entity is more efficient for private entities than working with multiple states in a fragmented regime contingent upon various and often conflicting domestic laws. Consequently, commercial entities are in a position to leverage their influence within the industry to advocate for a harmonized framework. Morin recommended that attaching economic incentives to the existing voluntary guidelines can serve as an effective initial step in fostering collaboration among public and private stakeholders towards the development of a comprehensive STM system.[395]

As private entities emerge as leaders in space operations, they must leverage their presence to ensure they have a respected voice in the move towards international STM governance. A precedent for this exists in the aviation industry, as the International Air Transport Association represents and advocates for the private airline industry to regulators around the globe including ICAO.[396] A comparable type of commercial space association or conglomerate would prove effective in advancing space technology and establishing standards and norms of operation in managing space traffic, including the use of AI. Nevertheless, commercial entities will be pivotal in the development of space policies, it is crucial to recall that states are the subjects of international law. Therefore, despite the commercial sector's presence in the space industry, Article VI of the Outer Space Treaty makes states responsible for non-governmental

[395] Morin, supra note 62 at 26.
[396] IATA, "Vision and Mission" (last accessed on 8 September 2024), online: <iata.org/en/about/mission/>.

actors.[397] In looking towards an international STM regime, while it is important to acknowledge and rely upon the expertise and advancements provided by the commercial sector, the distinction between governmental and non-governmental entities must be maintained. This will ensure that no single private actor dominates or assumes control of STM without the consent of the international space community.

3. *ITU Comparison*

Lastly, the ITU illustrates that a single international authority can effectively oversee orbital traffic. GEO's characteristics make its orbital slots valuable to states and commercial space actors alike, and therefore, interested parties are willing to work through the ITU's authority. As technological capabilities have evolved over time, so has the ITU's constitution in order to maintain currency and meet the needs of GEO's occupants.[398] Furthermore, the ITU allows for contributions from academics and the commercial sector which enables it to effectively consider all stakeholders' interests as opposed to just states'.[399] As LEO becomes increasingly congested, states may come to view this region in a similar manner to GEO and recognize the need for an international body to oversee its activities.

4. *Hurdles to Implementation*

Unfortunately, given the current geopolitical climate, it seems unlikely that the level of trust and collaboration required for a top-down STM framework will materialize in the near future. A major policy concern that this type of regime presents is the amount of authority that would be ceded to a single entity. By voluntarily submitting to a global STM authority, states

[397] *Outer Space Treaty, supra* note 13 at art VII.
[398] Kristen Cordell, "The International Telecommunication Union: The Most Important UN Agency You Have Never Heard Of" (14 December 2020), online: <csis.org/analysis/international-telecommunication-union-most-important-un-agency-you-have-never-heard>.
[399] Jakhu, "STM for Near-space", *supra* note 48 at 321.

would not only be subject to on-orbit traffic rules, but to an STM authority that would have a level of control over when, how, and where a state's space objects operate. As a result, this could have a profound impact on the critical societal services that rely on space infrastructure. Relinquishing authority over the space objects that facilitate societal functions is likely not a viable option for many states which is understandable from safety, security, and sovereignty perspectives.

There are also logistical hurdles that make an international regime quite difficult to facilitate. Nag expresses concern over whether a standalone space traffic system would rely on a single authoritative master catalog of space objects, or if it should be comprised of multiple non-authoritative catalogs.[400] A single authoritative system would require all states to trust each other and transparently share SSA data, some of which may contain sensitive national security information. This is not only unlikely, but would also necessitate a greater amount of power (either human or machine) to ingest, filter, and deconflict all of the traffic data into a universal catalog.[401] Alternatively, a system dependent on multiple catalogs may encounter difficulties due to fragmented, inconsistent, or incomplete information.[402] Each option presents its own complexities, and this is but one of several challenging issues to be resolved before a top-down framework can be achieved.

Despite these and other lingering issues, it is difficult to envision how LEO will continue meeting the needs of a growing space sector in the coming decades without an international STM framework. The future of space requires an orderly system for avoiding conjunctions. It is incumbent on the international community to immediately begin collaborating towards such a

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[400] Nag, supra note 179 at 6.
[401] *Ibid.*
[402] *Ibid.*

system as there are many factors that must be resolved, and the space industry is not slowing down to wait on the law.

b. The More Likely Option – A Bottom-Up Evolution of Domestic and Soft Law

The absence of a definitive international STM authority has resulted in the need to implement STM policies at the domestic level. As noted above, a number of states have already begun efforts towards this by incorporating regulatory provisions addressing SSA and space debris. The hope would be that these policies eventually evolve into bilateral or multilateral agreements that can eventually serve as a foundation to kickstart an international STM regime.

1. *SPD-3*

The US taken the lead in developing domestic STM policy by way of the aforementioned SPD-3 which addresses the current and future risks presented by the increasing amount of congestion in space.[403] It also tasks specific federal agencies, namely NASA, the DoD, and the Federal Communications Commission (FCC), with implementing measures to achieve its goals.[404] Recognizing the value of the private sector, SPD-3 seeks to expand the use of commercial SSA services in order to advance STM science and technology.[405] Notably, the policy calls for a STM legal framework consisting of best practices, technical guidelines, safety standards, and behavioral norms.[406] With that charge, as a leader in global space operations, the US should spearhead STM's organization on both a domestic and global scale. SPD-3 addresses this by directing that regulatory agencies establish minimum standards for tasks such as collision

[403] SPD-3, *supra* note 55 at s 1.
[404] *Ibid* at s 6(f).
[405] Muelhaupt, *supra* note 100 at 84.
[406] SPD-3, *supra* note 55 at s 3(d).

avoidance, space objects cataloging, and creating orbital conjunction prevention protocols that can be distributed for implementation by other countries.[407]

Largely because of SpaceX, the US is responsible for over half of the active satellites in space, and hence, SPD-3 represents a substantial step toward managing space traffic.[408] If the US can implement an effective STM system, it will set an example that other countries can follow. The US can achieve this by conditioning future launch licenses on adequate in-orbit STM operations, including, but not limited to, enhanced SSA collection and sharing, AI-facilitated collision avoidance, compliance with a rules-for-the-road scheme, and promises to devote funds to ADR and OOS. This can be a highly effective tool to implement and enforce minimum STM standards, not only upon US operators, but also those from other nations who procure launches from the US government and private launch providers such as SpaceX. As these practices eventually become engrained in domestic law, their success (or failures, if applicable) can provide a foundation for future international law.

2. *Gaining Steam Around the Globe*

The comprehensive nature of SPD-3 is well-suited for a country like the US, which is a dominant force in the space industry. That said, such a robust model is not necessary for every nation. The IADC's debris mitigation guidelines and the LTS Guidelines both serve as solid foundations for nations to develop domestic STM requirements. SPD-3 encourages this, noting that "it is essential that spacefaring nations also adopt best practices for the common good of all spacefaring states."[409] These soft law instruments can prove quite fruitful for states looking to formulate domestic space policy, as their specificity on particular subject matters (e.g. space

[407] *Ibid* at s 5(c).
[408] Foust, *supra* note 28.
[409] SPD-3, *supra* note 55 at s 5(c).

debris) helps to address gaps in existing space treaties. The EU, Japan, Russia, and Australia have all developed their own versions of debris mitigation policies based on the IADC's guidelines.[410] In addition, several countries have also implemented, or are in the process of discussing national approaches to STM including Russia, China, and Japan.[411] For instance, France's 2008 Space Operations Act is a forward-leaning piece of legislation that requires French space entities to demonstrate SSA and debris mitigation plans during the licensing process.[412] This marked an early effort in ensuring that French space activities do not contribute to the long-term growth of space debris.[413]

One advantage of the IADC and UN LTS guidelines is that they were developed during the modern space era and reflect a balance between private and public interests. Whereas the five major space treaties were conceived before commercial space activities emerged on a large scale, these more contemporary guidelines provide models for how a future STM system might account for private actors' role in space. Accordingly, these soft law instruments offer a gateway through which individual states can use public-private partnerships with industry to formulate their own STM policies. Countries with developing space programs such as Argentina, Luxembourg, the United Arab Emirates, Australia, and South Korea are collaborating with private entities as well as other spacefaring nations in furtherance of STM practices, and in certain cases, means for increasing autonomous capabilities in space.[414] The result is that these nations have policies favorable to private space activity, which encourages investment in their space programs and STM operations.

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[410] Trevor Owen et al, *On the UN Space Debris Mitigation Guidelines: A Review and Proposal for Effective Norm Building* (Vienna: UNCOPUOS Space Debris Mitigation Project Group, 24 May 2024) at 4.
[411] ESPI, "Report 71", *supra* note 58 at 41.
[412] France, *French Space Operations Act*, JO 2008-518, 3 June 2008, at s 3.
[413] *Ibid.*
[414] European Space Policy Institute, *Emerging Spacefaring Nations - Executive Summary* (Vienna: European Space Policy Institute, 2021) at 6-9 [ESPI, "Emerging Nations"].

Another avenue for states to enhance their own STM procedures is through improving their compliance with the Registration Convention. Designed to ensure accountability, responsibility, and the identity of space objects, the Registration Convention elaborates on Articles VI, VIII, and XI of the Outer Space Treaty and calls on states to register space objects when they have been launched into orbit.[415] This is to be accomplished by registering the space object in both a national registry and a UN registry.[416] The Registration Convention outlines fundamental items that must be included in the UN registry, such as basic orbital parameters.[417] However, it leaves the contents of domestic registries up to individual states.[418] In many cases, the information entered into these registries is vague and incomplete, which limits the value of the registries from an STM perspective.[419]

As has been discussed at length, a key component of being able to manage space traffic is the ability to accurately identify, locate, and track objects in space. Accordingly, states can use this established treaty to help facilitate domestic STM policies in multiple ways. First, states that have not ratified the convention should do so. As of July 2024, the Registration Convention only had 72 signatories as opposed to the 137 signatories of the Outer Space Treaty.[420] By committing to the Registration Convention, states signal their intention to gather data that can enhance SSA. Whether or not this data is eventually shared globally may depend on factors such as national security; however, the practice of obtaining data that can assist with SSA is a promising first step. Second, when states impose stringent domestic registration requirements, it helps to ensure they retain jurisdiction and responsibility over space objects that may

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[415] *Registration Convention, supra* note 39 at art II-IV.
[416] *Ibid.*
[417] *Ibid* at art IV.
[418] *Ibid* at art II.
[419] Henry R. Hertzfeld, "Unresolved issues of compliance with the registration convention" (2021) 8:3 J Space Safety Engineering 238 at 238-239.
[420] *Status of International Agreements relating to activities in Outer Space, supra* note 303.

malfunction or become defunct. This is particularly important as satellite constellations become more prominent, as these large constellations often expect some amount of failed satellites from their outset.[421] Determining the ownership of space debris is crucial for STM because it allows the state with jurisdiction and control to collaborate with other states with ADR capabilities and can ensure they are held accountable in the case of a conjunction.

Twenty-five countries have demonstrated independent launch capabilities.[422] These countries can lead the way in creating domestic STM regulations through implementing registration and licensing requirements. By developing specific STM domestic policies that require space actors to share data, mitigate debris, and comply with on-orbit traffic rules prior to launching, these launch-capable nations can establish a framework for other spacefaring nations to follow. If the 25 countries currently holding the keys to space put their domestic STM into practice, it should soon become apparent which practices are effective and should morph into international standards, and which are disruptive, ineffective, or may lead to conflict. In turn, this will prompt discussion at UNCOPUOS aimed at codifying the successful practices into international law. Alternatively, if a bottom-up STM framework comprised of various domestic and soft law policies proves ineffective, it could generate discussions at the international level about the pressing need for a top-down global plan. Either way, there will be progress towards effective STM so long as individual states act now and take a strong stance on requiring space actors comply with rules pertaining to SSA, debris mitigation, and on-orbit traffic organization.

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[421] Ailor, *supra* note 26 at 316.
[422] CIA, “Space Launch Site(s)” The World Factbook, (last accessed 4 September 2024), online: <cia.gov/the-world-factbook/field/space-launch-sites/>.

3. *Incorporating AI into Domestic STM Law*

As nations actively pursue STM policies, they must also consider how to best regulate the use of AI. SPD-3 calls for autonomous collision avoidance but makes no reference to other means by which AI should or should not be employed in space.[423] AI law is still in its infancy as countries figure out how to best govern machine learning. Those countries that have formulated laws or policies regarding AI tend to focus on its impact towards human rights and protecting individuals' privacy.[424] Similarly, the UN has adopted AI-related resolutions aimed at protecting human rights.[425] While states are correctly weary about using AI to track human data and movement, this very practice of tracking objects is an absolutely necessity for STM. It is therefore essential that domestic STM frameworks include specific references regarding sharing of information with AI technologies to facilitate machine learning, advanced data processing, collision avoidance, and debris remediation tasks. Providing comprehensive tracking and observation data to STM systems is the most effective way to ensure safe navigation in congested orbits.

However, it is also essential to address concerns about how AI will utilize this data. It is therefore incumbent on states to ensure that AI used for STM is done in a legal manner. Specifically, state frameworks for STM must provide clear guidance on the accountability and responsibility of those employing AI. This should include requirements that AI-driven space technologies be transparent, maintain human involvement, and be designed to avoid harmful interference. In the absence of adequate legal frameworks defining the AI's role in STM, there is likely to be a lack of trust in its use, as well as concerns that it will evolve in unpredictable and

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[423] SPD-3, *supra* note 55 at s 5(b).
[424] White & Case, *supra* note 225 at United Nations.
[425] *Ibid.*

unmonitored ways. In a general sense, the challenge for legislators and policymakers addressing AI is to verify that the technology's governance is aligned with ethical and responsible principles, but also flexible so as to keep pace with its rapid evolution.[426] Specific to AI in space, it is essential that states retain an ability to manage this technology while simultaneously allowing it to adapt and resolve issues associated with overcrowding and congestion.

c. Conclusion

It is encouraging to see that several states are implementing or developing STM policies and frameworks. This demonstrates a general recognition of the challenges posed by the current space environment and states' commitment to addressing them. While the establishment of an international treaty and governing body for the management of space traffic is an attractive proposition, it would require the cooperation of major global players who have demonstrated an inability to agree on new space law.[427] Space actors should find it concerning that this issue has not been addressed more promptly, given the continued expansion of the space industry and the ever-increasing reliance on space-based resources. Until such a framework is established, it remains up to individual states to work within and amongst themselves to facilitate critical STM operations including improving SSA, tracking, and collision avoidance, as well as pressuring space operators to not only mitigate but remove space debris. The effectiveness of the bottom-up framework remains to be seen; however, inaction is not a viable option given the immediate need to manage traffic in space.

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[426] Ian Bremmer & Mustafa Suleyman, "Building Blocks for AI Governance" (December 2023), online: <imf.org/en/Publications/fandd/issues/2023/12/POV-building-blocks-for-AI-governance-Bremmer-Suleyman>.
[427] Khan, *supra* note 20 at 38-39.

Conclusion

"Space is starting to resemble the Wild West."[428]

In the 70-year history of space exploration, there have been four documented collisions between objects large enough to track.[429] Given the relatively low frequency of these noticeable conjunctions (approximately one every 17.5 years) it is understandable to question the value of investing in the complexity of STM. One might argue that it would be more cost-effective and straightforward to simply assume that space objects will continue to miss one another and hope that such luck continues. However, it is not a matter of if, but when our luck will run out, and by then the consequences of failing to address space traffic could be catastrophic. Modern security, economic, and societal functions are becoming increasingly, if not entirely, dependent space activities.[430] As a result, the number of objects in space is skyrocketing, with no signs of slowing down, and the freedom of use and access is becoming threatened by overcrowding, congestion, and an increased risk of collisions. Given the overpopulation of LEO, the next large collision could very well spark the cascading creation of debris predicted by Donald Kessler in 1978.[431]

Managing space traffic is feasible through enhanced SSA and space debris remediation, both of which demand the assistance of AI. AI's ability to facilitate these activities is crucial to tackling STM due to the overbearing amount of data that operators will have to analyze as space traffic grows and space tracking improves. In essence, AI will enable STM functions to shift computer-assisted human operations to non-human analysis, decision-making, and action.[432]

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[428] Christopher Munoz, "'Space Is the Wild West': Expert Says International Action Needed to Address Growing Space Debris Problem" (17 October 2023), online: <syr.edu/blog/2023/10/17/space-is-the-wild-west-expert-says-international-action-needed-to-address-growing-space-debris-problem/> *quoting* Sean O'Keefe (former NASA administrator).

[429] See Aerospace, *supra* note 15. Note: this tally does not include intentional ASAT tests or deliberate collisions to destroy or remove satellites from orbit.

[430] Sadat, *supra* note 170 at 10.

[431] Kessler, *supra* note 71.

[432] Long, *supra* note 185 at 711.

This is a significant transfer of power that must be accompanied with guarantees from those employing AI technologies that they will be used ethically and remain subject to human oversight. However, if done properly, in addition to enabling more efficient, consistent, and effective STM operations than human operators, AI technologies can also facilitate compliance with existing legal obligations outlined in international law. Fortunately, there is a significant compatibility between ethical standards of AI use and outer space law. The ability for these two areas to be neatly harmonized paves the way for AI standards to be incorporated into future STM frameworks. Doing so will maximize AI's ability to manage and reduce congestion in orbit.

Chapter 1 of this thesis identifies that although there is no officially adopted definition of STM, it generally is understood to consist of technical measures that impact how space objects travel through orbit, and a regulatory means for governing how operators safely share the space environment. It also identified soft law principles currently aimed at STM which states can implement at their discretion. The comparison between space and the sea and air domains illustrated why mere adoption of the ICAO or COLREGs model is insufficient to meet the unique needs of outer space. Chapter 2 reviews various scholarly proposals to define and resolve STM on a global scale, and highlighted concerns that have been raised regarding using AI for STM. Chapter 3 briefly explains AI and machine learning for the purposes of this thesis and introduces the ethical principles of AI that align closely with space law concepts as discussed in the chapters that follow.

Chapter 4 outlines how AI can enhance SSA in three ways: 1) improving the ability to detect small objects in space beyond current capabilities, 2) providing more accuracy in tracking space objects as they traverse space, and 3) increasing the ability to avoid conjunctions. Chapter 4 contends that by enhancing SSA, AI not only makes space safer but also facilitates states' compliance with their obligations under the Outer Space Treaty, including those related to responsibility, supervision, and due regard. Finally, it emphasizes the importance of re-interpreting the Liability Convention in light of the modern space environment so as to account for AI-caused damage. Such an interpretation is crucial to ensure that states remain accountable for the actions of their AI technologies in space.

Chapter 5 examines the role of remediating space debris as a critical aspect of STM, given the potential risks posed by uncontrolled debris to active space objects. It explores AI's critical role in not only mitigating debris by facilitating reusable rocketry, OOS, and end-of-life de-orbiting, but also as an indispensable component in actively removing debris from space. In this way, AI helps states assert control over debris and exercise due regard to avoid contamination of the space environment, as required by the Outer Space Treaty. Chapter 5 cautions that while AI can be an invaluable tool in reducing space debris, it is essential to confirm that its deployment is ethical so that it cannot be tainted by biases in development or exploited for malicious purposes.

Chapter 6 surveys potential frameworks for specific STM governance beyond the scope of existing space law treaties and soft law instruments. The growth of the space industry has led to an increased need for a system to govern traffic in orbit. Chapter 6 scrutinizes two potential governance frameworks: a top-down approach, in which STM is regulated and coordinated at the international level; and a bottom-up approach, in which governance is left to individual states to develop policies, practices, and standards that may eventually be adopted at the international level. The former option is preferable, but the current geopolitical landscape makes it unlikely. Therefore, international norms are more likely to be developed via the bottom-up approach. Using domestic law to create a baseline for STM practices has the additional benefit of allowing states to include the rapidly expanding AI technology in their STM policies. In turn, this will help to lay a foundation for governing its use in space.

The current trajectory of increasing dependence on space for nearly every aspect of daily life, as well as its use to pursue economic profit, will render it unsustainable if the global community fails to effectively manage space traffic. Experts estimate that within the next decade, the space economy will be worth nearly 2 trillion dollars, 1.5 billion more than it was in 2023.[433] This level of growth will render highly valuable orbits unsustainable unless action is immediately taken to facilitate safe navigation in these areas. Even if other orbits can eventually be used in a means similar to LEO, congestion will remain a problem as technology opens doors to activities such as space colonization, celestial mining, and space warfare.

The private sector must be given an opportunity to contribute to the development of international standards and best practices for STM, as well as the governance structures that will keep space sustainable. Regulators must provide support to industry partners engaged in the study and development of technologies, such as AI, that can adaptively help reduce congestion in orbit. The advantages of international collaboration in ensuring the safety of space operations extend beyond the domain of space traffic. Practices such as enhanced SSA and debris mitigation can deter hostilities by increasing transparency and fostering trust and confidence between states regarding the beneficial utilization of space. For these benefits to be realized, space actors must leverage AI's capabilities to facilitate compliance with international legal obligations, thereby ensuring valuable regions of space continue to be freely accessible and open for the shared interests of all.

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[433] Alizée Acket-Goemaere et al, "Space: The $1.8 trillion opportunity for global economic growth" (8 April 2024), online: < mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth>.

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