The Enforcement of Law and Policy on STM with the Emergence of Advanced Technologies

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Space Traffic Management (STM) using advanced technologies is effective for the safety and sustainability of outer space by improving Space Situational Awareness (SSA), data sharing information system, collision avoidance, and space debris mitigation methods. Nevertheless, developing an effective STM using advanced technologies without considering an effective legal and regulatory framework can pose some difficulties in terms of monitoring and enforcement. This paper presents the relevance of innovative advanced technologies and STM, focusing on the enforcement of law and policy. It highlights an urgent need to update the legal framework to ensure their practicality amidst the widespread use of advanced technologies in space activities. It also examines the fact that the utilization of advanced technologies in the environment of outer space presents both opportunities and challenges, especially with the emergence of Artificial Intelligence (AI) and Machine Learning (ML). Although revising all regulations is anticipated to be a challenging and time-consuming process, it can be implemented through communication and cooperation between spacefaring countries, private space operators, and other relevant entities at the national and international levels, as well as permanent monitoring and evaluation of all technologies to ensure that they are used in a manner that is consistent with established laws and policies.

Keywords: Space Traffic Management, Space Law and Policy, advanced technologies, Space Safety and Security, Space Situational Awareness.

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Introduction

Recent developments in space activities, especially in the private sector, and the huge amount of space debris in outer space without any significant achievements in space debris control necessitate the implementation of an international STM regime. According to the current space law regime, there is no international consensus on the definition and scope of STM. In general, STM includes technical and regulatory provisions to promote safe access into outer space, operations in outer space, and re-entry from outer space to Earth, free from physical or radio-frequency interference, as stated in the International Academy of Astronautics (IAA) report (Contant-Jorgenson et al., 2006). However, it is not a proper definition for STM, and it consists of its objectives rather than the concept of STM (Yang, 2019). The objective of STM to provide safety, stability, and sustainability of space activities is consistent with the principles of space law, which include international cooperation and peaceful purposes. It is a vital necessity in space law to establish an international STM regime that involves appropriate technical capacity and effective regulatory arrangements at both domestic and international levels. The enforcement of law and policy on STM is crucial to ensuring the management of risks. However, the emergence of advanced technologies is completely evolving the scope of space operations (Yang, 2019).

At the same time, many spacecrafts are launched into different orbits around the Earth with various missions, such as commercial, defense, scientific, and educational. Ensuring the safety of all space missions and the long-term sustainability of space exploration is a crucial necessity. All of the risks and threats in the environment of outer space must be taken into consideration, and the legal framework should consider all kinds of space missions (Marty et al., 2023). As mentioned above, according to the Cosmic Study on STM published in 2006 by the IAA study group, STM is defined as the collection of technical and regulatory measures that support the safety of space missions (Contant-Jorgenson et al., 2006). This definition encompasses a broad variety of the procedures involved in launching, tracking, controlling, supervising, and re-entering all kinds of spacecrafts with any purpose. Additionally, STM's primary objective is to ensure the sustainability and safety of space operations by reducing the possibility of spacecraft collisions and reducing the amount of space debris. It includes ensuring concerns regarding the application of law and policy with developing advanced technologies in the space environment. Even though advanced technologies offer incredible prospects for space traffic control, they cause new difficulties for space legislation. For example, there are issues with the existing laws governing liability issues in the event that highly intelligent computers cause harm (Martin & Freeland, 2021). Therefore, the regulations have not kept up with technological advancements in outer space, and there is a lack of a coherent legal system. The rules have not been able to keep pace with technology, and today there are shortcomings in the legal environment (Schrogl, 2008).

This paper highlights the legal regulatory framework of STM that must keep pace with advanced technologies, especially with the increase of commercial companies, mega-constellations of small satellites, and space tourism in the future. The primary contribution and difference of this work includes addressing the challenges and opportunities of advanced technologies in outer space.

The use of advanced technologies in STM

NewSpace advanced technologies provide effective opportunities to enhance STM's capabilities while also creating new challenges. The Regulatory Horizons Council (RHC) has identified key technologies, which are the fundamental building blocks for current and future space capabilities, including AI and ML, novel materials and nanotechnology, software and automation, quantum technologies, and robotics. For instance, the opportunities of AI and ML include analysis of large, complex data sets, real-time and predictive spatial awareness, and enhanced decision-making, whereas their challenges include biased or partial training data, "black box" decision-making, lack of trust or public concern, cybersecurity, standards for interoperability, and liability issues (Report, 2024).

Therefore, with the emergence of NewSpace, the number of private space companies using advanced technologies has increased (Heinrich et al., 2022). It includes large LEO constellations and small satellites like cube satellites, which will radically change space operations and, combined with new sensor systems, necessitate changes in the way STM is conducted. For instance, there are multiple constellations, each with thousands of satellites, being proposed to provide global broadband Internet services (Peterson et al., 2018).

The opportunities of advanced technologies

To control space traffic and ensure the sustainability and safety of space operations, many innovative technologies are under development. Despite the lack of precise data on their quantity, research indicates that most technological innovations remain unimplemented. But based on the available information, less than ten percent of patent applications are filed worldwide. Actually, the vast majority of novel technologies in the twenty-first century remain unpatented (Krichevsky, 2018). We are currently experiencing the greatest shift in the space environment since activities in outer space first began. Globally, commercial opportunities in the space area are providing innovation among a large number of multitude actors across a spectrum of markets that include new satellite platforms and launch services, data gathering, analysis, and transmission for information services (Hayden et al., 2020).

Firstly, modern space communication systems use sophisticated software to enable different stages of space missions. With the emergence of AI and ML, satellites can seamlessly manage these systems, making decisions in real-time without waiting for instructions. Drawing on AI, cognitive technologies are being developed to enhance the efficiency and sustainability of communication networks for space missions. In space, one of the issues that a cognitive radio can manage is interference from solar and astronomical electromagnetic radiation. Cognitive radio applications use ML to either transmit beyond the interference range or correct distortions within it. AI has allowed rovers and orbiting devices to gather and evaluate scientific data automatically, deciding which information to communicate to Earth without human intervention, whereas previously they managed onboard systems like power usage (Soroka & Kurkova, 2018).

Secondly, space traffic control uses technologies including AI, to monitor and direct spacecraft movement in orbit through Space Surveillance and Tracking (SST) and SSA. In this field, mitigating space debris in outer space is gaining significant boosts (Muelhaupt et al., 2019). The space industry needs uninterrupted access to reliable, actionable information to adequately address space traffic. Innovations in technology could help collect reliable information through revolutions in the space industry. The aim of the advanced technologies used in SST and SSA is to identify objects in space and determine their position, their necessary features, and their motion in orbit, with a specific interest in the motion relative to other objects for sustainability and security reasons. Globally, both institutional and private entities are deploying or planning SST systems, including radars and telescopes. This trend will result in a more comprehensive knowledge of the orbital population. Currently, numerous databases have been developed using data gathered from various sources worldwide. It could be useful to merge and share measurements from these databases. Although there are many issues related to the protection of some data, specifically issues related to military systems (Bonnal et al., 2020). SSA entails the constant tracking of satellites and debris in orbit using ground-based radar and optical stations to forecast the orbital trajectory of debris (Sheer et al., 2023). Therefore, satellite operators can prevent potential collisions with space debris by positioning their operational spacecraft away from their intended debris orbits (Pelton, 2019). Ground-based sensors are indispensable for achieving effective SSA and STM. Accurate orbital parameters, technical status, and knowledge of the attitude of cooperative and non-cooperative Resident Space Objects (RSOs) are crucial under normal or contingency operations. Particularly for Active Debris Removal (ADR) missions, targeted studies of candidate objects are vital (Shan et al., 2016). ADR and On-Orbit Servicing (OOS) missions require a high level of preparedness, incorporating high-quality and actionable information on target objects from the planning phase onward. This information includes particular knowledge of the target's shape, size, etc. (Karamanavis et al., 2023).

Thirdly, automated collision avoidance systems use innovative algorithms and ML to predict potential collisions between objects in space and take the necessary actions to avoid them. Similar to air traffic control, STM is keeping an eye on and guiding the movement of spacecrafts in orbits in order to avoid collisions. Advanced algorithms and ML are used in automated collision avoidance systems to predict potential collisions and take the necessary actions to avoid them.

Fourthly, the current methods for describing avoidance manoeuvres and recognizing collision probabilities in outer space mainly rely on human procedures, which means that they depend on human experts to analyse the optimal manoeuvre for collision avoidance as well as to determine if an occurrence is a high or low risk. Existing methods face issues such as insufficient data and a lack of scalability. Additionally, a multitude of false alarms and ambiguity indicate that the optimization of data processing methods remains incomplete. At the same time, every space operator needs to have access to performable information about RSO and their relative movement, as well as performable information regarding the environmental conditions in space in a more general sense. So, current methods for satellite operators are non-scalable and require a lot of time. Operator effort is required to handle an exponential growth in the number of space objects, including debris and active satellites. This increases the possibility of human error and incorrect classification, which makes operations more expensive. Furthermore, it is more difficult for insurance providers to appropriately handle the risk faced by operators due to the complexity and lack of certainty around the risk exposure assessment. Advanced technologies provide reliable, practical data and an assurance of uninterrupted information to effectively tackle STM. As the space industry develops, the adoption of these advanced technologies for STM and space activities towards autonomy will be significant to ensure space sustainability and limit the number of risks to space assets (Manfletti et al., 2023).

Fifthly, following the theme of the protection of the Earth, climate change is an important challenge to our environment with potentially catastrophic consequences and is an area where satellite technologies can support tackling the threat (Bru¨nner et al, 2018). Satellites provide impartial information to monitor the environment and develop and validate models, improving our predictive capabilities. However, greater effort has to be placed in producing actionable information related to specific needs and issues, reducing the vast amount of data to simpler interpretations that can inform the political discourse (Aglietti, 2020).

Finally, researchers are developing Space Debris Removal (SDR) technologies, such as harpoons, nets, and robotic arms, to capture and remove debris from orbit, thereby mitigating the amount of space debris and the risk of collisions. Therefore, advanced technologies, such as AI and ML algorithms, enhance the quality and speed of each stage and procedure of space activities and decisions, making them the most important samples in the space industry.

The challenges of advanced technologies

On the one hand, advanced technologies can greatly improve STM efficiency, providing significant opportunities in outer space. On the other hand, if they are not used properly, they raise significant privacy and legal concerns. To realize the sustainable and equitable benefits of these technologies, space exploration and communication require careful consideration and collaborative approaches. Specifically, the increasing launches of private companies like SpaceX's Starlink, Amazon's Project Kuiper, and OneWeb, the growth of LEO mega constellation satellites, and future space tourism pose the most critical challenges to outer space.

Firstly, without a proper regulatory framework in place, there is a risk of misuse of advanced technologies by the widespread operation of satellites, particularly by private operators, potentially leading to a more congested outer space environment, collisions of space assets, and the growth of space debris. With so many satellites communicating wirelessly, coordinating Radio Frequencies Interferences (RFI) becomes more complex, requiring international cooperation. The issue of the overcrowded radio-frequency spectrum, as well as the sustainability of the space environment, which is threatened by the growing amount of space debris, have to be tackled.

Secondly, there are challenges with data protection. Technologies like AI require large volumes of data, but weakly drafted laws and regulations can prevent useful access without mitigating the risk of AI activities (Oche et al., 2021). In January 2020, the United States imposed immediate interim export controls regulating the dissemination of AI technology software that possesses the ability to automatically scan aerial images to recognize anomalies or identify objects of interest, such as vehicles, houses, and other structures (Carlin et al., 2020). Also, the use of AI in satellite imagery raises concerns about losing control over one's private information and causes privacy and legal issues (Finn et al., 2013).

Thirdly, cyber-attacks on critical infrastructure could disrupt satellite operations, compromise communication systems, or even endanger the safety of astronauts on board spacecraft. Hackers could potentially control satellites or manipulate data, leading to serious consequences for space traffic. Advanced technologies, such as drones and autonomous robots, can be misused for harmful purposes, including surveillance and weaponization.

Fourthly, advanced technologies have the potential to automate many aspects of STM, reducing the need for human intervention. However, this chance provides reliable, practical data and an assurance of uninterrupted information to effectively tackle STM, it can also lead to a lack of human oversight and decision-making, which is essential for addressing unforeseen challenges or emergencies in space. The use of space technologies capable of functioning completely without human intervention could result in unpredictable outcomes, which pose fundamental issues for the international community (Abashidze et al., 2023).

Finally, there are challenges to the liability of intelligent space objects. Existing liability regulations in space law treaties are not adequate to address the future role of AI in space activities. In addition to the liability issues, the current international treaties that regulate the activities of States in the environment of outer space aren't sufficient for issues arising from the potential use of advanced technologies.

The current legal framework of STM

Since the space age began, approximately 16990 satellites have been sent into orbit, with roughly 11500 still in orbit as of December 2023 (Space, 2024). The significant increase in space activities necessitates the development of the best rules and regulations for an international STM legal framework. So far, there is no established international legal system for STM. There are still many debates between countries on whether STM is an international issue or an internal one to manage.

Considering the hard law, the Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, or the Outer Space Treaty (OST) provides the basic framework for international space law. Article I of the OST stipulates that the outer space shall be free for exploration and use by all States without discrimination of any kind, on the basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies. Article II of the OST stipulates that outer space is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means. Except for the prohibitions on nuclear weapons tests in space and the prohibition on the placement of nuclear weapons or other weapons of mass destruction in space, which have been mentioned in Article IV, there aren't any international, legally binding treaties or agreements that restrict the freedom of countries action in outer space. It is also stipulated in Article III that States Parties to the Treaty shall carry on activities in the interest of maintaining international peace and security and promoting international cooperation and understanding. The Convention on International Liability for Damage Caused by Space Objects, or the Liability Convention, provides in Article II that launching States shall be absolutely liable to pay compensation for damage caused by their space objects on the surface of the Earth or to aircraft in flight. The Convention on Registration of Objects Launched into Outer Space, or the Registration Convention, also provides in Article II that the launching State shall register the space object by means of an entry in an appropriate registry, which it shall maintain. Each launching State shall inform the Secretary-General of the United Nations of the establishment of such a registry.

While the basic principles outlined in these treaties align with the establishment of a Space Traffic Management (STM) regime, there is currently no legally binding international treaty regime in place to exclusively address space traffic rules (Gleason, 2020). There are only international initiatives aimed at establishing voluntary standards or guidelines to enhance the sustainability and safety of space operations as soft law. There are some soft laws, like the Long-Term Sustainability of Outer Space Guidelines (LTS) by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), that could strengthen STM as the most important issue for the safety and security of space activities in outer space (Polkowska, 2021). Although there is no legal framework on how to calculate the chance of collisions and different probabilities of space risks (Li et al., 2022), there are a number of agreements (Spencer et al., 2024). Satellite operators implement bilateral agreements between themselves to decrease accidental collision risks (Nonreimbursable, 2021). Meanwhile, the European Cooperation for Space Safety Standards (ECSS) is also intended to organize clear standards for European space operations. The International Organization for Standardization (ISO) has also made many suggestions to improve safety in outer space by mitigating space debris and regulating space activities, even though ISO standards are not binding (Kaul, 2019).

Furthermore, many countries assume responsibility for their space operations by highlighting the importance of STM. For example, France believes that STM should remain the responsibility of States because it concerns their security (Marty et al., 2023). In this regard, national space policy documents exist for STM, such as the U.S. Space Policy Directive-3, the most significant national measure for STM regulation, and the European Union's joint communication.

Advanced space technologies and the need for the enforcement of an appropriate legal framework

Following the challenges of advanced technologies in outer space, there are many challenges with the enforcement of law and policy in this environment. If there is a threat of the rule of law being displaced by the rule of technology, the legal community needs to address these developments as an urgency (Brownsword & Yeung, 2008). Advanced technologies, including AI and ML, provide new services offered through applications of space data. They can be used to improve SSA and assist in more accurate tracking of space debris and other objects in orbit. This can help reduce the risk of collisions and improve safety for all spacecraft in orbit. However, malfunctioning or hacked automated collision avoidance systems could potentially lead to spacecraft collisions and increase space debris. Similarly, improper use of satellite servicing or debris removal technologies could unintentionally damage existing satellites or create new debris (Frey & Lemmens, 2017).

The increase of advanced technologies has led to the diversity and growth of space operations and, subsequently, the increase of space object break-ups, explosions, collisions, and other anomalous events resulting in fragmentation, rendering human activities that rely on space platforms precarious or even impossible (Kessler & Cour-Palais, 1978; Klinkrad, 2017; McKnight et al., 2021). At the same time, it could pose more futuristic legal complexities, including challenges with space tourism and liability issues. With the era of private space flights, it is becoming vital to have a common understanding of the current space legal systems through the applicability of the Liability Convention in handling damage that might occur during space tourism (Wang & Li, 2021). Based on Article III of the Liability Convention, fault liability is assumed to be the fault of a State or the fault of a person. Here is where we can identify the first challenge, identifying the liable entity when a decision is taken by an intelligent space object. Hence, challenging liability issues arise with the increased implementation of innovative space technologies. The growth of space tourism also requires a robust regulatory regime to ensure that companies comply with safety and operational standards. A clear licensing system needs to be developed to assess and approve commercial space operations. The rapid pace of technological advancements in space tourism necessitates a flexible legal framework that can adapt to new innovations, such as reusable rockets and suborbital flights, while still ensuring safety and compliance with existing laws.

On the one hand, States should consider the development of a new international treaty, the amendment of existing treaties, or the adoption of an interpretative declaration, if at least temporarily, as an adequate measure to resolve relations arising from the use of advanced technologies in space activities. Space activity is defined as both activity in outer space and activity on Earth associated with outer space (Abashidze et al., 2022). It needs States to be pragmatic to work on a resolution to reflect the demands of all parties in a balanced manner, so they can achieve a clear understanding of the deficiencies of the old legal system in dealing with new threats and challenges and see the direction of rule interpretation and rule-making (Wang & Chen, 2023). This could be a possible solution for States to participate in cooperative efforts to access and use the space environment (Blount, 2021).

On the other hand, national regulatory bodies and legislators must approve further special regulations. The national legislation of countries has not yet made prominent achievements for managing the emergence of new technologies in outer space, and every country faces significant challenges due to technological advancements. All courts will encounter challenges in applying traditional rules to new technologies like AI (Dempsey, 2020).

Conclusion

While advanced technologies present new opportunities for space exploration and utilization, their irresponsible use also poses new challenges to outer space's safety and sustainability. In this situation, there is a need to enforce law and policy within the framework of STM. To enforce the required rules and regulations, governments and industry must cooperate both in international forums and at the national level. Establishing a legal framework and implementing advanced technologies in pace operations require consistent communication between countries and the private sector. As a result, the enforcement of an effective legal regime on STM should include data sharing, which requires countries' cooperation, as well as regular updating of the law and policy to keep up with the evolution of technologies.

🕮 References

Abashidze, AK, Ilyashevich M., and Latypova A. (2022) Artificial intelligence and space law. *J. Legal Ethical & Regul*. Volume 25, Special Issue 3. Available online: https://www.abacademies.org/articles/Artificial-intelligence-and-space-1544-0044-25-S3-040.pdf

Aglietti, G. (2020) Current Challenges and Opportunities for Space Technologies. *Frontiers in Space Technologies*, Volume 1. https://doi.org/10.3389/frspt.2020.00001

Blount, P. (2021) Space Traffic Coordination: Developing a Framework for Safety and Security in Satellite Operations. *Space: Science Technology*, Volume 2021, 1-10. https://doi.org/10.34133/2021/98303

Bonnal, C., Francillout, L., Moury, M., Aniakou, U., Perez, J.C.D., Mariez, J. and Michel, S. (2020) CNES technical considerations on space traffic management. *Acta Astronautica*, Volume 167, 296-301. https://doi.org/10.1016/j.actaastro.2019.11.023

Bru¨nner, C., Ko¨nigsberger G., Mayer H., and Rinner A. (2018) Satellite-Based Earth Observation Trends and Challenges for Economy and Society: Trends and Challenges for Economy and Society. Conference proceedings. https://doi.org/10.1007/978-3-319-74805-4

Brownsword, R., and Yeung K. (2008) Regulating technologies: legal futures, regulatory frames and technological fixes. Bloomsbury Publishing.

Dempsey, JX. (2020) Artificial Intelligence: An Introduction to the Legal, Policy and Ethical Issues. USA, Berkeley: Berkeley Center for Law & Technology.

Contant-Jorgenson, C., L´ala P., and Schrogl KU (2006) The IAA cosmic study on space traffic management. *Space Policy*, Volume 22, 283-288. https://doi.org/10.1016/j.spacepol.2006.08.004

Carlin, John P., Nicholas J. Spiliotes, Charles L. Capito, Joseph A. Benkert, Panagiotis C. Bayz, Amy S. Josselyn, Jonathan M. Babcock (2020) US department of commerce imposes immediate export controls on artificial intelligence software used to automatically detect and identify objects remotely. The Journal of Robotics, Artificial Intelligence & Law, Volume 3, 9.

Finn, RL., Wright D., and Friedewald M. (2013) Seven Types of Privacy. In: European Data Protection: Coming of Age. Ed. by Gutwirth S, Leenes R, Hert P de, and Poullet Y. Dordrecht: *Springer Netherlands*, Volume 3, 32.

Frey, S., and Lemmens S. (2017) Status of the Space Environment: Current Level of Adherence to the Space Debris Mitigation Policy. *Journal of the British Interplanetary Society*, Volume 70, 118-124.

Gleason, MP. (2020) Establishing space traffic management standards, guidelines and best practices. *Journal of Space Safety Engineering*, Volume 7, 426–431.

Hayden, Nancy Kay, Reinhardt Jason Christian, Stewart Mallory, Doak Justin E, Gunda Thushra, and Abel Kelsey (2020) Artificial Intelligence and Autonomy in Space: Balancing Risks of Unintended Escalation. Conference: Proposed for presentation at the 38th International Systems Dynamics Society Conference held July 19-24, 2020 in Bergen, Norway.

Heinrich, S., Lucken, R., Mazieres, F., Belaud, A.? and Giolito, D. (2022) Space sustainability in the NEWSPACE Era: NO NEWSPACE without GREENSPACE. *Journal of Space Safety Engineering*, Volume 9, 464-468.

Karamanavis, Vassilis, Heinrich Dirks, Lars Fuhrmann, Frank Schlichthaber, Nora Egli, Thomas Patzelt, and Jens Klare (2023) Characterization of deorbiting satellites and space debris with radar. Advances in Space Research, Volume 72. Issue 8, 3269-3281. https://doi.org/10.1016/j.asr.2023.07.033

Kaul, S. (2019) Integrating Air and Near Space Traffic Management for aviation and near space. *Journal of Space Safety Engineering*, Volume 6,150-155.

Kessler, DJ and Cour-Palais BG. (1978) Collision frequency of artificial satellites: The creation of a debris belt. *Journal of Geophysical Research: Space Physics*, Volume 83, 2637-2646.

Krichevsky, S. (2018) Super global projects and environmentally friendly technologies used in space exploration: realities and prospects of the space age. *Philosophy and Cosmology*, Volume 20, 92-105. https://doi.org/10.29202/phil-cosm/20/8

Klinkrad, H. (2017) *Orbital Debris and Sustainability of Space Operations*. In: Handbook of Satellite Applications. Ed. by Pelton JN, Madry S, and Camacho-Lara S. Springer International Publishing, 1413-46.

Li, JS, Yang Z., and Luo YZ. (2022) A review of space-object collision probability computation methods. *Astrodynamics*, Volume 6, 95-120.

Manfletti, C., Guimara˜es M., Soares C. (2023) AI for space traffic management. *Journal of Space Safety Engineering*, Volume 10, 495-504.

Marty, JY., Bonnal C., Faucher P, and Francillout L. (2023) Space traffic management as a necessity for future orbital operations a French perspective. *Acta Astronautica*, Volume 202, 278-282.

Martin, AS., and Freeland S. (2021) The advent of artificial intelligence in space activities: New legal challenges. *Space Policy*, Volume 55, 101408.

McKnight, Darren, Rachel Witner, Francesca Letizia, Stijn Lemmens, Luciano Anselmo, Carmen Pardini, Alessandro Rossi, Chris Kunstadter, Satomi Kawamoto, Vladimir Aslanov, Juan-Carlos Dolado Perez, Vincent Ruch, Hugh Lewisi, Mike Nicolls, Liu Jing, Shen Dan k, Wang Dongfang, Andrey Baranov, Dmitriy Grishko (2021) Identifying the 50 statistically-most-concerning derelict objects in LEO. *Acta Astronautica*, Volume 181, 282–91. https://doi.org/10.1016/j.actaastro.2021.01.021

Muelhaupt, T., Sorge, M., Morin, J., and Wilson, R. (2019) Space traffic management in the new space era. *Journal of Space Safety Engineering*, Volume 6, 80-87. https://doi.org/10.1016/j.jsse.2019.05.007

Nonreimbursable Space Act Agreement Between the National Aeronautics and Space Administration and Space Exploration Technologies Corp for Flight Safety Coordination with NASA Assets (2021) NASA. Available online: https://www.nasa.gov/wp-content/uploads/static/saa/domestic/33007_NASA-SpaceX_Starlink_Agreement_Final_(Fully_Signed).pdf

Oche, P., Ata E., and Ibekwe N. (2021) Applications and Challenges of Artificial Intelligence in Space Missions. IEEE Access. Volume 12. Available online: https://ieeexplore.ieee.org/document/9634015

Pelton, J.N. (2019) A path forward to better space security: Finding new solutions to space debris, space situational awareness and space traffic management. *Journal of Space Safety Engineering*, Volume 6, 92-100.

Peterson, G., Sorge, M., and Ailor, W. (2018) Space traffic management in the age of new space. Center for Space Policy and Strategy, the Aerospace Corporation. Available online: https://aerospace.org/sites/default/files/2018-05/SpaceTrafficMgmt_0.pdf

Polkowska, M. (2021) Space traffic management (STM) – Legal aspects. *Polish political science yearbook*, Volume 50, 159-169.

Report on the Future Regulation of Space Technologies. Tech. rep. Regulatory Horizons Council (2024) RHC. Available online: https://assets.publishing.service.gov.uk/media/66278d17838212a903a7e5af/rhc_report_on_the_future_regulation_of_space_technologies_executive_summary.pdf

Schrogl, KU (2008) Space traffic management: The new comprehensive approach for regulating the use of outer space – Results from the 2006 IAA cosmic study. Acta Astronautica, Volume 62: 272-276.

Shan, M., Guo J., and Gill E. (2016) Review and comparison of active space debris capturing and removal methods. *Progress in aerospace sciences*, Volume 80, 18-32. https://doi.org/10.1016/j.paerosci.2015.11.001

Sheer, A., Fatima S., Farooqui MO., and Kasuri M. (2023) A Panacea to Address the Legal, Administrative and Economic Aspects of Space Debris. *Advances in Space Research*, Volume 72. https://doi.org/10.1016/j.asr.2023.02.023.

Soroka, L., and Kurkova K. (2019) Artificial Intelligence and Space Technologies: Legal, Ethical and Technological Issues. Advanced Space Law, Volume 3, 131-139. https://doi.org/10.29202/asl/2019/3/11

Spencer, DB, Sorge ME, and Skinner MA. (2024) Establishing "norms of behavior" for satellite collision avoidance maneuver planning. *Journal of Space Safety Engineering*, Volume 11, 120-126.

Space Environment Statistics. Space Debris (2024) ESA. Available online: https://sdup.esoc.esa.int/discosweb/statistics/

Wang, G., and Li C. (2021) Applicability of the Liability Convention for Private Spaceflight. *Space Science & Technology*. Volume 2021. https://doi.org/10.34133/2021/9860584

Wang, G. and Chen J. (2023) On the New Initiative for Responsible Space Behaviours Proposed by UK, U.S. and other States. *Space Science & Technology*, Volume 3, 10. https://doi.org/10.34133/space.0033

Yang, Kuan (2019) Chinese perspective on an international regime of space traffic management. *Journal of Space Safety Engineering*, Volume 6, 156-160.