Risk-Based Model for the Legal Regulation of Artificial Intelligence in Space Activities

Diana Levchenko

Ph.D. in Law, Associate Professor at the Department of Management and Innovative Development, KROK Business School, KROK University (Kyiv, Ukraine)
E-mail: diana.levchenko5@gmail.com
https://orcid.org/0000-0001-8343-2260

Levchenko, Diana (2026) Risk-Based Model for the Legal Regulation of Artificial Intelligence in Space Activities. *Advanced Space Law*, Volume 17, 28-40. https://doi.org/10.29202/asl/17/3

The increasing integration of artificial intelligence into space activities enhances the autonomy, efficiency, reliability, and scientific potential of space missions. At the same time, the use of AI for spacecraft control, autonomous navigation, data processing, robotic exploration, mission planning, and life-support systems generates complex legal, technical, organisational, cybersecurity, and data-related risks. This article aims to substantiate a risk-based model for the legal regulation of artificial intelligence in space activities and to identify its principal characteristics. The research applies systemic, comparative legal, formal legal, analytical, and risk-oriented methods.

The study demonstrates that the existing framework of international space law establishes fundamental principles applicable to AI-enabled space activities but does not adequately address algorithmic autonomy, dynamic system behaviour, limited human intervention, opacity of decision-making processes, and the allocation of responsibility among multiple actors. The risks associated with space-based AI are classified into four interconnected levels: institutional and governance risks; systemic and mission-level risks; operational and assurance-related risks; and cyber, information, and data-oriented risks.

It is argued that legal requirements should be differentiated according to the autonomy of the AI system, the criticality of its functions, the probability and severity of potential harm, and the possibility of effective human oversight. The proposed model is characterised by its multilevel, mission-centric, proportionate, life-cycle-oriented, evidence-based, preventive, and adaptive nature. It also requires controlled autonomy, continuous monitoring, independent verification and validation, clear allocation of obligations and liability, integrated cybersecurity safeguards, and international regulatory interoperability.

Keywords: artificial intelligence; space activities; risk-based regulation; international space law; legal liability; human oversight; cybersecurity.

Received: 2 April 2026 / Accepted: 29 May 2026 / Published: 30 June 2026

Introduction

Any new technology which has captured the attention and imagination of human beings has often subsumed, until the last century, within its legal framework at the international level, domestic or State-level governance systems, and pertaining to core aspects of its regulations; further leaving its implementational aspects to States and their governments. Thus, when space technologies were new and being introduced during the Cold War era, marked by increasingly volatile and ever-changing political commitments and stances of sovereign nations and the international community, binding treaties were adopted and enacted to govern space technologies to maintain certainty. However, since the 1980s, there have been other objects and subjects of its legal regulation, thus constituting and comprising what we refer to as the global space governance system. Artificial intelligence ('AI') technologies and systems, preceded by cyber activities, are the newest domains that need urgent attention of the international community, including international space law and policy enthusiasts, academicians, technical experts and social scientists, and law and policy-makers. In brief, AI systems are being developed with the core objective of mimicking the capabilities of the human mind artificially through machines (Mishra, 2022).

Artificial intelligence is gradually becoming one of the defining technological components of modern space activities. The use of AI in autonomous navigation, spacecraft control, the processing of large datasets, fault prediction, mission planning, the robotic exploration of space objects, crew life-support systems, and operational decision-making significantly expands the capabilities of both public and private actors engaged in space activities. At the same time, the increasing autonomy of AI systems, their integration into critical processes, and the limited possibilities for human intervention in the space environment give rise to a new category of legal risks that must be appropriately regulated.

1. The concept of AI-system and its impact on space activities

George Boole was the first to describe a formal language for logical reasoning in 1847. The next milestone in artificial intelligence history was in 1936, when Alan M. Turing described the Turing-machine. Warren McCulloch and Walter Pitts created the model of artificial neurons in 1943, and in 1944 J. Neumann and O. Morgenstern developed the theory of decision, which provided a complete and formal framework for specifying the preferences of agents. In 1949, Donald Hebb presented a value-changing rule for the connections of the artificial neurons that provided the chance of learning, and Marvin Minsky and Dean Edmonds created the first neural computer in 1951. Artificial intelligence (AI) was born in the summer of 1956, when John McCarthy first defined the term. It was the first time the subject caught the attention of researchers, and it was discussed at a conference at Dartmouth. The next year, the first general problem solver was tested, and one year later, McCarty regarded as the father of AI, announced the LISP language for creating AI software. Lisp, which stands for list processing, is still used regularly today. Herbert Simon stated in 1965: "Machines will be capable, within twenty years of doing any work a man can do." However, years later, scientists realized that creating an algorithm that can do anything a human can do is nearly impossible. Nowadays, AI has a new meaning: creating intelligent agents to help us do our work faster and easier (Benko, 2009; Russel & Norvig, 2005; McDaniel, 1994; Shirai & Tsujii, 1982; Mitchell, 1996; Schreiber, 1999).

Artificial Intelligence is an area of computer science that raises many questions in philosophy, neuroscience, and cognitive science. It is also an area of technological innovation that has completely transformed some aspects of human life and continues to do so. Several broad projects are pursued within AI, depending on whether one is using AI systems to model human psychology or to describe idealized rationality, and depending on whether the focus is on the behavior of a model or also on its internal structure. There are many successful approaches to AI, including symbolic systems and connectionism, and these approaches often compete to explain the full range of cognitive capabilities. There are also philosophical debates about whether it is possible in principle to build a genuinely intelligent computer system. Whereas many approaches to AI have advocated strict divisions of labor between disciplines, we endorse explanatory pluralism, which uses varied approaches to model disparate aspects of cognition and leverages the rich array of AI methods to provide broader insights into the mind and brain (Noelle, 2022).

Artificial Intelligence (AI) refers to computer systems designed to perform tasks that typically require human intelligence. These tasks include visual perception, speech recognition, decision-making, and language translation. AI encompasses various techniques such as machine learning, neural networks, and deep learning, which enable systems to think and act in an intelligent manner (Rothman, 2018; Hulsen, 2023).

The concept of AI involves foundational elements such as agents, logic, search algorithms, and reasoning under uncertainty. These components form the basis for practical applications and algorithms within the field. AI also covers subdisciplines like automated planning, intelligent agents, information retrieval, and natural language and speech processing, which contribute to the system's ability to interact with and interpret complex data (Chowdhary, 2020; Ertel, 2024).

AI systems are often developed through examples and case studies that illustrate fundamental principles and real-world applications. This approach helps in understanding how AI can be implemented to solve practical problems and build intelligent networks (Rothman, 2018; Nagy, 2018). The field also addresses recent developments including constraint satisfaction problems, adversarial search, game theory, and statistical learning theory, which expand the capabilities and theoretical underpinnings of AI (Chowdhary, 2020).

In summary, AI is a multidisciplinary area focused on creating systems capable of intelligent behavior by employing various algorithms and learning techniques. It integrates theoretical foundations with practical applications to enable machines to perform tasks traditionally requiring human cognition.

Artificial intelligence is applied to many fields and contributes to many important applications and research areas, such as intelligent data processing, natural language processing, autonomous vehicles, and robots. The adoption of artificial intelligence in several fields has been the subject of many research papers. Still, recently, the space sector is a field where artificial intelligence is receiving significant attention (Russo, 2022).

The concept of Artificial Intelligence (AI) for space encompasses the application of AI techniques to address various challenges in space sciences and operations. AI is increasingly recognized for its potential to enhance mission design, space exploration, and Earth observation by enabling intelligent data processing, autonomous decision-making, and automation in complex and remote environments (Russo, 2022; Ieracitano, 2023; Chien, 2014). This involves developing systems capable of operating independently in hostile or inaccessible conditions, thereby reducing human intervention and operational costs (Chien, 2014).

AI's role in space extends to improving the reliability and safety of missions by managing risks associated with hardware, software, and human factors. For example, NASA has employed AI systems in the Mission Control Center to support flight decisions during space shuttle missions, and ongoing efforts aim to integrate AI frameworks to enhance resilience and performance in current and future missions such as the James Webb Space Telescope and Artemis programs (Kalia, 2025). These frameworks address challenges like automation uncertainties, cognitive biases, and complex mission architectures (Kalia, 2025).

The space sector's evolving value chain benefits from AI through cross-sector and cross-border collaborations, where AI and machine learning contribute to transforming space technologies and big data management. Applications include AI-driven Earth observation data analysis, robotics for space exploration, astrophysics research, in-orbit servicing, and safety improvements in space tourism (Madi, 2024). The interdisciplinary nature of AI in space involves contributions from engineers, risk analysts, policy makers, and computer scientists, highlighting the multifaceted impact of AI across technical and regulatory domains (Madi, 2024).

Overall, AI for space is conceptualized as a set of intelligent tools and methodologies aimed at enhancing operational autonomy, safety, data utilization, and mission efficiency in the space domain, while addressing the unique challenges posed by space environments and mission complexities.

Artificial Intelligence (AI) systems in space activities refer to software or machines that exhibit intelligence by reasoning, making decisions, analyzing data, perceiving, and acting in ways similar to human beings. These systems are increasingly integrated into space exploration and settlement, providing sophisticated tools that enhance or replace human competences in various space-related tasks. AI enables intelligent machines to support astronauts and space missions by processing data, assisting in decision-making, and performing autonomous operations essential for living and working in space environments (Kumar, 2018).

The impact of AI on space activities is multifaceted. AI technologies contribute to the transformation of the space sector by supporting Earth observation through big data analysis, enabling robotic exploration, and facilitating emerging markets such as in-orbit servicing and space tourism safety. These applications demonstrate AI's role in improving mission efficiency and scientific return, as well as addressing complex challenges in space operations. The integration of AI spans across the space value chain, involving cross-sector and international collaborations, and is relevant to engineers, policy makers, and technical experts (Madi, 2024).

The European Space Agency (ESA) exemplifies the use of AI in space missions, where AI systems observe, perceive, and act upon their environment to maximize mission success. However, the adoption of AI in space is still limited by challenges such as the interpretability of neural network models and legal concerns. Issues related to liability, confidentiality, and data protection arise as AI applications evolve, raising questions about the adequacy of existing space law frameworks to address these new challenges (Singer, 2024).

In summary, AI systems in space activities function as intelligent tools that enhance operational capabilities and scientific outcomes. Their impact extends from data processing and robotic exploration to safety and legal considerations, reflecting a growing but complex integration of AI in the space domain.

2. Main areas of use of AI in space activities

Artificial Intelligence is applied in various critical areas of space activities, enhancing operational efficiency, safety, and scientific outcomes. One primary area is spacecraft operations, where AI integrates data acquisition, processing, decision support, and feedback mechanisms to improve predictive maintenance, anomaly detection, navigation, and control. This integration contributes to increased reliability and safety in mission execution. AI also plays a significant role in spacecraft health monitoring and organizational processes, supporting mission success through improved system management (Dhar, 2025).

The ambitious short-term and long-term goals set by various national space agencies require a radical advance of new technologies into the space sector, one of which is undoubtedly the development of intelligent space agents. In recent years, this has led to increasing interest in artificial intelligence across the entire aerospace community. Indeed, technologies and machines that can independently perform various functions in areas such as space, where conditions are hostile and dangerous to human life, are increasingly used. Therefore, one of the complicated legal problems of our time is the increasing use of and dependence on technology and processes related to artificial intelligence and space technologies (Soroka & Kurkova, 2019).

In planetary missions, AI facilitates autonomous navigation and data processing, enabling spacecraft to operate with reduced human intervention. Machine learning and deep learning techniques support scientific discovery, predictive analytics, and mission planning, thereby enhancing decision-making capabilities in complex and remote environments. Emerging AI technologies, such as quantum and neuromorphic computing, are also explored for their potential to advance data processing and autonomous decision-making in space missions (Ojo, 2024).

Automation through AI is recognized as a means to address the increasing complexity and cost of space missions. Intelligent systems capable of independent decision-making are necessary for operating in remote and hostile environments, reducing the need for constant human control and intervention (Chien, 2014). This is particularly relevant for future missions involving human crews beyond low Earth orbit, where AI is expected to support autonomous biomonitoring, research, and healthcare independent of Earth-based resources (Space, 2023).

In deep space exploration, AI applications include hyperspectral imagery analysis and autonomous robotic systems. Hyperspectral algorithms assist in the capture and interpretation of space images, while robotic systems contribute to efficient exploration activities on planetary surfaces such as Mars. These AI-driven technologies aim to improve the understanding of the solar system and support long-term exploration strategies (Omar, 2021).

Overall, AI is utilized in spacecraft operations, autonomous navigation, data analysis, mission planning, health monitoring, robotic exploration, and autonomous life support systems, reflecting its multifaceted role in advancing space activities.

3. Applicability of international space law to the use of AI

The implementation of AI systems in the sector of space activities (although equally applicable to all sectors) has various nuances, such as the introduction of objective 'expert legal knowledge'. In Machine learning phases, the international community is (and will further be) required to constitute and determine space-specific «high level objectives». Because this technology (along with other new technologies, such as cyber technology) knows no state boundaries, it has the potential to upend traditional and historical ways of law-making, both at the international and State government levels. A top-down approach is not only forthcoming but also unsustainable and unsuitable; thus, it also lays the foundations for a bottom-up approach involving all stakeholders at all stages of the AI life cycle. In view of the constantly changing and evolving subjective and objective international standards for regulation of space conduct, the researcher wishes to also introduce the need for socio-legal research, particularly highlighting the need to be in sync with legal consciousness approaches. In doing so, one can locate and deal with ongoing issues and future challenges for conceptualizing an international rules-based order for the introduction and operation of AI technologies in space activities. The new space era 4.0 is also marked by increasing private sector presence and operations in space activities, with supervisory roles being played by State governments. This submission would thus capture some of the modifications or interpretational nuances which may be required in the context of interpretation and regulation of the binding international treaties applicable to the space ecosystem (Mishra, 2022).

The applicability of international space law to the use of artificial intelligence (AI) involves several considerations related to existing treaties, regulatory gaps, and the evolving nature of AI technologies in space activities. Current international space law, including foundational treaties such as the Outer Space Treaty and the Liability Convention, does not explicitly regulate AI but provides principles that could inspire the development of AI-specific legal frameworks aimed at harm prevention and responsible use in space (Ramuš, 2023; Treaty, 1967; Convention, 1972). These treaties establish general obligations and liability rules that may be adapted to address AI's autonomous functions and potential risks.

Existing international space law mechanisms are identified as insufficient for regulating dual-use AI systems, particularly regarding definitions, responsibility codification, and control of autonomous actions. This insufficiency highlights the need for new legal approaches that focus on prohibiting specific harmful outcomes, such as orbital debris creation or uncontrolled autonomous attacks, rather than regulating AI technology per se. Proposals include international agreements with annexes listing prohibited AI uses and accountability mechanisms for states, which could complement or extend current space law (Koskina, 2026).

The integration of AI in space activities raises challenges related to military applications, autonomy, and power imbalances. The 1967 Outer Space Treaty's provisions on peaceful use, control, and non-discrimination are tested by AI-enabled autonomous weapons and military systems, which are not explicitly addressed in existing law. This situation calls for future legal frameworks that consider both terrestrial and space contexts, including principles from international humanitarian law and emerging AI regulations like the European AI Act, which currently excludes military AI systems (Bratu, 2026).

AI should be understood as a system designed by humans, which, by analyzing the environment, is capable of acting (without active control or supervision from an individual) or being idle autonomously to achieve a specific goal. From the point of view of AI legal regulation, the main concern is that currently the definition of AI cannot be specified at the global level, and its normative definition is rare. Still, there are some examples, like the Artificial Intelligence Act, which laid the foundation for the legal regulation of AI use, if not at the global level, but at least at the European one. Still, there are some examples, like the Artificial Intelligence Act, which laid the foundation for the legal regulation of AI use, if not at the global level, but at least at the European one. This issue is indirectly raised in the Guiding Principles on Business and Human Rights, but mostly it has a national background (Soroka, 2022; Regulation, 2024).

Furthermore, the rapid development of AI and autonomous systems in space missions and potential human colonies necessitates new legal standards beyond traditional space law. These include cybersecurity, environmental protection, data governance, and ethical considerations specific to AI behavior and decision-making in space environments (Pagallo, 2024). The evolving space governance system must adapt to these technological changes, incorporating bottom-up approaches involving multiple stakeholders and addressing socio-legal dimensions such as ethics, environmental costs, and data privacy (Mishra, 2022).

In conclusion, while international space law provides foundational principles applicable to AI use in space, it currently lacks specific provisions to fully regulate AI technologies and their dual-use nature. There is an ongoing scholarly and policy discourse advocating for the adaptation and expansion of space law frameworks to address AI's unique challenges, emphasizing harm prevention, accountability, and ethical governance.

4. Risk system for using AI in space activities

AI is a future technology that, even today, expands the boundaries of human perception and enhances capabilities where, a few years ago, there seemed to be no prospects for a full and comprehensive study. Moreover, one can hardly imagine the development of the space industry without AI, although there are still some issues from the point of view of legal problems and risks (Soroka et al., 2022).

We propose a classification of the various risks associated with the use of AI in space activities, which may be broadly divided into four levels. The first layer is institutional and managerial risks. NASA's OIG says NASA "has not adopted a standard definition of AI" and lacks an "AI-specific classification mechanism," which is exactly the sort of gap a risk system has to close. The space-focused Trusted AI work says to "estimate the level of trust required as a function of mission criticality and key stakeholders," and frames its guidance as "best practices" for the people who review and fly these systems (National, 2023; Slingerland, 2022). The corresponding conclusion was formed in 2022, however, in connection with the adoption of the Artificial Intelligence Act (2024), the problem has acquired another dimension – the problem of a clear division of competence between developers, operators, customers, regulatory authorities and other participants in space activities. This level also includes the risks of uncertainty of requirements for the permissible degree of autonomy, the required level of reliability and trust in the system depending on the criticality of the mission, the nature of the functions performed and the range of interested parties.

The second layer is hazard analysis at the mission level, not just the model level. An aerospace FMEA paper adapts FMEA to the aerospace domain, identifies 23 AI-related failure modes, and says the unmitigated risk can be "medium to critical." A separate space-exploration paper flags "aggregate and cross-cutting risks associated with hardware, software, firmware, and human interactions," which is the right mental model for space autonomy: the failure is usually sociotechnical, not just algorithmic (Khalil, 2026; Kalia, 2025).

The third layer is assurance before and during operation: simulation, verification and validation, independent monitors, and a fail-safe fallback to human or conventional control. The xAI space papers say autonomous capabilities must be reliable enough to "run spacecraft systems" without human input when necessary, and that confident use of these systems depends on "understanding risks and quantifying the uncertainties that produce those risks" (Allen, 2025).

The fourth layer is cyber, information and data-oriented risks. A recent space-safety review says "AI cyber security is becoming an important aspect to ensure space safety and operational security" and argues for "technical standardisation"; a newer governance framework says the architecture should "integrate governance structures, reliability and safety engineering practices, data and ML lifecycle controls, cybersecurity mechanisms, and decision-intelligence feedback loops into a single architectural view" (Yettapu, 2023).

Thus, the system of risks associated with the use of AI in space activities may be broadly divided into four levels: (1) institutional and governance risks; (2) systemic risks; (3) operational and assurance-related risks; and (4) cyber, information, and data-oriented risks. All levels of the risk system are interdependent. Accordingly, a risk-based model for the legal regulation of artificial intelligence in space activities should provide for a comprehensive assessment of risks, their periodic reclassification, the differentiation of regulatory requirements depending on the criticality of the functions performed, and the mandatory documentation of measures aimed at preventing, minimising, and controlling potential adverse consequences.

5. Features of a Risk-Based Model for the Legal Regulation of Artificial Intelligence in Space Activities

A risk-based model for the legal regulation of artificial intelligence in space activities should be based on the recognition that legal requirements applicable to AI systems cannot be identical for all technologies, actors, and space missions. The extent of regulatory intervention should be determined with due regard to the level of autonomy of the system, the criticality of the functions it performs, the scale of potential adverse consequences, the possibility of human intervention, the nature of the data being processed, and the operating conditions of the space object. Accordingly, the greater the potential risks associated with the use of AI to human life and health, space infrastructure, the outer-space and terrestrial environments, information security, or mission continuity, the stricter the requirements governing the development, testing, certification, deployment, and oversight of such a system should be.

We propose the following features of a risk-based model for the legal regulation of artificial intelligence in space activities:

1) multilevel nature of regulation, encompassing a set of interrelated institutional, systemic, operational, cyber, information, and data-oriented risks. Each level of risk should be assessed in conjunction with the other elements of the space system;
2) mission-centric nature of legal regulation. The object of assessment should be the entire space mission into which the AI system is integrated. The reliability of an algorithm does not guarantee mission safety where risks arise from the interaction between software, hardware, communication channels, the ground segment, operators, external information systems, and the conditions of the space environment. Therefore, the legal assessment should cover the entire sociotechnical system within which the AI operates;
3) differentiation of legal requirements according to the criticality of the functions performed. For highly critical functions, enhanced requirements should be established in relation to accuracy, reliability, explainability, resilience, redundancy, verification, certification, and the capacity for the safe termination of system operation;
4) regulation of AI throughout its entire life cycle. Risks should be assessed at the stages of system design, data preparation and selection, model training, testing, integration into the space system, launch, operation, updating, modification, and decommissioning. A risk-based model should provide for continuous monitoring, reassessment of conformity, and periodic risk reclassification;
5) clear allocation of competence, obligations, and legal liability among all participants in the life cycle of an AI system. Legal regulation should define the functions of developers, data providers, integrators, space technology manufacturers, operators,

customers, owners of space objects, independent auditors, certification bodies, and public regulatory authorities;

6) combination of preventive and adaptive regulation. Space missions are characterised by high costs, the difficulty of remedying malfunctions after launch, and the potentially irreversible nature of their consequences. Priority should therefore be given to the early identification, prevention, and minimisation of risks. A risk-based model should combine stable baseline obligations with mechanisms allowing the timely revision of technical standards, risk criteria, and oversight procedures;
7) mandatory application of verification, validation, and independent safety assurance procedures for AI systems;
8) provision of controlled autonomy for AI systems. The permissible degree of autonomy of an AI system should be determined according to the criticality of the mission, communication latency, the possibility of timely operator intervention, and the nature of potential consequences. Critical operations should be supported by independent monitoring mechanisms and the capacity to transition to a backup mode, conventional algorithmic control, or human oversight;
9) evidence-based approach to risk management. Developers and operators should document the rationale underlying the classification of the system, the results of risk assessments, the characteristics of datasets, testing procedures, identified limitations, known failure scenarios, risk-mitigation measures, software modifications, and incidents occurring during operation;
10) integration of cybersecurity, information security, and data governance into a unified system of legal safeguards;
11) need for the international interoperability of regulatory requirements. Space activities generally involve actors from different states, the use of transnational infrastructure, data exchange, and the joint management of missions. National rules governing AI should therefore be aligned with international space law, the general principles of state responsibility for national space activities, requirements relating to the registration and supervision of space objects, and international technical standards.

Thus, a risk-based model for the legal regulation of artificial intelligence in space activities should be comprehensive, multilevel, mission-centric, and life-cycle-oriented. Its principal purpose is to establish a legally defined mechanism for the timely identification, assessment, allocation, minimisation, and control of risks.

Conclusions

Existing international space law contains general principles applicable to the use of artificial intelligence in space activities. These include the principles of the peaceful use of outer space, the international responsibility of states for national space activities, the proper supervision of non-governmental entities, liability for damage, international cooperation, due regard for the interests of other states, and the prevention of harmful contamination of the outer-space and terrestrial environments. However, these provisions were formulated before the emergence of autonomous systems and do not take into account the specific features of algorithmic decision-making, machine learning, dynamic changes in system behaviour, the opacity of certain models, and the difficulty of establishing a causal link between the operation of AI and adverse consequences. International space law therefore retains its regulatory significance but requires functional reconsideration, further specification, and supplementation with specialised legal, technical, and organisational mechanisms.

A risk-based model should form the basis of the appropriate legal regulation of artificial intelligence in space activities. Such a model should provide for the differentiation of legal measures depending on the level of system autonomy, the criticality of the functions performed, the scale of potential harm, operating conditions, the possibility of human control, the nature of the data being processed, the duration of the mission, and the system's capacity to affect other space objects, people, infrastructure, and the environment. Accordingly, legal regulation should be proportionate to the level of risk: the greater the probability of serious, systemic, or irreversible consequences, the stricter the requirements governing the development, testing, certification, operation, monitoring, and termination of the system should be.

The proposed classification of risks associated with the use of artificial intelligence in space activities encompasses four interrelated levels: institutional and governance-related; systemic; operational and assurance-related; and cyber, information, and data-oriented. Institutional and governance-related risks arise from the absence of harmonised terminology, an unclear allocation of competence, insufficiently defined requirements concerning permissible levels of autonomy, and the lack of specialised mechanisms for classifying AI systems. Systemic risks are associated with the complex interaction between software, hardware components, communication channels, ground infrastructure, operators, and the external environment. Operational and assurance-related risks concern deficiencies in verification, validation, testing, independent auditing, monitoring, and safe backup-control procedures. Cyber, information, and data-oriented risks include the possibility of external interference, data manipulation, model compromise, and breaches of the confidentiality, integrity, and availability of information.

A risk-based model for the legal regulation of artificial intelligence in space activities should apply throughout the entire life cycle of an AI system – from defining its intended purpose, designing the system, and developing datasets to training, testing, integration, launch, operation, updating, modification, and decommissioning. In this regard, the necessary elements of a risk-based model for the legal regulation of artificial intelligence in space activities include continuous monitoring, reassessment of conformity, periodic risk reclassification, the documentation of incidents, and the mandatory review of risk-management measures following significant changes to the system.

A key condition for the effectiveness of the proposed model is a clear allocation of powers, obligations, and legal liability among all participants in the AI life cycle. The legal status and limits of liability should be defined for model developers, data providers, integrators, manufacturers of space technology, operators, customers, owners of space objects, independent auditors, certification bodies, and public regulatory authorities. Ultimate legal liability should remain connected to the acts or omissions of natural and legal persons and to the international obligations of the states under whose jurisdiction or control the relevant space activities are conducted.

Of particular importance is the introduction of a controlled-autonomy regime for AI, under which the permissible degree of independence of an AI system should be determined with due regard to the criticality of the operation, the remoteness of the space object, communication latency, the possibility of timely operator intervention, and the severity of potential consequences.

Therefore, a risk-based model for the legal regulation of artificial intelligence in space activities should be regarded as a comprehensive legal mechanism for the timely identification, assessment, classification, allocation, minimisation, and control of risks. The defining characteristics of a risk-based model for the legal regulation of artificial intelligence in space activities are its multilevel nature, mission-centric approach, proportionality, whole-life-cycle orientation, controlled autonomy, evidence-based character, combination of preventive and adaptive regulation, clarity of liability, and international interoperability. The introduction of such a model is capable of ensuring a balance between promoting technological innovation and protecting human life and health, space infrastructure, information security, the outer-space and terrestrial environments, as well as the legitimate interests of states, private operators, and other participants in space activities.

🕮 References

Allen, B. D. (2025) Explainable AI (xAI) and autonomous systems for persistent human-machine operations in space, on the Moon, and on to Mars. In AIAA SCITECH 2025 *Forum. American Institute of Aeronautics and Astronautics*. https://doi.org/10.2514/6.2025-1913

Benko, A. & Sik Lányi, C. (2009) History of Artificial Intelligence. In M. Khosrow-Pour, D.B.A. (Ed.), Encyclopedia of Information Science and Technology, Second Edition (pp. 1759-1762). *IGI Global Scientific Publishing*. https://doi.org/10.4018/978-1-60566-026-4.ch276

Bratu, I., & Freeland, S. (2026) Winner takes all? Legal implications of autonomous weapons systems and the militarization of outer space. *Acta Astronautica*, 238, 803–814. https://doi.org/10.1016/j.actaastro.2025.09.031

Chien, S., & Morris, R. (2014) Space applications of artificial intelligence. *AI Magazine*, 35(4), 3–6. https://doi.org/10.1609/aimag.v35i4.2551

Chowdhary, K. R. (2020) Fundamentals of artificial intelligence. *Springer.* https://doi.org/10.1007/978-81-322-3972-7

Convention on international liability for damage caused by space objects: United Nations (1972) *United Nations Treaty Series,* 961, 187. Available online: https://treaties.un.org/doc/Publication/UNTS/Volume%20961/volume-961-I-13810-English.pdf

Dhar, S., Baghel, N., Bhoi, S., Anand, A., Singh, A. V., and Mishra, S. (2025) Positioning of machine learning based cosmic intelligence in stellar spacecraft operations. In 2025 International Conference on Artificial Intelligence and Machine Vision (AIMV) (pp. 1–5). *IEEE*. https://doi.org/10.1109/AIMV66517.2025.11203530

Ertel, W. (2024) Introduction to artificial intelligence (N. T. Black, Trans.; 3rd ed.). *Springer.* https://doi.org/10.1007/978-3-658-43102-0

Hulsen, T. (2023) Explainable artificial intelligence (XAI): Concepts and challenges in healthcare. *AI,* 4(3), 652–666. https://doi.org/10.3390/ai4030034

Ieracitano, C., Mammone, N., Di Clemente, M., Mahmud, M., Furfaro, R., and Morabito, F. C. (Eds.). (2023) The use of artificial intelligence for space applications: Workshop at the 2022 International Conference on Applied Intelligence and Informatics (Vol. 1088). *Springer.* https://doi.org/10.1007/978-3-031-25755-1

Kalia, P., Calvani, H., Patterson, J., & Crumbly, T. (2025) Strategic artificial intelligence learning (SAIL) and applications - Mastering risk in space explorations. In 2025 Annual Reliability and Maintainability Symposium (RAMS) (pp. 662–667). *IEEE.* https://doi.org/10.1109/RAMS48127.2025.10935023

Khalil, Y. F. (2026) Failure modes and effects analysis of AI-enabled technologies for aeronautical and astronautical applications. *Journal of Research in Engineering and Computer Sciences*, 4 (3): 10–31. https://doi.org/10.63002/jrecs.403.1513

Koskina, A. (2026) Artificial Intelligence and International Space Law: Dual-Use Challenges. *Journal of Digital Technologies and Law,* 4(1), 98–124. https://doi.org/10.21202/jdtl.2026

Kumar, S., & Tomar, R. (2018) The role of artificial intelligence in space exploration. In 2018 International Conference on Communication, Computing and Internet of Things (IC3IoT): 499–503. *IEEE.* https://doi.org/10.1109/IC3IoT.2018.8668161

Madi, M., & Sokolova, O. (Eds.). (2024) Artificial intelligence for space: AI4SPACE: Trends, applications, and perspectives. *CRC Press*. https://doi.org/10.1201/9781003366386

McDaniel, G. (1994) IBM dictionary of computing (pp. 32-33, 586). New York: *McGraw-Hill.*

Mishra, N. (2022) The need for an International rules-based framework for Artificial Intelligence technologies and systems in space activities [Master's thesis, McGill University]. *McGill eScholarship. mcgill.ca.* Available online: https://mcgill.scholaris.ca/server/api/core/bitstreams/0efc3a52-4c72-48b2-82f1-3fa99c344e45/content

Mitchell, M. (1996) An introduction to genetic algorithms: 35-81. Cambridge, MA: *MIT Press.*

Nagy, Z. (2018) Artificial intelligence and machine learning fundamentals: Develop real-world applications powered by the latest AI advances. *Packt Publishing.* 330 p.

National Aeronautics and Space Administration, Office of Inspector General. (2023) *NASA's* management of its artificial intelligence capabilities (Report No. IG-23-012). Available online: https://oig.nasa.gov/wp-content/uploads/2023/12/ig-23-012.pdf

Noelle, D. C., & Yoshimi, J. (2022) Artificial intelligence and computational theories of mind. In B. D. Young & C. D. Jennings (Eds.), Mind, cognition, and neuroscience: A philosophical introduction: 127–148. *Routledge.* https://doi.org/10.4324/9781003241898-11

Ojo, O. L., Afolalu, A. S., Ajiboye, Y., et al. (2024) Artificial intelligence in space exploration: Improving data analysis and decision-making for planetary missions. In 2024 IEEE 5th International Conference on Electro-Computing Technologies for Humanity (NIGERCON): 1–4. *IEEE.* https://doi.org/10.1109/NIGERCON62786.2024.10927127

Omar, A. A., Farag, M. M., and Alhamad, R. A. (2021) Artificial intelligence: New paradigm in deep space exploration. In 2021 14th International Conference on Developments in eSystems Engineering (DeSE): 438–442. *IEEE.* https://doi.org/10.1109/DeSE54285.2021.9719425

Pagallo, U. (2024) The new laws of outer space: Ethics, legislation, and governance in the age of artificial intelligence. *Hart Publishing.*

Ramuš Cvetkovič, I., & Drobnjak, M. (2023) As above so below: The use of international space law as an inspiration for terrestrial AI regulation to maximize harm prevention. In A. Završnik & K. Simončič (Eds.), Artificial intelligence, social harms and human rights: 207–238. *Palgrave Macmillan.* https://doi.org/10.1007/978-3-031-19149-7_9

Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence and amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2014/90, (EU) 2019/543, (EU) 2020/876, (EU) 2021/690 and (EU) 2021/787 and Regulation (EU) 2019/1020 (Artificial Intelligence Act) (2024) *European Union*. Available online: http://data.europa.eu/eli/reg/2024/1689/oj

Rothman, D., Guet, N., and Rothman, J. (2018) Artificial intelligence by example: Develop machine intelligence from scratch using real artificial intelligence use cases. *Packt Publishing Ltd*. 490 p.

Russel, S., & Norvig, P. (1995) Artificial intelligence: A modern approach (p. 69). *Panem-Prentice Hall.*

Russo, A, Gianluca L. (2022) Using Artificial Intelligence for Space Challenges: A Survey." *Applied Sciences*, vol. 12, no. 10, p. 5106. https://doi.org/10.3390/app12105106

Schreiber, G. (1999) Knowledge engineering and management. The Commonkads methodology (pp. 13-23). Cambridge, MA: *MIT Press.*

Shirai, Y., & Tsujii, J. (1982) Artificial intelligence. Tokyo: *Iwanami Shoten.*

Singer, A. (2024) Artificial intelligence in space: Overview of the European Space Agency and its role in the AI environment. *Ljubljana Law Review*, 84(1): 255–278. https://doi.org/10.51940/2024.1.255-278

Slingerland, P., Perry, L., Kaufman, J., et al. (2022) Adapting a trusted AI framework to space mission autonomy. In 2022 IEEE Aerospace Conference (AERO): 1–20. *IEEE.* https://doi.org/10.1109/AERO53065.2022.9843376

Soroka, L., Danylenko A., and Sokiran M. (2022) Legal Issues and Risks of the Artificial Intelligence Use in Space Activity. *Philosophy and Cosmology*, Volume 28: 118-135. https://doi.org/10.29202/phil-cosm/28/10

Soroka, L., & 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

Space missions out of this world with AI. (2023) *Nature Machine Intelligence,* 5, 183. https://doi.org/10.1038/s42256-023-00643-3

Treaty on principles governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies (1967) *United Nations Office for Outer Space Affairs.* Available online: https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html

Yettapu, S. D. R. (2023) A unified artificial intelligence governance and reliability engineering framework for secure and autonomous software-intensive and cyber-physical systems. *Journal of Frontiers in Multidisciplinary Research*, 4 (1): 605–608. https://doi.org/10.54660/.JFMR.2023.4.1.605-608