Blaming Galileo: Liability for Damage Caused by Artificial Intelligence Operating Based on GNSS

*Ioana Bratu**

Abstract

Due to the latest technological developments, Global Navigation Satellite Systems (GNSS), including Galileo, are being integrated as an essential component in artificial intelligence (AI) systems. Even though it is unlikely that a loss of signal will lead to an accident caused by an AI system, this scenario cannot be totally ignored. Recent incidents revealed a series of vulnerabilities that need to be addressed before more AI systems using GNSS signals can become active participants in our societies. In this context, it becomes clear that the most pressing issue is the one related to liability: who will be liable in case an accident is caused by an AI system due to a GNSS signal failure at a critical point during navigation? Taking into consideration the debates concerning Galileo's potential acceptance of liability, this paper investigates if international space law is able to prevent potential liability gaps, thus avoiding situations where incidents occur and liability cannot be attributed.

1. Introduction

The economic benefits of GNSS are compared with the ones offered by the introduction of the Internet, a fact demonstrated by the increasing GNSS global market size.[1] With the advent of AI systems, the role of GNSS is increasing due to their important role in the operation of these emerging technologies. Such growing reliance on GNSS is starting to raise a series of concerns. One of them is related to the attribution of liability in case of potential GNSS malfunctions, such as signal failures.

The concept of liability in the context of GNSS did not initially present much importance, given the military origin of the GNSS developed by US (GPS)

* Ioana Bratu, Amsterdam Law & Technology Institute | ALTI, Vrije Universiteit Amsterdam. i.bratu@vu.nl.

1 *See* Francis Lyall and Paul B Larsen, *Space Law: A Treatise* (2nd edition., Routledge, Taylor & Francis Group 2018) 339.

and Russia (GLONASS) and the explicit liability denial by their owners.[2] The discourse changed once the European GNSS, Galileo, started to be developed and the European Union considered accepting liability, given the civil scope of Galileo and the potential offering of commercial services.

Nevertheless, in the absence of specific legislation covering GNSS liability, the "core" of international space law needs to be investigated, specifically the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies ("Outer Space Treaty") and the Convention on International Liability for Damage Caused by Space Objects ("Liability Convention"). As such, the purpose of this paper is to analyze if the current liability regimes introduced by these two space treaties cover potential incidents caused by AI operating based on GNSS, due to signal failures.

2. Framing GNSS in a European Context

GNSS are considered a critical space technology and one of the driving forces behind human security and economic development.[3] The GNSS market size continues to grow. In 2019, it was evaluated at USD 161.27 billion and, by 2027, it is expected to reach USD 386.78 billion.[4] In the United States, GPS is considered a "fifth utility" alongside water, electricity, gas and telecommunications.[5]

In Europe, back in 1990s, plans were initiated for a European GNSS and for the first time the world was going to benefit from a civilian-operated system, designed based on the users' needs.[6] The European approach to become independent in what concerns satellite navigation involved multiple projects, with Galileo being an important component. The original Galileo management structure was conceived as a collaboration between the private and the public sector, in the form of a public-private partnership ("PPP").[7] However, this initial approach was abandoned, due to a failure in concession negotiations and public investments were made available for replacing the

2 *See* Ram S Jakhu, *National Regulation of Space Activities* (Springer Science & Business Media 2010) 188.

3 *See* Nie Jingjing, 'Future of Uniform International Rules on GNSS Liability, The Session 5: Recent Developments in Space Law' (2011) 54 Proc Int'l Inst Space L 339, 2.

4 *Cf*. 'GNSS Market Size Worldwide 2019-2029' (*Statista*, no date) https://www.statista.com/statistics/1174527/gnss-market-size-worldwide/ accessed 9 January 2022.

5 European Commission, 'Commission Staff Working Paper. European Global Navigation Satellite System Impact' (European Commission 2011).

6 *See* Joseph Awange, 'Basics of Galileo Satellites' in Joseph Awange (ed.), *GNSS Environmental Sensing: Revolutionizing Environmental Monitoring* (Environmental Science and Engineering, Springer International Publishing 2018) 115.

7 *See* Stephan Hobe, *Space Law* (Nomos Verlag 2019) 157.

initially envisaged private funding.[8] Currently, in accordance with the Regulation approving the European Space Programme ("Regulation 696/2021"), the European Union is the owner of Galileo, while the European Commission, the European Space Agency and the European Union Agency for the Space Program share responsibilities from implementation to technical support.[9]

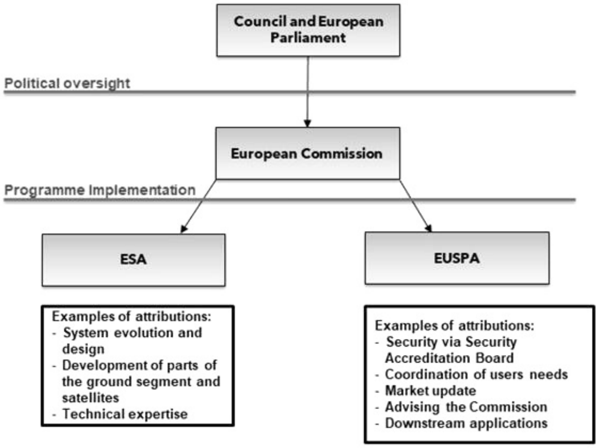

Figure 1. Outline of Galileo Management Structure[10]

3. The role of GNSS for the operation of AI systems

In the context of the European Space Programme, the relationship between space technologies and AI systems is becoming increasingly noticeable. Initially, references to synergies between space related activities and AI systems were integrated in AI policy documents, such as the White Paper on Artificial Intelligence of 19 February 2020.[11] The White Paper identified key sectors, alongside AI, in which the EU has the potential of becoming a global

8 *See* Frans von der Dunk, 'European Space Law' in *Handbook of Space Law* (Edward Elgar Publishing 2015) 261.

9 Regulation of the European Parliament and of the Council of 28 April 2021 establishing the Union Space Programme and the European Union Agency for the Space Programme, OJ L 170, 12.5.2021, p. 69–148

10 *Cf.* European Commission, 'Communication from the Commission to the European Parliament and the Council – Progressing Galileo: Re-Profiling the European GNSS Programmes, COM (2007) 534 Final' (19 September 2007); *See also* Lesley Jane Smith, 'Legal Aspects of Satellite Navigation' in Frans von der Dunk, Fabio Tronchetti (Eds.) *Handbook of Space Law* (Edward Elgar Publishing 2015) 564.

11 European Commission, 'White Paper on Artificial Intelligence. A European Approach to Excellence and Trust' (19.02.2020).

leader. Those were health, transport, finance, agri-food value chains, energy, environment, and also Earth observation and space. The synergies are also emphasized in Regulation 696/2021, Recital (4):

> it is necessary to exploit synergies between the transport, space and digital sectors in order to foster the broader use of new technologies, such as e-call, digital tachograph, traffic supervision and management, autonomous driving and unmanned vehicles and drones.

Similar to GNSS, AI has a significant impact on humanity. The beneficial effects of the "soft" revolution created by this emerging technology can be noticed in a variety of sectors, from health, retail, legal and financial services etc.[12] Given its rapid integration in our societies, corresponding risks need to be taken into consideration and, thus, addressed from a regulatory perspective. Initiatives are starting to take shape, with Europe being at the forefront of policy innovation. The proposal for a Regulation of AI systems ("AI Act"),[13] released in April 2021, is considered to be the world's first attempt at horizontal regulation of AI systems.[14] The AI Act provides a comprehensive definition of AI systems. The concept includes from basic systems, such as symbolic expert systems, to more advanced systems, reaching high automation levels and operating based on sophisticated learning approaches, such as machine learning, a process inspired by the neural networks of the human brain.[15] One of the key elements in differentiating between various AI systems is the degree of human control deployed in the decision-making process.[16] In case of more advanced systems, human control decreases up to the point where an operator of such an AI system may claim that an activity performed by the system was outside of his or her control because it was executed by an autonomous operation of the AI system.[17]

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12 *See, e.g.*, Bertrand Braunschweig and Malik Ghallab, *Reflections on Artificial Intelligence for Humanity* (Lecture notes in artificial intelligence, Springer 2021).

13 European Commission, 'Proposal for a Regulation of the European Parliament and of the Council Laying down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending Certain Union Legislative Acts (COM(2021) 206 Final)' (21 April 2021).

14 Michael Veale and Frederik Zuiderveen Borgesius, 'Manuscript: Demystifying the Draft EU Artificial Intelligence Act' (5 July 2021).

15 *See* Ioana Bratu and others, 'Autonomous Space Objects and International Space Law: Navigating the Liability Gap' (2021) 18 Indonesian Journal of International Law 423.

16 *See* John Zerilli and others, 'Algorithmic Decision-Making and the Control Problem' (2019) 29 Minds & Machines 555, 556.

17 European Parliament, 'Civil Liability Regime for Artificial Intelligence. European Parliament Resolution of 20 October 2020 with Recommendations to the Commission on a Civil Liability Regime for Artificial Intelligence' (20 October 2020).

Depending on the autonomy level involved, GNSS can be implemented in AI systems as an informational system only, without exerting any degree of control, or as an independent system, by giving directions to the system directly.[18] In the latter case, GNSS would exert a certain degree of control over the AI system, operating as an essential element of independent decision-making, without any interference of, for example, human drivers or pilots.[19]
An example of the crucial role of GNSS in the operation of AI systems is offered by the road transportation sector, where the European GNSS, Galileo, is considered a "critical component" or a "key enabling technology" for autonomous driving, with the first Galileo-enabled self-driving vehicle successfully demonstrated in 2019.[20]

4. Sources of GNSS Signal Failures and Their Impact on AI Systems

For offering their services, i.e. position, navigation and timing ("PNT"), GNSS providers need to make sure that their signals observe four performance indicators: (i) *accuracy*, the difference or error between actual information and computed PNT information, (ii) *availability*, the percentage of time that the services available to the user within a certain coverage area; (iii) *integrity*, the ability of the system to warn users when the signal is not adequate for navigation and (iv) *continuity*, the ability to provide the required performances during an operation without interruption once the operation has started.[21]
Any potential disturbance of these indicators (collectively referred to as "signal failures") may adversely impact any systems reliant on GNSS.[22] Signal failures can be caused by electronical or physical harmful interferences, either intentionally or unintentionally.[23] Intentional electronic interferences usually include jamming, spoofing or other electronic means of manipulating signals.[24] Jamming is usually an intentional interference with satellite signals,

18 *See* Dejian Kong, *Civil Liability for Damage Caused by Global Navigation Satellite System* (Wolters Kluwer Law International 2019) 110.
19 *See* ibid.
20 'Galileo: A Critical Component for Autonomous Driving' (19 March 2018) https://www.euspa.europa.eu/newsroom/news/galileo-critical-component-autonomous-driving accessed 23 July 2021.
21 *See* Elliott D Kaplan and C Hegarty, *Understanding GPS: Principles and Applications* (2nd edn, Artech House 2006) 360.
22 Lyall and Larsen (n 1) 339.
23 Frans von der Dunk, 'The "Space Side" to "Harmful Interference"—Evaluating Regulatory Instruments in Addressing Interference Issues in the Context of Satellite Communications' in (3rd Workshop of Satellite Communications on Harmful Interference, Baden-Baden, Germany, Nomos Verlagsgesellschaft and Hart Publishing 1 January 2015) 87.
24 David Livingstone and Patricia Lewis, 'Space, the Final Frontier for Cybersecurity?' (Chatham House The Royal Institute of International Affairs 2016) 8.

using radio noise and electromagnetic signals, for the purpose of sabotage, malicious mischief or personal privacy protection.[25] Spoofing techniques mimic GNSS signal structure and content, aiming to coerce GNSS receivers into generating false positions.[26] This interference can mislead a receiver into producing a precise but erroneous navigation solution.[27] Due to this misleading action, the spoofing attack can be significantly more harmful than jamming because the target receiver cannot properly identify the threat.[28] Electronic interferences can also occur unintentionally, caused by out-of-band emissions mainly from other services or by in-band emissions, in particular from other systems.[29]

Because of the potential mutually de-stabilizing impact, destroying satellites with kinetic force is usually not an ideal method for interfering with GNSS signals.[30] However, space is becoming increasingly crowded due to the growing number of space objects and space debris. This increases the risks of collisions in space.[31] Recently, a Galileo satellite, GSAT0219, engaged in a first collision avoidance manoeuvre for mitigating a potential conjunction with a large piece of space debris, an inert rocket body that has been in orbit since 1989.[32]

Given the essential role of GNSS in the operation of AI systems, any GNSS signal failure would have negative consequences on the proper functioning of these systems. In the literature, electronic interferences are considered the

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25 *See* National PNT Advisory Board, 'Jamming the Global Positioning System - A National Security Threat: Recent Events and Potential Cures' (White Paper, 4 November 2010); *See also* Livingstone and Lewis (n 24).

26 *See* Xi-jun Cheng and others, 'Analysis on Forgery Patterns for GPS Civil Spoofing Signals' (November 2009) 2009 Fourth International Conference on Computer Sciences and Convergence Information Technology 353, 353–56.

27 *See* Manuel Cuntz and others, 'Jamming and Spoofing in GPS/GNSS Based Applications and Services – Threats and Countermeasures' in *Future Security* (Communications in Computer and Information Science, Berlin, Heidelberg, Nils Aschenbruck and others eds, Springer 2012) 197.

28 Todd E Humphreys and others, 'Assessing the Spoofing Threat: Development of a Portable GPS Civilian Spoofer' (2008) 2314.

29 Matthias Wildemeersch and Joaquim Fortuny-Guasch, 'Radio Frequency Interference Impact Assessment on Global Navigation Satellite Systems' (JRC Scientifical and Technical Reports, 2010) 15.

30 Madeleine Moon, 'The Space Domain and Allied Defence' (8.10.2017) 7.

31 Hamid Kazemi and others, 'Liability for Space Debris in the Framework of Private International Space Law 56th Colloquium on the Law of Outer Space: Session 4: Legal Aspects of Space Debris Remediation' (2013) 56 Proc Int'l Inst Space L 367, 268.

32 Inside GNSS, 'Galileo Satellite Checks Out, Dodges Space Debris, Returns to Active Service' (*Inside GNSS - Global Navigation Satellite Systems Engineering, Policy, and Design*, 24 March 2021) https://insidegnss.com/galileo-satellite-checks-out-dodges-space-debris-returns-to-active-service/ accessed 20 May 2021.

main "threats". Special attention is given to autonomous vehicles[33] and drones.[34] Several staged simulations revealed what impact GNSS electronic interferences on autonomous vehicles would have. For example, in 2019, Regulus Cyber, a private company dealing with smart sensors security, engaged in a test drive using Tesla's "navigate on autopilot" feature, for demonstrating how the autonomous vehicles would react to a GPS spoofing attack. The test began with the vehicle driving normally and having the autopilot navigation feature activated. When the spoofing attack began, the vehicle was three miles away from the planned exit but reacted as if the exit was just 500 feet away, abruptly slowing down.[35]

During GNSS signals attacks, the AI systems are fed with purposely erroneous or unreliable data. In this way, the attacker may influence the control of the vehicles, by creating, for example, different situational awareness, false collision warnings, or choose wrong positioning of the vehicle.[36] Any such disturbance will lead to false decisions to be taken concerning the vehicle functionalities, including passengers' safety.

5. The European Approach to GNSS Signal Failures

Preoccupations on GNSS liability have started in Europe since 2000, with the legal doctrine proposing various models, such as the Galileo functional/legal model.[37] Reports from the European Commission and previously enacted Regulations expressly referred to the need of addressing liability for losses potentially suffered by users or third parties.[38]

33 *See, e.g.*, Siham Bouchelaghem and others, 'Autonomous Vehicle Security: Literature Review of Real Attack Experiments' in *Risks and Security of Internet and Systems* (Lecture Notes in Computer Science, Cham, Joaquin Garcia-Alfaro and others eds, Springer International Publishing 2021) 268; Shaoshan Liu, *Engineering Autonomous Vehicles and Robots: The DragonFly Modular-Based Approach* (John Wiley & Sons 2020).

34 Huu Phuoc Dai Nguyen and Dinh Dung Nguyen, 'Drone Application in Smart Cities: The General Overview of Security Vulnerabilities and Countermeasures for Data Communication' in Rajalakshmi Krishnamurthi and others (eds.), *Development and Future of Internet of Drones (IoD): Insights, Trends and Road Ahead* (Studies in Systems, Decision and Control, Springer International Publishing 2021) 196.

35 Inside GNSS, 'Tesla Model S and Model 3 Prove Vulnerable to GPS Spoofing Attacks, Research from Regulus Cyber Shows' (*Inside GNSS - Global Navigation Satellite Systems Engineering, Policy, and Design*, 24 June 2019) https://insidegnss.com/tesla-model-s-and-model-3-prove-vulnerable-to-gps-spoofing-attacks-research-from-regulus-cyber-shows/ accessed 16 May 2021.

36 European Union Agency for Cybersecurity, 'Cybersecurity Challenges in the Uptake of Artificial Intelligence in Autonomous Driving' (2021) 40.

37 Frans von der Dunk, 'Liability for Global Navigation Satellite Services: A Comparative Analysis of GPS and Galileo' (2004) 30 Journal of Space Law 129, 145.

38 European Commission, 'Mid-Term Review of the European Satellite Radio Navigation Programmes (COM 2011) 5' (18.01.2011); Regulation (EC) No

Despite such preoccupations, currently there is no legal instrument clearly addressing the "European problem" of GNSS liability.[39] The new Regulation 696/2021, in Article 97, provides that liability arising from contractual relationships shall be governed by the relevant law applicable to the respective contract, while for non-contractual liabilities, general principles common to the laws of the Member States shall be taken in consideration. In Article 10, the European regulator mentions that all services provided by Galileo "shall be provided without any express or implied warranty as regards their quality, accuracy, availability, reliability, speed and suitability for any purpose." The purpose behind such denial of liability is explained under Recital 23, i.e., encouraging the use of the services offered by Galileo. Whether or not eliminating warranties encourages the use of certain services is a different discussion and exceeds the purposes of the present paper.

Under the current organizational structure, the European Commission will be responsible for the implementation of Galileo, based on attributions delegated by the European Union, in its capacity as owner of Galileo. Despite this, it is still not clear how the *owner* or other institutions, acting based on such delegation powers may be held liable in a GNSS related claim.[40]

In the absence of a special regulatory framework dealing with liability for damage caused by GNSS signal failures, the "general" rules of international space law would need to be investigated, specifically the provisions of the Outer Space Treaty and the Liability Convention. Even though these treaties do not specifically address GNSS operations, it does not automatically mean that international space law will not be applicable to such operations. That is mostly because, after having launched GNSS, states are bound by the rules of international space law.[41]

6. International Space Law and GNSS Signal Failures

The Outer Space Treaty and the Liability Convention provide the legal grounds for accountability, i.e. responsibility and liability, related to space related activities. Art. VI of the Outer Space Treaty provides that states shall

683/2008 of the European Parliament and of the Council of 9 July 2008 on the further implementation of the European satellite navigation programmes (EGNOS and Galileo) 196 OJ L (EP, CONSIL US 2008).

39 Ingo Baumann, 'Liability for GNSS Signals and Services' (*Inside GNSS - Global Navigation Satellite Systems Engineering, Policy, and Design*, November–December 2015) https://www.insidegnss.com/auto/novdec15-LAW.pdf.

40 Smith (n 10) 595.

41 Simona Spassova and Andreas Loukakis, 'The Legal Implications of Erroneous GNSS Signal, Resulting from Harmful Interference 58th IISL Colloquium on the Law of Outer Space - Jerusalem, Israel: 1st Session' (2015) 58 Proc Int'l Inst Space L 79, 88; Paul B Larsen, 'Legal Liability for Global Navigation Satellite Systems' (1993) 36 Proc on L Outer Space 69, 70.

bear "international responsibility" for national activities in outer space, while Art. VII refers to "international liability" to be attributed to a state that launches or procures the launching of an object into outer space. The present paper will not discuss the accountability dilemma, differentiating between the concepts of responsibility and liability mentioned in the Outer Space Treaty, therefore it will not investigate whether Art. VI can be read as a back-up option to Art. VII of the Outer Space Treaty and the corresponding Art. II and III of the Liability Convention.[42] This paper will focus on the provisions of the Liability Convention and its potential application to incidents caused by GNSS signal failures. In doing so, the investigation will include an analysis of its key elements, "space object", "damage" and "causation".

6.1. Defining "space object"

The notion of "space object" represents a fundamental concept in international space law.[43] Despite its important role, only partial and inconsistent definitions can be found in international space law.[44] For example, the Liability Convention under Article 1 (d) defines the term only by mentioning that the "space object" includes "component parts" of a space object as well as its "launch vehicle" and "parts" thereof.

Given these unclarities, the legal definition of "space object" has been actively discussed in legal doctrine. A systematic analysis of the legal doctrine revealed two schools of thought in the interpretation of the term "space object". The first school of thought is represented by the majority of the legal scholars who interpret "space object" as a physical object only, thus excluding the possibility of extending the definition to an intangible object, such as a satellite signal.[45] This line of interpretation would lead, in theory, to the impossibility of attributing liability for GNSS signal failure.

The second school of thought includes authors arguing that intangible objects, for example, electromagnetic waves, were not *per se* excluded from the applicability of the Liability Convention.[46] Even though physical damage caused by tangible parts of a space object represented the main concern of the

42 For a detailed discussion on this matter, *see* Frans von der Dunk, 'Liability versus Responsibility in Space Law: Misconception or Misconstruction?' [1991] Proceedings of the Thirty-Fourth Colloquium on the Law of Outer Space 363.

43 Vladimir Kopal, 'Some Remarks on Issues Relating to Legal Definitions of Space Object, Space Debris and Astronaut Definitional Issues in Space Law' (1994) 37 Proc on L Outer Space 99, 103.

44 Stephen Gorove, 'Aerospace Object - Legal and Policy Issues for Air and Space Law' (1997) 25 J Space L 101, 107.

45 *See, e.g.*, Stephan Hobe, *Cologne Commentary on Space Law / Vol. 2, Rescue Agreement, Liability Convention, Registration Convention, Moon Agreement.* (Heymann 2013) 139, WorldCat.org; Carl Q Christol, 'International Liability for Damage Caused by Space Objects' (1980) 74 Am J Int'l L 346, 354.

46 Ram S Jakhu and Paul Stephen Dempsey, *Routledge Handbook of Space Law* (Routledge 2017) 165.

Liability Convention drafters, it cannot be said with absolute certainty that damage from intangible electromagnetic waves was not taken into consideration.[47] Exceptionally, it was argued that satellite signals can be construed as independent, standalone objects.[48] Such interpretations would, of course, trigger the applicability of the Liability Convention for damage caused by GNSS signals.

Observations related to the "component part" of a space object were also included in both schools of thought. It was argued that component parts would include any object, without which, the spacecraft would be regarded incomplete.[49] This line of argumentation may prove crucial in the quest for defining a satellite signal in the light of the Liability Convention. Signals are without any doubt a *sine qua non* element of satellites, in the absence of which, satellites could not be considered fully operational, thus, making the Liability Convention entirely applicable.[50]

The debate between the legal scholars concerning the definition of "space object" reveals an urgent need for an updated definition of this term, *de lege ferenda*, for including, among others, satellite signals. In such context, a suggestion for an updated definition could be read as follows:

> *the term space object means any item launched or attempted to be launched physically into outer space. It includes all its tangible and intangible components, such as, without limitation, software, hardware, equipment, installations, launch vehicles and other parts thereof, without which, the full operation of the space object would not be construed as possible.*

6.2. Defining "damage"

According to Art. I of the Liability Convention damage is represented by: "loss of life, personal injury or other impairment of health; or loss of or damage to property of states or of persons, natural or juridical, or property of international intergovernmental organizations."

Similar with the situation concerning the definition of the "space object", the definition of "damage" is actively debated in the legal doctrine, in accordance with two main schools of thought. The majoritarian opinion of the legal scholars is that the notion of "damage" includes only direct damage, while indirect damage is excluded from the applicability of the Liability

47 *See* Smith (n 10) 585.
48 *Cf*. BD Kofi Henaku, 'The International Liability of the GNSS Space Segment Provider Section I' (1996) 21 Part 1 Annals Air & Space L 143, 165.
49 *Cf*. Stephen Gorove, 'International Protection of Astronauts and Space Objects' (1971) 20 DePaul L Rev 597, 607.
50 *See* Smith (n 10) 584.

Convention.[51] This means that non-physical damage is not compensable under the Liability Convention.

In a different school of thought, some authors believe that the term "damage" is broad and, because of this, it is clear that all potential injuries are covered even if they do not consist just in physical consequences.[52] Such argumentation would allow the possibility to cover damage caused by GNSS signal failures.

6.3. Defining "causation"

Given the difficulties in interpreting the notion "damage", some authors suggest a different approach. Instead of extending the definition of "damage" to non-physical damage, they have studied the attribution of liability by proving the link between the space object, i.e. the satellite, and the damage caused by the said space object.[53] It was argued that the language of causation should be approached from a double perspective, directness and proximate causation.[54] Directness would imply the existence of a clear and unbroken causal link between cause and effect.[55] In such case, as long as the satellite signal is not considered an standalone space object[56] or a *sine qua non* component of a satellite,[57] using directness as a standard for attributing liability would automatically exclude claims related to damage caused by a satellite signal failure.

The concept of proximate causation does not have a generally accepted meaning in practice.[58] In the context of GNSS liability, applying this concept would require an interpretation of damage through the lens of two criteria: normality and foreseeability.[59] For the normality criterium, assuming that the

51 Frans von der Dunk and Fabio Tronchetti, *Handbook of Space Law* (Research Handbooks in International Law, Edward Elgar Publishing 2015) 84; Valérie Kayser, *Launching Space Objects: Issues of Liability and Future Prospects* (Kluwer Academic Publishers 2001) 49; Edward R Finch, 'Outer Space Liability: Past, Present and Future' (1980) 14 The International Lawyer 123, 126, JSTOR; IHP Diederiks-Verschoor and Vladimir Kopal, *An Introduction to Space Law* (3rd edn, Kluwer Law International 2008) 39; Larsen (n 41) 70.

52 WF Foster, 'The Convention on International Liability for Damage Caused by Space Objects' (1972) 10 Canadian Yearbook of International Law 137, 155.

53 Carl Q Christol, *The Modern International Law of Outer Space* (Pergamon policy studies on international politics, Pergamon Press 1982) 97, WorldCat.org; D Kong, 'Civil Liability for Damage Caused by Global Navigation Satellite System' (s.n 2018) 80; Hobe (n 45) 129; Nicolas Mateesco Matte, *Aerospace Law: From Scientific Exploration to Commercial Utilization* (Carswell Co 1977) 157, WorldCat.org.

54 Carl Q Christol, *Space Law: Past, Present and Future* (Kluwer 1991) 223.

55 Marco Frigessi di Rattalma and Tullio Treves, *The United Nations Compensation Commission: A Handbook* (Kluwer Law International 1999) 21, WorldCat.org.

56 *Cf*. Henaku (n 48) 165.

57 *See* Smith (n 10) 584.

58 Kong (n 53) 85.

59 Henaku (n 48) 168.

signal is considered a *sine qua non* component of the satellite, the damage could be presumed to be a normal consequence in case of a satellite malfunction. Related to the second criterium, the foreseeability test is closely connected to a reasonability test, as follows: in order to determine if the damage was caused by a satellite signal, it would be required to analyze if a reasonable person in the position of a provider of satellite signals should have foreseen the alleged damage as likely to arise from its design, launch and the operation of the satellite.[60]

Applying these criteria for GNSS signal failures would imply that if a claim is made under the current provisions of the Liability Convention, certain aspects should be taken in consideration. Firstly, the analysis of normality and foreseeability will most likely be assessed in the context of the professional status of the signal provider. Secondly, a thorough technical assessment from an independent technical advisor would be required,[61] for the purpose of identifying if the cause of the incident was the signal failure, e.g., the interruption of the signal for a specific time period, leading to, for example, the impossibility of an autonomous vehicle to properly assess the surrounding environment. Subject to these two conditions, the concept of proximate causation has the potential of offering a solution in the extremely unclear legal scenario caused by the lacunar provisions of the Liability Convention.

7. Conclusions

GNSS offer many advantages for the modern world and they represent a key component in the technical configuration of AI systems. Several vulnerabilities, however, cast doubts on the reliability of GNSS. Electronic interferences and kinetic interferences, either intentional or unintentional, can affect the quality of GNSS signals. Moreover, such vulnerabilities have the potential of leading to significant disturbances in the operation of AI systems.

The legal doctrine has been divided over the question of whether international space law, in particular the provisions of the Liability Convention, can offer solutions in case of GNSS signal failures. For mitigating the risks of a liability gap, the following options can be considered: (i) a broad interpretation of the term “damage” for including GNSS signals or (ii) a case-by-case assessment depending on the causal link between the damage and the GNSS signal. However, both options represent theoretical solutions which were not tested in practice yet. Therefore, even though their aim is to avoid situations where liability cannot be attributed, they do not offer legal certainty. This leads to the conclusion that, in its existing form, international space law fails to offer a comprehensive system

60 ibid 169.
61 ibid 170.

for GNSS liability. In such context, another potential solution, *de lege ferenda*, would require updating the definition of the "space object" for including GNSS signals, and, thus, allowing compensation for any damage caused by GNSS signal failures.