Space Traffic Management: Not Just Air Traffic Management for Outer Space and More Than Data Analytics

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Abstract

Space Traffic Management is a complex concept that consists of technical, organisational and regulatory elements. It is not foreseen in the Outer Space Treaties and yet considered a crucial concept for a safe and sustainable access to space and interference free operations in space. Space Situational Awareness and Space Surveillance and Tracking are not identical to Space Traffic Management which is broader and reaches farther. Space Situational Awareness and Space Surveillance and Tracking are cognitive elements of Space Traffic Management. Air Traffic Management is often used as a reference for Space Traffic Management. However, not only the legal regimes of sovereign airspace as opposed to the regime of Outer Space are substantially different. Alone the differences of the physical characteristics support different technical approaches in air space and Outer Space. Motions in air space that follow aerodynamics and ballistics tend to be short lived and henceforth air traffic control has evolved from short term, tactical measures. Opposed to that, objects in Outer Space follow orbital dynamics and their trajectories persist for longer periods, so that control procedures need to address longer term effects and be of a strategic nature. In that context, Air Traffic Management has evolved in an opposite direction than Space Traffic Management. During recent years, rule-making for Space Traffic Management takes new roads. Lacking hard treaty law, an increasing range of non-binding standards, national regulations, practices of private bodies, voluntary information exchanges and cooperative routines tend to synchronize selected elements of Space Traffic Management. In addition, data analytics is taking an expanding role in Space Situational Awareness.

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I. INTRODUCTION

The Outer Space Treaty of 1967[1] establishes an order for outer space among States, which are the guardians of this order and are responsible for their national space activities, even when they are not undertaken by State entities. In 1967 outer space appeared vast, and its use seemed to have no limits. More than fifty years later, we see congestion in Earth orbits. An increasing number of operational space objects and uncontrolled man-made space debris render the access to outer space from Earth and the use of valuable orbits and areas in the vicinity of the Earth increasingly difficult. Emerging mega constellations in Low Earth Orbit (LEO) and the resulting debris will aggravate this situation. Globally acting private enterprises which drive these developments under the slogan 'New Space' seek authorization for the launch of their space objects and the use of frequency spectrum from those States whose national regulations promise the easiest and quickest results. In these areas, the Outer Space Treaty has shortcomings and orbital capacity conflicts are emerging.[2]

Space Traffic Management is intended to establish a broad range of technical and regulatory measures that reach beyond the level of detail of the Outer Space Treaty, while maintaining its overall purpose.

II. DEFINITION

There is no internationally agreed definition of Space Traffic Management. The term is not mentioned in any of the space treaties. Etymologically, it seems related to the aviation concept of Air Traffic Management, despite the different physical properties and legal regime that govern (national) air space. In 2006, the Cosmic Study of Space Traffic Management came forward with the following definition:

> "*Space Traffic Management (STM) means the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference.*"[3]

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1 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, 1967, 610 U.N.T.S. 205.

2 Irene Klotz, "Showdown at LEO – FCC approves lower orbit for SpaceX satellites – OneWeb calls SpaceX tactic 'coercive'", *AW&ST*, 6-19 May 2019, p. 50.

3 International Academy of Astronautics, *Cosmic Study on Space Traffic Management*, Corinne Contant-Jorgenson, Petr Lála, Kai-Uwe Schrogl (eds.), 2006; see also

This definition is often used as a reference. It provides a broad frame and indicates that there is a lot of room to be filled. It mentions technical and regulatory provisions. The technical measures can be developed in a dynamic fashion taking into account the advancement of the state of the art, and the technical requirements of traffic and frequency de-confliction in increasingly congested parts of Outer Space.

The reference to regulatory provisions leaves open whether States or non-State actors will act as rule-maker, whether rules will be binding (treaty) law or non-binding technical standards, whether rule-making will be centralized or de-centralized, and finally, whether the entire set of Space Traffic Management regulations will coherently follow the same regulatory pattern or become a patchwork.

Concerning the subject matter of the technical and regulatory provisions, the definition of the 2006 Cosmic Study uses the concept of non-interference, which it links to both, physical aspects and radio-frequencies. It specifies further that 'free from interference' relates to the safe access into outer space, operations in outer space and return from outer space to Earth. By referencing the concept of non-interference, the definition establishes bridges to both, the Outer Space Treaty in a broader sense (Articles IX and XII), and the ITU Constitution[4] (Article 45) regarding the avoidance of harmful radio interference.

The breadth of the concept has led to some confusion and to a lack of understanding of Space Traffic Management in discussions, also in the UN Committee on the Peaceful Uses of Outer Space (COPUOS).[5]

III. THE RELATIONSHIP BETWEEN SPACE SITUATIONAL AWARENESS AND SPACE TRAFFIC MANAGEMENT

Space Situational Awareness and Space Surveillance and Tracking are not identical to Space Traffic Management which is broader and reaches farther.

"*A space situational awareness system consists of three principal elements and activities:*

International Academy of Astronautics, *Space Traffic Management – Towards a roadmap for implementation*, Kai-Uwe Schrogl, Corinne Jorgenson, Jana Robinson, Alexander Soucek (eds.), Paris 2018, p. 22.

4 *Constitution of the International Telecommunication Union*, 2018, UNTS No. 31251 multilateral.

5 UNGA COPUOS, 62nd Sess. Vienna 12-21 June 2019, A/AC.105/L.318/Add.2, section 55; for more details of the discussion, see the Report of the Legal Subcommittee on its fifty-eighth session, held in Vienna from 1 to 12 April 2019, A/AC.105/1203, sec. XI General exchange of views on the legal aspects of space traffic management.

- *the collection of data and information, typically including the detection and tracking by ground-based and space-based optical and radar sensors, and collection by other sources, like registration information and exchanges with other public and private bodies including satellite operators;*
- *the arrangement of the collected information in a systematic manner, typically by keeping and updating a data base or catalogue of all space objects and space debris, including their orbital parameters; and*
- *computer processing capacity to predict the status, events and threats in the future, most importantly to issue reliable conjunction information, i.e. predicting with a useful probability collision conflicts among man-made and possibly also natural space objects*."[6]

Space Situational Awareness and Space Surveillance and Tracking are cognitive elements of Space Traffic Management. Based on this, a Space Traffic Management system "*will consist of a space situational awareness element and arrangements for the avoidance of collisions and an efficient use of congested orbits and radio frequencies. For that purpose, a space situational awareness system needs to be established that is as precise as possible and is agreed as the decisive cognitive reference tool…. In any case, States need to agree first to a space situational awareness system that can serve as the reference for all actions to be undertaken subsequently as part of space traffic management*."[7]

Space Situational Awareness requires cooperation and pooling of data and information to improve the quantity of data in order to improve the quality of conjunction information and collision warnings,[8] possibly combined with a more elaborate registration system.[9]

IV. SPACE TRAFFIC MANAGEMENT VERSUS AIR TRAFFIC MANAGEMENT

Air Traffic Management is often used as a reference for Space Traffic Management. However, the concept of Air Traffic Management is a composite set of services and infrastructure which have evolved over time and are based on the legal regime of sovereign national air space and the physical properties that apply therein.

6 Stefan A. Kaiser, "Legal and policy aspects of space situational awareness", in *Space Policy* 31 (2015) 5, 6.
7 *Ibid*, page 11.
8 *Ibid*, page 7, 8; also Stefan A. Kaiser, "Space Situational Awareness, Key to a New Space Security Architecture" in *52nd Proceedings of the IISL Colloquium on the Law of Outer Space*, 2009, Daejeon, Republic of Korea.
9 Stephan Hobe, "Space Traffic Management – Some Conceptual Ideas", in *ZLW* 1, 2016, 3, 18.

The International Civil Aviation Organization (ICAO) defines Air Traffic Management as "*the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management* — [provided] *safely, economically and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.*"[10]

The historic core of these services is Air Traffic Services (ATS), "*a generic term meaning variously, flight information service, alerting service air traffic advisory service, air traffic control service ….*"[11] Within that group of services, air traffic control is the central functionality to prevent collisions and to expedite and maintain an orderly air traffic flow.[12] This historic development is also the reason why ICAO Annex 11 is entitled "Air Traffic Services" rather than "Air Traffic Management", which is broader, but emerged only later. Air Traffic Services have in common that they are *tactical,* which means they concern information which is specific to certain airspace users with a short term validity to maintain safe, economic and efficient air traffic. For controlled aircraft in controlled airspace, air traffic control issues air traffic control clearances to maintain horizontal and vertical separation among airspace users. Air traffic control units are established by virtue of the sovereignty of national air space or by international agreement.

Besides these tactical measures of air traffic services, the umbrella concept of Air Traffic Management encompasses also the *strategic* instruments of air traffic flow management and airspace management. *Strategic* means here longer term arrangements. Air traffic flow management is a service to ensure a safe, orderly and efficient flow of air traffic taking account of the different capacity of air traffic services provided in different airspaces. It coordinates controlled flights, so that their continuous flow is maintained, even when they traverse airspace with a reduced air traffic service capacity as compared to neighbouring airspaces. The *strategic* dimension of air traffic flow management takes thus account of the entire duration of a flight in a given spatial, temporal and organisational environment.

Airspace management is another *strategic* instrument of Air Traffic Management. EUROCONTROL defines it as "*a planning function with the primary objective of maximising the utilisation of available airspace by dynamic time-sharing and, at times, the segregation of airspace among various categories of airspace users on the basis of short-term needs.*"[13]

10 ICAO, *PANS-ATM Procedures for Air Navigation Services — Air Traffic Management* (Doc 4444) 2007, 15th ed. (Amdt 5), Chapter 1, Definitions, Air Traffic Management.

11 ICAO, PANS-ATM, *ibid*, Chapter 1, Definitions, Air Traffic Services.

12 ICAO, PANS-ATM, *ibid*, Chapter 1, Definitions, Air Traffic Control.

13 EUROCONTROL, *Specification for Airspace Management (ASM) Support System Requirements supporting the ASM processes at local and FAB level Part I - Baseline Requirements*, 1.0 Edition, 26/09/2017, section 5., Definitions, Airspace Management.

Airspace management is a *strategic* planning tool, because it relates generally to a multitude of flights of diverse users and concerning longer periods, albeit in a dynamic fashion.

Based on the understanding of the amalgam of tactical and strategic measures of Air Traffic Management, the technical and regulatory provisions for Space Traffic Management require a closer look at the similarities and differences in air space and outer space.

Alone the differences of the physical characteristics support different technical approaches in air space and Outer Space. Motions in air space that follow aerodynamics[14] and ballistics[15] tend to be short lived. They are subject to gravitational forces and atmospheric drag. Aircraft may always change their course and altitude, depending on the control inputs of their pilots and henceforth air traffic control has evolved from short term, tactical measures to prevent collisions among swiftly responding air traffic participants. In case of an air accident, debris is subject to the Earth's gravity and the airspace is typically clear from debris within minutes.

Opposed to that, objects in Outer Space follow orbital dynamics, their trajectories persist for longer periods, and only sporadically, when necessary, flight control provides inputs to change their orbits. Their orbits are predictable, subject only to minimal natural effects like solar radiation and atmospheric drag, depending on the proximity to the Earth.

As a result of these different physical properties, the control regimes of air traffic and space objects are different. Air traffic is controlled in the sense that pilots control aircraft and operators control unmanned aerial vehicles, so that they can prevent collisions and interfere, in case a collision risk becomes imminent.[16]

Looking at space traffic, only a small number of space objects is controlled, so that operators have at least the possibility to initiate collision avoidance manoeuvres. The population of non-operational space objects and man-made space debris by far outnumbers controlled space objects. Collision avoidance manoeuvres following conjunction information can be initiated only, if at least one of the conflicting space objects is controlled. For the vast majority

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14 ICAO defines (aerodynamic) aircraft as "*any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface*". Part I of Annex 1, Annex 6 to the Convention on International Civil Aviation, 1944, 15 UNTS 295 (ICAO Doc. 7300).

15 Ballistic bodies are typically launched by rockets or guns – other than by aerodynamic lift – and without reaching orbital speed they return to the surface of the Earth by gravitational forces. Suborbital flight vehicles and lower rocket stages typically follow ballistic trajectories.

16 The term 'control' is used here in broad sense and not only for flights in controlled airspace and under the control of an air traffic control unit. Also flights operated under visual flight rules are under control of a pilot (in the aircraft or on the ground) to avoid collisions.

of collision conflicts among non-controlled space objects, no tactical short term measure is possible. This statistical situation will not change in the foreseeable future. To the contrary, following the Kessler effect, the population of space debris in Earth orbits will continue to increase based on cascading collisions of the further fragmenting debris. Man-made space debris may persist in Earth orbits, depending on the perigee, up to hundreds of thousands of years. This adds an entirely special challenge to Space Traffic Management, which is not a factor in Air Space Management.
Another aspect of Space Traffic Management are response times. Flight manoeuvres of space objects, contrary to those of aircraft, are not the result of an instant decision of a pilot. Considering the scarce resource of fuel and the predictable trajectories of space objects, space operators plan manoeuvres as long term measures, for station keeping, orbit adjustments, or in case conjunction information indicate a possible collision. Avoidance manoeuvers in outer space need far longer lead times than in airspace.

V. TECHNICAL MEASURES FOR SPACE TRAFFIC MANAGEMENT

1. Strategic versus tactical control measures

Considering orbital dynamics, the comparatively small number of controlled space objects and typical response times for controlling space objects, it is apparent that control procedures of Space Traffic Management need to address longer term effects and be more of a strategic nature. These strategic measures include, but not limited to:

- zoning and protection of defined orbits, areas, points;[17]
- orbital slot coordination;[18]
- radio frequency allocation and assignment;[19]
- debris mitigation measures, including space object design requirements and procedures;[20]

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17 Inter-Agency Space Debris Coordination Committee, *Space Debris Mitigation Guidelines*, Oct. 15, 2002 (revised in 2007), IADC-02-01, https://www.iadc-home.org/documents_public/view/id/82#u.;
UN, *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space* [COPUOS Space Debris Mitigation Guidelines], Report of the Committee on the Peaceful Uses of Outer Space, UN Doc. A/62/20, June 15, 2007, 47-50 [Annex], http://www.unoosa.org/pdf/gadocs/A_62_20E.pdf.;
UNGA, *Resolution, International Cooperation in the Peaceful Uses of Outer Space*, UN Doc. A/RES/62/217, Dec. 22, 2007, [paragraphs 26 - 28], https://undocs.org/A/RES/62/217.

18 Based on Art. 44 ITU Constitution 2018, Use of the Radio-Frequency Spectrum and of the Geostationary-Satellite and Other Satellite Orbits and the related ITU Radio Regulations.

19 Based on Art. 1, 2 a) ITU Constitution.

20 IADC, *supra* note 17.

- de-orbiting of space objects at end-of-life, including placement in graveyard orbits;[21]
- debris removal procedures.

Strategic measures have in common that they do not de-conflict a specific critical (collision) situation. They rather address the overall traffic situation and seek relief through measures that statistically reduce the probability of collisions and other kinds of interference.
Typical tactical measures of Space Traffic Management include, but are not limited to

- generation and dissemination of conjunction and collision information and warnings;
- orbital manoeuvers for station and position keeping to keep separation to other space objects,
- orbital manoeuvers for collision avoidance following safety critical conjunction information;
- automatic collision avoidance systems.

Automatic collision avoidance systems for orbital traffic based on information exchanging transponders, similar to the Traffic Collision Avoidance System (TCAS) used in aviation, are partly seen as new tactical tools - but they have operational limitations. Not only the number of controlled space objects which could potentially be used for such tactical manoeuvers is small. Unlike in aviation, the required information exchanges between the transponders of the involved space objects may not work due to the distances, speeds and response times in orbit.[22]
Considering this, Space Traffic Management will evolve in a different direction than Air Traffic Management. As understood today, the focus of Space Traffic Management will firstly be on strategic long term measures; technologies and procedures for tactical measures to prevent orbital collision will follow.

2. De-confliction of space objects and aircraft in (national) air space

With an increasing number of space objects, also with sub-orbital trajectories, the traffic de-confliction between aviation and space traffic has become a factor around space ports.[23] It is however clear that the existing air law instruments relating to (national) airspace can appropriately accommodate these requirements. Within existing structures of Air Traffic Management, certain portions of airspace can be (temporarily) assigned for space launch or

21 IADC, *supra* note 17.
22 "Could Satellites Use Aviation's TCAS?", *AW&ST*, 16-29 September 2019, p. 35; Stephan Hobe, *supra* note 9, p.17.
23 Bill Carey, "Air Traffic Management, Bringing Commercial Space Into the Mainstream", *AW&ST*, July 1-14, 2019, p. 60.

landing operations or for sub-orbital flights. As part of its national airspace design or on the basis of Article 9 of the Chicago Convention,[24] States may assign or (temporarily) reserve certain portions of the airspace for space traffic operations,[25] taking into consideration the high speed, high altitude and any other factors specific to space objects. Using modern information technology, these assignment and reservations can be accomplished in a dynamic fashion. Existing Air Traffic Management allows such a four dimensional dynamic use of airspace already today. Orbital dynamics do not exist in these sectors of the airspace and States have full sovereign control over them,[26] so that there is no need to create Space Traffic Management for these portions of airspace.

VI. SPACE TRAFFIC MANAGEMENT VERSUS DATA ANALYTICS

Today, data analytics, or more generally information science, play an important role in many fields and this also applies to Space Traffic Management. However, its role, capabilities and limitations need to be properly understood. Data analytics has its role in space situational awareness systems, or more precisely, in creating conjunction information based on the data and information of space objects and debris held in data bases or catalogues and in updating the same. While data analytics has the capacity to project the status of space objects, events and threats for the future, in accordance with the principles of orbital mechanics, it finds its limits in the underlying factual data and information. Data bases and catalogues need constant updating from external sources like sensors, operator provided data and information and any other source with a reliable a meaningful impact on overall space situational awareness. For the calculation of conjunction information, data analytics needs to provide precise information related to a specific object, henceforth the need for highly accurate sensor data. For this application, it is not sufficient to generate mere statistical models leading to overall (collision) probabilities, but to calculate specific, highly accurate conjunction events in a four-dimensional setting.

Data analytics is an important complement to the sources of data and information representing values of the actual physical properties, but it cannot be a stand-alone source by itself. Another limitation of the role of data analytics in Space Traffic Management is rooted in the relationship between the latter and space situational awareness. Space situational awareness, represents the cognitive element of Space Traffic Management.

24 Convention on International Civil Aviation, *supra* note 14, Article 9.
25 This airspace may be called restricted, temporarily-reserved, special use airspace or similarly in accordance with national designations.
26 Convention on International Civil Aviation, *ibid*, Articles 1, 2.

Data analytics does not embody the regulatory framework that forms part of Space Traffic Management. Data analytics cannot make the value judgements and policy decisions, which are required to establish Space Traffic Management as a set of regulations for promoting a safe and interference-free use of outer space including an unimpeded access to and return from outer space.

VII. REGULATORY MEASURES FOR SPACE TRAFFIC MANAGEMENT

Regulatory measures raise several issues:

- How do they fit into the existing international legal framework,
- what is their substance and
- who establishes them?

1. Linking regulatory measures to the Outer Space Treaty

Considering that Space Traffic Management will encompass regulations that are not part of the existing space law treaties, the question arises how these regulations will fit into the framework of the Outer Space Treaty which serves as the overarching charter of public international law for activities in outer space. The technical provisions for Space Traffic Management, the strategic as well as the tactical measures, are tools for using and sharing the limited resource of portions of outer space close to the Earth and the frequency spectrum. When these technical provisions are transformed into regulatory provisions, they constitute limitations to the freedom of the use and explorations of outer space as stipulated in Article I of the Outer Space Treaty. In law, it is nothing unusual that freedoms have limitations. Every freedom has its inherent limitations in the freedom of others. The Outer Space Treaty does not mention the inherent limitations to the freedom of the use and explorations outer space, but it paraphrases this effect by stating that it shall be carried out for the benefit and in the interests of all countries, without discrimination of any kind, on a basis of equality and that outer space shall be the province of all mankind. Moreover, Article IX requires consultations in case an activity could cause potentially *harmful interference* – a concept used in the Cosmic Study's definition of Space Traffic Management to allow access to, operations in and return from outer space to be *free from interference*. These are the anchoring points for regulatory measures. Likewise, during the last decades COPUOUS has created various notions derived from the mentioned principles of the Outer Space Treaty.[27]

27 See also the introductory discussion in the Legal Sub-Committee of COPUOS about Space Traffic Management, *supra* note 5.

Such derivatives include the Draft Guidelines for the Long-term Sustainability of Outer Space Activities.[28]

2. The substance of regulatory measures

The regulatory measures are the tools to formally implement the technical measures for Space Traffic Management. The breadth of the definition of the Cosmic Study of Space Traffic Management leads to a similarly broad scope of regulatory measures. The notions used in the literature for regulatory measures for Space Traffic Management differ and can lead to some confusion. At a closer look, space traffic rules (also called rules of the road) are not the same as space safety rules, or rules for cooperation in Space Situational Awareness. For this reason, we should distinguish between regulatory measures implementing strategic versus tactical technical measures. It is debatable, if certain technical measures for space safety, like the design of spacecraft and their 'space worthiness'[29] constitute a separate category or fall under strategic measures. The same applies to (future) rules governing Space Situational Awareness.

Several areas of *strategic* technical measures have already been formalized at a various degree, other technical measures are applied by space operators as a matter of practice: geo-stationary slot allocation, radio frequency management, protected areas, debris mitigation measures, de-orbiting procedures. The substance of these regulatory measures is far from complete, their sources of rule-making are diverse and their legally binding or non-binding effect is not consistent. Despite the shortcomings of this regulatory patchwork, the technical community has embarked on approaches to tackle areas of strategic technical measures and supporting services like measures for Space Situational Awareness.

Far less developed are *tactical* regulatory measures, an area that is typically described as space traffic rules or rules of the road in the narrow sense. Space traffic rules can be considered as the core of the regulatory measures of Space Traffic Management, but they are not yet in place. They need to consist of rules for maintaining physical separation, preventing collisions, priority of way, just as we know them from aviation and other means of surface transportation. There seems to be consensus that such space traffic rules are required, but the different properties of orbital dynamics prevent the adoption of the 'rules of the air' we know from ICAO Annex 2. Besides

28 COPUOS Conference room paper by the Chair of the Working Group on the Long-term Sustainability of Outer Space Activities, UN A/AC.105/2018CRP.20, 27 June 2018. These guidelines spell out principles on the policy and regulatory framework, safety, international cooperation, capacity building and awareness, and scientific and technical research and development, however they do not mention Space Traffic Management.

29 Used here in analogy to airworthiness, as established in Annex 8 to the Convention on International Civil Aviation, *supra* note 14.

general principles, like the obligations to act diligently, to avoid collisions and harmful interference, air operator responsibility and authority, the duty of space operators to inform each other and to cooperate, air law provides hardly any specific guidance for space traffic rules.[30]

As a central obligation for preventing collisions, space operators need to maintain separation and, if necessary, to initiate avoidance manoeuvers. The questions are, who of the space operators has to act, how, and how do space operators interact among each other?

Space traffic rules need to establish obligations to maintain spatial separation, to initiate avoidance manoeuvers and to give priority of way in conflict situations. For example, priority for the right of way could be established depending on the vulnerability and the damage potential of the space object.[31] However, such a prioritization has no leverage on the growing population of space debris. From the perspective of traffic flow, debris constitute traffic obstacles, but are not active traffic participants who respect the right of way of others.

It also needs to be understood that the increasing congestions of certain orbital regions for commercial purposes, puts a political burden on the creation of space traffic rules. Advocating free entrepreneurship for space activities can be played against space safety. The latest experience with SpaceX and ESA[32] has also shown, that operators of mega-constellations may ignore collisions hazards, because the loss of one of their space object appears acceptable. A short-sighted view, in light of the possibly resulting debris. Space traffic rules should therefore be flanked by obligations for responsive communication to coordinate the way ahead. Another conclusion from the recent events: space traffic rules should not incentivize those who are non-responsive or risk-taking.

Furthermore, space traffic rules need to be designed as common rules for space operators, regardless by which State they are authorized to operate under Art. VI OST. The licensing conditions for space operations granted by States under their authority of Art. VI OST is determined by national legislation. Internationally agreed or established space traffic rules could set synchronized regulatory measures for all space operators and thus add a new regulatory level to address space operators, rather than States which are directly bound by the space treaties. Space traffic rules could synchronize the

30 Stefan Kaiser, "Rules of the Road for Space Traffic", in *46th Proceedings of the IISL Colloquium on the Law of Outer Space*, 2003, Bremen, Germany, pp. 351, https://ssrn.com/author=3715966.

31 *Ibid.*, priority should be given space objects which are manned or are in an emergency.

32 Thierry Dubois, Irene Klotz, "Proliferation of Smallsats Prompts Call for Rules of the Road", *AW&ST*, 16-29 September 2019, p. 34.

licensing conditions States apply under Art. VI OST and reduce 'license shopping' of space operators.

3. Bottom-up versus top-down

During recent years, rule-making for Space Traffic Management has taken new roads. Lacking hard treaty law, an increasing range of non-binding standards, national regulations, practices of private bodies, voluntary information exchanges and cooperative routines tend to synchronize selected areas that fall under Space Traffic Management. Kai-Uwe Schrogl, *et.al.*, call this an 'incremental bottom-up' as opposed to a 'top-down' approach.[33]

The top-down approach would establish regulations for Space Traffic Management that flow down from the space treaties and supplement them in a greater level of detail at a lower regulatory level. At the moment, the reluctance of States to negotiate new treaty law for outer space is the roadblock for this approach. The distinction between the 'bottom-up' and the 'top-down' approach may be merely descriptive to explain in which direction – up or down - a regulatory measure evolves. But there is a conceptual difference. Outer space is governed by States collectively under the terms of the Outer Space Treaty. States have to provide a public order in Outer Space. This is especially important for those aspects, which are not in detail regulated by treaty law, like Space Traffic Management.

4. The role of States, operators and service providers

The bottom-up approach may appear practical, when non-state actors fill the regulatory gaps that States are reluctant to address or for which they prefer unilateral solutions.[34] However, it needs to be assured that regulatory functions remain in the realm of States. The increasing number of non-State actors who undertake space activities in a competitive environment cannot take-over the role of States for establishing such aspects of the public order in outer space, which the Outer Space Treaty does not yet sufficiently detail for the forthcoming capacity constraints. The right of the appropriate State to authorize space activities of space operators (and the obligation to continuously supervise them) under Article VI of the Outer Space Treaty is not intended to delegate this authority to the space operator. The multilateral role of States for establishing and maintaining a public order in Outer Space does not imply a laissez-faire policy.

Furthermore, the role of service providers needs to be defined. In space situational awareness we see private entities and groups who analyse the available orbital data in order to issue conjunction information and collision warnings. No doubt, this is a useful service. However, it needs to be assured that data and information, contained in catalogues and data basis are

33 IAA, Space Traffic Management, *supra* note 3, pp. 128-134.
34 Space resource mining is a good example.

generally available and accessible. Space debris can be characterized as (dynamic) obstacles for space traffic. The data and information collections are therefore the maps of certain orbital regions and need to be generally available. Several solutions are possible, including broadening the scope of the Registration Convention under the stewardship of the United Nations or creating an international master data base with constant updates.

VIII. CONCLUSIONS

There is no internationally agreed definition of Space Traffic Management. The definition commonly used in academia is broad.

Space Situational Awareness is the cognitive element of Space Traffic Management. It is a prerequisite for Space Traffic Management which requires cooperation of States and space operators for the sharing of data and information. Data analytics has a crucial role in Space Situational Awareness. Its models can calculate the future positions of space objects and conjunction information, but data analytics finds its limits in the underlying factual data and information and it cannot make the value judgements and policy decisions required for Space Traffic Management.

The regulatory provisions for Space Traffic Management will be based on the substance of the technical measures, which can be divided into long term strategic measures and short term tactical measures.

Regulatory measures are the implementation of these technical measures. Currently we see a patchwork of regulatory measures related to strategic technical aspects. ITU procedures govern orbital slot coordination, radio frequency allocation and assignment, while non-binding guidelines, standards and recommendation have partly evolved for the protection of defined zones, debris mitigation measures and de-orbiting and re-orbiting of space objects at end-of-life. So far, there are no debris removal procedures. The other big void are regulatory provisions for short term tactical aspects. There are no rules for priority of way, there is no obligation to perform orbital manoeuvers for maintaining spatial separation and collision avoidance. In short, there are no space traffic rules.

What is so difficult about space traffic rules?

Firstly, long existing air traffic rules do not fit for outer space, because of the physical properties of orbital ballistics. Secondly, priority of way rules for outer space mean a deviation from the space faring nation's *perceived* limitless freedom of the use and exploration of outer space.

However, there is no limitless freedom. As certain orbits close to the Earth become congested, the inherent limitation to the freedom of use, as formulated in Article I of the Outer Space Treaty, need to be regulated. We cannot maintain any longer the first come, first served principle in congested orbits.

Capacity constraints in certain orbits, the growing debris problem and the planned mega constellations require Space Traffic Management including space traffic rules. This cannot be left to the space operators themselves. Even in aviation flight regimes, where pilots have the sole responsibility for collision avoidance without support from air traffic control, they do so under established visual flight rules established by (international) air law.[35] The same applies in Outer Space. When space operators take over (a defined degree of) coordination among each other for maintaining separation and collision avoidance, they need to follow rules. It is neither up to them to establish these rules, nor to take unilateral action. The time has come for States to establish international space traffic rules. Otherwise, space debris will set the rules by establishing a factual limit.

35 Visual Flight Rules (VFR), Chapter 4 of Annex 2 to the Convention on International Civil Aviation, *supra* note 14.