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Security of Space Traffic Management in the New Space Environment

Master's thesis

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Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
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In Prague on 30. 7. 2020 Jakub Pražák

References

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Abstract

The thesis elaborated on the sufficiency of space traffic management in the context of the emergence of the New Space environment. New Space introduces new space actors and private companies that wish to exploit outer space for business and profits. However, new ecosystem brings new challenges that endanger space activities and sustainability of outer space and are connected to the unsatisfactory legal regime, congested orbits, increasing number of space debris, and deteriorating relations among major space powers. The current status of space traffic management has significant deficiencies and requires substantial revitalization and reconsideration of norms. Though the states are still main actors in managing space activities, they are unable to push forward new rules to satisfy the needs of space of fast-paced New Space ecosystem. Hence, they should incorporate the commercial sector in negotiations to create new norms and legislative that would meet new space traffic requirements. Moreover, international bodies such as the United Nations Committee on the Peaceful Uses of Outer Space should take a leading position, and national legislation should be coordinated according to international standards. The private sector can also be contributing to the development of new technology that would enhance general space situational and domain awareness and solve technical deficiencies such as debris removal. Finally, international guidelines should be turned into generally respected rules that will secure the sustainability of an outer space environment.

Abstrakt

Diplomová práce se zabývá kvalitou řízení vesmírného provozu v kontextu prostředí New Space. New Space představuje vzestup nových vesmírných aktérů a soukromých společností, které hodlají využívat vesmír pro komerční zisk. Nicméně nový vesmírný ekosystém vytváří nové výzvy, které ohrožují vesmírné aktivity udržitelnost vesmírného prostředí a jsou spojeny zejména s nedostatečnou právní úpravou, přeplněností orbit, narůstajícím množstvím vesmírného smetí a zhoršujícími se vztahy vesmírných mocností. Současná pravidla řízení vesmírného provozu má značné nedostatky a vyžaduje úpravy a přehodnocení stávajícím norem. Ačkoliv jsou státy stále hlavním aktérem řízení vesmírných aktivit, nejsou schopny včas vytvářet nová pravidla a přizpůsobit se potřebám rychle rostoucímu New Space prostředí. Komerční sektor by se měl tudíž aktivně podílet na vesmírných vyjednáváním a tvorbě nových norem, který uspokojily požadavky řízení vesmírného provozu. Mezinárodní instituce jako Komise pro mírové využití kosmického provozu v rámci Organizace spojených národů by měly zaujmout vůdčí pozici a národní legislativa by se měla přizpůsobit mezinárodním standardům. Soukromý sektor také může přispět a vývoji nových technologií, které by přispěly k povědomí o vesmírném prostoru a vyřešily by technické nedostatky jako je odstraňování vesmírných trosek. Mezinárodní pokyny by měly být všeobecně respektovány jako obecná pravidla, která zajistí udržitelnost vesmírného prostředí.

Keywords

Space traffic management, New Space, space security, space situational awareness

Klíčová slova

Správa vesmírného provozu, New Space, vesmírná bezpečnost, povědomí o vesmírném prostoru

Název práce

Bezpečnost správy vesmírného provozu v prostředí New Space

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Table of Contents

1. Introduction

The modern world is increasingly dependent on space technology, and interruption of space services would have devastating consequences. For instance, disruption of a global navigation satellite system (GNSS) would lead to loss of communication and observation services, bank transfers, the exact time determined by satellites and some internet connectivity would be cut off, and traffic management and infrastructure would collapse. Various fields ranging from defence or energy to finance and food supply would be affected, and the loss caused only during the first five days would be at least $6.8 billion (Robinson et al., 2018, p. 6).

In recent years outer space became more competitive. Three decades ago, the United States (U.S.) space market dominance was unchallenged; however, the 1990s entailed the rise of the national space programme and commercial launch companies. We observed the reincarnation of Soviet (Russian) space programme and Chinese development of advanced space technology. Moreover, the competitiveness of outer space is not only limited to profits but also prestige that aims at ambitious space missions of Moon or Mars exploration that resembles with the ideas of Jules Verne or even Werner von Braun, introducing the space as a destiny of humankind. According to Harrison, the prime space goals and exploration will not be achieved in the name of a particular nation but more likely by our species, driven by the development of the commercial space sector (Harrison, 2013, pp. 126-127).

What we now label as the "Old Space" is connected to the Cold War development where space activity was associated solely with state actors. Nevertheless, this system is currently challenged by the "New Space" commercial actors that resulted in the new space ecosystem. The space industry is gradually growing from $350 billion in 2015 to estimate $640 billion by 2030 (Quintana, 2017, p. 90) and should reach $1 trillion by 2040 (Robinson et al., 2019 pp. 21-24; Stanley, 2019), with dominating share of commercial activities. In 1999, Stanford University introduced the small satellite (CubeSat) of 10 x 10 x 10 cm cubic units and started the revolution in the commercial space industry. However, the increasing number of small satellites raise concerns over the sustainability of space environment, orbit congestions, regulation issues and overall impact on New Space ecosystem (Paikowsky, 2017, pp. 84-88; Quintana, 2017, pp. 88-109). Consequently, space congestion will cause difficulties in space situational awareness and space traffic management. Though there have been some efforts for regulation, represented mainly by International Telecommunications Union (ITU), space remained relatively vacant due to the limited number of space actors. Nevertheless, the emergence of New Space increases the numbers of space actors and systems with needs for further regulation. Moreover, the space powers are reluctant to establish certain space norms, struggling with an enhanced contest over space territory (Harrison, 2013, pp. 123-131).

So far, only legally binding document loosely connected to space traffic management is Outer Space Treaty from 1967. Nevertheless, the treaty is not directly addressing the problematics of space traffic management nor space situational awareness and provide only suggesting formulations that, however, cannot serve as a clear indication for international space traffic norms. In brief, Articles I, VI, and IX can be related to space traffic and promote mutual cooperation and shared interests of all countries, and the states with the ability to track space objects should grant information about potential hazards or collisions to other states. Unfortunately, these suggestions do not establish sufficient guidance for space traffic management (Palanca, 2018, pp. 3-4). Accordingly, the thesis will focus on the development and establishment of space traffic management norms and will address the new challenges in the perspective of the new space ecosystem.

In my thesis, I will first outline the strategic significance of outer space and provide the theoretical background of theoretical astropolitical approaches, namely neo-classical astropolitics, astroeconomics, and critical astropolitics. Secondly, I will explain the emergence of New Space with focus on its dynamics identifying its challenges. Then, I will describe the existing space traffic management mechanisms and determine its drawbacks in the context of New Space. After that, I will give an analysis of space traffic management (STM) in the general space environment from the discussed astropolitical perspectives. The thesis concludes that space traffic norms are unsatisfactory and further emphasis should be given to the cooperation between states and private actors in the implementation of new rules and development of new space technology. Furthermore, international bodies should be encouraged in constitution of functional mechanisms and space actors should be committed to their guidance.

1.1. Methodology

The thesis will be written as a case study focusing on the norms of space traffic management and options for space situational awareness. A case study was selected because it enables to detailed description and assessment of the problem of space traffic management with identification of critical challenges and builds solid ground for further analysis and policy solutions.

Outer space is becoming increasingly congested and in the near future may quickly become overcrowded. The rising number of space actors requires a response for facing challenges posed by the growing density of space traffic. Thus, my primary research question states:

- Are the current space traffic management mechanisms sufficient for sustainable and secured space traffic?

I believe the research question will reveal the challenges to space traffic management and its insufficiencies. A hypothesis states that contemporary space traffic management mechanisms do not suitably address the issues stemming from the emergence of New Space. If the hypothesis proves to be supported and match my predictions, I will ask the secondary research question:

- How should the space traffic challenges be addressed and what are the proposals for the improvement of safety and security of the space traffic?

Since space is an independent strategic domain[1], I intend to build upon the theories proposing various space strategies for asserting control over space orbits and outer space. Based on this knowledge, it is possible to describe the basics of orbital mechanics and movements that are relevant for understanding the importance of space traffic management and required enhanced space situational awareness. Even though these theories are often based on the "hard" military security of space assets, the principles can be easily applied to the "soft" security in the New Space environment. Outer space has its own physical principles and geographical boundaries that limit the space traffic and demands a specific attitude of states to ensure the peaceful uses of the space domain. Understanding the principles of orbital movement will then serve as a solid basis for recognition of space security challenges for

[1] Space was declared as warfighting domain by the U.S. (see https://www.bbc.com/news/av/world-us-canada-50875940/trump-space-is-the-world-s-newest-war-fighting-domain) and operational domain by NATO (see https://www.defensenews.com/opinion/commentary/2019/12/16/nato-declares-space-operational-domain-but-more-work-remains/)

space traffic management. While outer space seems like a vast openness without geographical limits, the satellite movements are in reality very limited for various reasons. Specific orbits are exploited for particular reasons, and its congestion will have a significant impact on the safety and security of space traffic management. Moreover, I will put space traffic management in the context of existing astropolitical theories that will help to explain how STM should be approached in the New Space environment for the policy analysis.

Identification of space traffic challenges is an essential part of the thesis. Subsequently, it will be possible to determine how these challenges are addressed in the international space regime and if the international norms are well prepared for the emergence of New Space. My hypothesis claims that the measures of space traffic management need to be reconsidered, and the states will have to re-evaluate the options for the enhanced space situational awareness to ensure the orbital space security of space assets. My primary research question will be answered positively if it can be concluded that the challenges of the New Space environment are suitably incorporated in the norms of space traffic management. If I identify distinctive drawbacks in the rules of space traffic management, I will then propose the solutions on how to mitigate the deficiencies for the future.

Ailor (2015, pp. 232) defined space traffic management (STM) as *"an organized process that assures the long-term use of space and space assets without harmful interference. Space traffic management includes policies, regulations, services, and information that:*

- *Minimize the possibility of short- and long-term collisions, radio frequency, or other interference among orbiting objects, both operating satellites and debris*
- *Assure compliance with rules and regulations imposed by governments and with best practices adopted by launch and satellite operators*
- *Minimize interference with and by non-satellite operations such as ground-based telescopes and directed energy sources*
- *Provide warnings to minimize possibilities of loss of operations or other detrimental effects resulting from space weather and other predictable events."*

Ailor's definition is unique due to its concise statement about what STM should encompass and is thus a suitable basis for further analysis of the STM components and norms. In this context, it is also appropriate to mention a definition of space situational awareness (SSA) that will be discussed later as an indispensable aspect of STM and was defined by a White House Directive as *"the knowledge and characterization of space objects and their* *operational environment to support safe, stable, and sustainable space activities."* (The White House, 2018)

The thesis will draw upon academic articles, monographs and scholarly literature dedicated to the problematics of space law and space security. To provide more information about STM development assessments by independent organizations dealing with space security issues will also be considered. The thesis will also regard primary sources represented by space law treaties and official state and international organizations documents. Additionally, various online sources will be used to supplement recent information and developments that were not yet sufficiently explored by academic literature.

The thesis's contribution rests in the description and analysis of space traffic management in the context of the New Space environment, which reveals its insufficiencies and implications for the future development of space relations and security.

The thesis also includes an additional step that was not considered in the thesis proposal. The final version of the thesis is theoretically enhanced by astropolitical approaches to the originally proposed orbital mechanics and space strategies as a theoretical background. I believe that the discussion of astropolitics approaches will theoretically embed the thesis and will institute the basis for the more in-depth analysis.

2. Astropolitics and Theoretical Approaches to Outer Space

Human activities are gradually extending beyond the Earth. Even though Bowen (2018, pp. 151-157) believes that our shared understanding is that outer space is politically different, he claims that human beings remain *homo politicus* and that *"[a]stropolitics is what humans seek to make of it."* (Bowen, 2018, p. 151) States are still driven by their fears, honour, and interests and it remains unclear whether the political economy will change the motivations of states. In the paraphrased words of Carl von Clausewitz, *"space warfare is the continuation of Terran politics by other means."* (Bowen, 2018, p. 151) Outer space contains vast resources that have the potential to determine the political, military, and economic destiny of humankind and in importance can be compared, for instance, to Mackinder's heartland (Dolman, 1999, pp. 83-106). Thus, in this chapter, I will briefly present the existing astropolitical theories and describe their perception of the outer space environment and its exploitation.

Humankind is increasingly dependant on space technology and services such as navigation, weather services, communication, military support for operations, and other applications (Milowicki and Johnson-Freese, 2008, p. 17). Briefly, most of the space systems are stationed in Low Earth orbit (LEO) at an altitude between approximately 150 and 800 km and are used mostly for reconnaissance, remote-sensing, meteorological, electro-optical, infrared, and radar-intelligence satellites, or piloted flights. In Medium Earth orbit (MEO) between 800 and 35 000 km are placed navigation satellites. Geosynchronous orbit (GEO) at an altitude of about 35 000 km provides global coverage over the Earth and is thus suitable for communication or early warning systems. Highly elliptical orbits with perigees as low as 250 km and apogees up to 700 000 km are used for communication and observation of Arctic regions (Dolman, 1999, pp. 87-89; Tellis, 2007, pp. 53-54)

Though outer space may be perceived as boundless and without physical limitation, in reality, space exploitation is confronted with many constraints. In brief, the constraints can be divided into (1) quantitative, representing resource scarcity; (2) quantitative, meaning available technological capability; and (3) natural, which incorporates features typical of the outer space environment such as electro-magnetic fields, solar wind, or radiation (Wang, 2009, pp. 435-436). In addition to that, in view of traditional domain analogies, outer space has its specific lines of communication (LOC), common routes, choke points, or outer space accesses that must be acknowledged before space launches. However, the fact that space movement is three-dimensional and in constant motion with narrow ability to manoeuvre and change of direction without distinctive geographical limits requires an original approach for space exploitation. As a result, space operations are always global in nature, overreaching other domains (Kleinberg, 2007, pp. 5-18).

Moreover, operations in outer space are determined and restricted by its specific characteristics. For the satellite movements, spare propulsion is more critical than relative distance. Large space bodies are surrounded by so-called "gravity wells" that launched satellites have to overcome to operate in outer space. In practical terms, the gravity well of Earth is 22 times deeper than that of the Moon, meaning the propulsion requirements to travel 35 000 km from Earth are 22 times higher than it would be from satellite send from Moon. Thus, a launch to the Moon from Earth is more expensive than it would be to travel from the Moon to Mars. Similarly, the further from the planet the satellite is, the lower is the gravitational force (Dolman, 1999, pp. 93-99). For saving propulsion, satellites are moving in orbital paths and are deployed to stable orbits where they require manoeuvres only for corrections in trajectories (Dolman, 1999, pp. 84-89). The geographical features of outer space affect international politics and relations, where the states are competing for limited space resources and activity room and seek to seize their pivotal position to ensure their freedom of access and development of capabilities (Wang, 2009, p. 436). Thus, the geography and outer space conditions determine the behaviour of space actors, meaning environment determinism is clearly visible in outer space and is reflected in societal and economic development (Frenkel, 1994, p. 290).

However, this struggle for access to outer space and natural resources embedded astropolitical theories that can be connected to traditional international relations (I.R.) theories and political geography approaches. Derived from Wang (2009), firstly, (1) before the mid-twentieth century realism was the dominant I.R. theory, consistent with classical geopolitics (geography-power approach), which shared a concern for geographical factors and a state's power. The application to outer space then led to the constitution of *neo-classical astropolitics*. Secondly, (2) during the 1970s and 1980s neoliberal institutionalism theories developed, or the (political-economic) geoeconomics approach, which is linked to the market conquest (by technological superiority) and economic benefits. In outer space this approach was extended into *astroeconomics*. Lastly, (3) after the 1980s radical constructivism became popular, related to critical geopolitics (post-structural approach), which emphasized the constitutive effect of discourse, culture, and history. The consideration of these ideas for the outer space environment resulted in the establishment of *critical astropolitics* (Wang, 2009, p. 439).

Neo-classical astropolitics is based on realist assumptions that the states struggle for power in an anarchic system. Their goal is to ensure their survival and access to resources. The cooperation is limited and takes place only under compelling reasons and do not aim to grant advantage for the partner. Classical geopolitics argues that resources, strategic locations, and projection of power are more important for ensuring states' positions in an anarchical and self-help international system. Thus, this provides the connection between geography and power – the state focuses on the projection of power and influence over strategic territory with access to resources. The advancement in space technology enables this projection of power to get an advantage over opponents to get a pivotal position and exploit space resources. Hence, outer space dominance will secure survival in the Space Age (Wang, 2009, pp. 439-440). The *neo-classical astropolitics* is represented by Dolman's *Astropolitik* theory, which also aimed to serve as a policy recommendation for the U.S. to assert space dominance. Dolman suggested for the U.S. to take over strategic locations and regions in outer space to gain access to space resources and exploitation. In such cases, the U.S. would become the sole ruler not only over outer space but also over the whole Earth and would have the responsibility of moral authority (Havercroft and Duvall, 2009, pp. 42-58).

On the contrary, neoliberal institutionalism emphasizes the role of international institutions and their impact on the international system. Cooperation and economic interactions are joint and desirable. The states pursue absolute-gains rather than relative gains, and these can be achieved via mutual collaboration and shared interests. This enables the actors to maximize their utility without the need to necessarily maximize their power. Moreover, international institutions contribute to the identification of common goals and interests and regulate states' behaviour. Interdependence thus has a positive effect on peace. However, it should be pointed out that even though the states' can profit from cooperation, this mechanism sometimes fails due to the anarchical international system and states do not fulfil their agreements and obligations. In such cases, the international institution provides insurances of reciprocal commitments, higher levels of regularity, improves information transparency, and curtails the transaction costs of cooperation. These institutions are established voluntarily with the aim of solving collective problems and to set the rules in which the states seek for economic supremacy. The approach became significant during the 1970s as a reaction to the economic crisis, such as the collapse of the Bretton Woods system in 1971 or the oil crisis between 1973-1974. The states' realized that the territoriality stressed by realists underestimated the impact of economics and control of the world market. Thus, in geoeconomics, the focus of the state is to ensure access to resources but also to protect their position in the world market. For clarification, there is a slight inconsistency between geoeconomics and neoliberal institutionalism in the sense that geoeconomics is not necessarily liberal (Luttwak, 1990, pp. 17-23). *Astroeconomics* thus perceives outer space as a new market with commercial importance and value. Cooperation and regulation through international institutions in outer space will maximize profits. The states only compete when they find themselves in a mixed-motive situation, and when the cooperation seems to be less convenient than the competition (Wang, 2009, pp. 440-442). Havercroft and Duvall (2009, pp. 42-58) argued that such approach applied to outer space would limit the outer space conflict by collaborative uses of outer space, exploration, and security. However, they also emphasized that such a vision does not consider the space of dominance of only one state.

Last but not least, constructivist approaches provide an alternative to I.R. theories derived from rational-choice metatheory such as realism or liberalism (Wang, 2009, pp. 438-443). I.R. constructivists and critical geopolitics focus on *"the constitutive effects of cultural context (e.g., knowledge, experience, and language) on actors' identity (i.e., role-specific understandings and expectations about self to a larger social group and the world) and virtual practices."* (Wang, 2009, pp. 443) Therefore, critical astropolitics perceives geopolitics as a discursive practice that is caused by the historical process. The constructivists highlight the influence of social knowledge on their understandings of interest and power. Social identities are constructed as a result of power operations constituted by discourse (Wang, 2009, pp. 438-443). According to the critical perspective of Havercroft and Duvall (2009, pp. 42-58), the power exercised from outer space has altered the perception of a state's sovereignty. While the government would remain central, the territoriality would have little importance. All the individuals, institutions and states would be hierarchically structured towards the centre, and the dominant state would have the monopoly on violence that could be projected at any moment to every individual all around the globe.

The astropolitical approaches will be used as a starting point for the analysis of space traffic management and will be contributing to evaluating maturity and appropriateness of STM from different perspectives later in the thesis.

3. Emergence of New Space

The Space Race during the Cold War cost both the United States and the Soviet Union large amounts of money. If we consider the beginning of the competition, the U.S. spending on space explorations in 1957 was estimated to $0,1 billion in comparison to $0,2 to $0,3 billion on the side of the USSR. In 1964, the expenditures increased to $6,2 billion in the U.S. and between $2,0 to $4,0 billion in the USSR (Comparison of U.S. and estimated Soviet expenditures for space programs, 1998). When the competition was escalating in 1969 by the Moon race, the Soviet expenditures were around $6,76 billion, from which $1,56 billion were military spending (Expenditure Implications of Soviet Space Program, 1998, p. 4). The overall costs of the Apollo programme that brought America to the Moon in 1969 then reached $25 billion, equal to roughly $100 billion in today's value (Wall, 2011). However, until the 1990s, space competition remained a matter of prestige rather than warmonger or business ambition since the states were limited in uses of outer space due to technical immaturity. However, after the dissolution of the Soviet Union, the situation has changed, and space actors seek to exploit outer space for profits.

During the past 20 years, we may observe the changes in the space ecosystem that is being referred to as a New Space that is connected to a sharp rise of commercial actors in the space sector (Quintana, 2017; Paikowsky, 2017). The space actors became well aware of the prospects of commercialization of outer space. New private companies aim to embed themselves in the sector to provide a wide scale of services ranging from telecommunications, launch services, Earth observation, SSA, on-orbit servicing, to mining on celestial bodies. The space commercial market snowballed by approximately 79% since 2009. Space economy is currently worth about $350 billion and is expected to exceed $1 trillion by 2040 (Robinson et al., 2019 pp. 21-24; Stanley, 2019). The dynamics of New Space were briefly, but aptly described by Joel Achenbach in the Washington Post in 2013: *"Old Space […] is slow, bureaucratic, government-directed, and completely top-down. Old Space is NASA, cautious and halting, supervising every project down to the last thousand-dollar widget. Old Space is Boeing, Lockheed, and Northrop Grumman. Old Space coasts on the glory of the Apollo era and isn't entirely sure what to do next. NewSpace is the opposite of all that. It's wild. It's commercial, bootstrapping, imaginative, right up to the point of being delusional."* (Achenbach, 2013; Vernile, 2018, p. xxi) Though it is no easy task to conclude all the features that and define the New Space, Vernile (2018) managed to summarize its key characteristics that include:

- *"New entrants in the space sector including large information and communications technology (ICT) firms, start-ups and new business ventures;*
- *Innovative industrial approaches with announcements and initial developments of ambitious projects based on new processes;*
- *Disruptive market solutions offering, for example, integrated services, lower prices, reduced lead times, lower complexity or higher performance among other value proposition features;*
- *Substantial private investment from different sources and involving different funding mechanisms;*
- *New industry verticals and space markets targeting the provision of new space applications;*
- *Innovative public procurement and support schemes involving new R&D*[2] *funding mechanisms and costs/risks sharing arrangements between public and private partners.*
- *Involvement of an increasing number of spacefaring nations investing in the acquisition of turnkey space capabilities or even in the development of a domestic space industrial base."* (Vernile, 2018, p. xxii)

To be more specific, New Space entrants bring new approaches and business models that provide disruptive solutions and challenge the traditional "old space" companies models that have to re-think their historical approach and invent new strategies in more competitive ways. Moreover, comprehensive information and communication technology companies such as Google or Facebook are interested in the synergy of information and space applications technology and might be interested in collaboration with emerging space start-up companies. The new approaches generally aim to reduce costs and make space services more affordable. That may include, for instance, industrial organization optimization, supply chain rationalization and vertical integration, miniaturization, proven technologies re-use, economies of scale, production line automatization and digitalization, or standardized architecture. Market disruption solutions are focused on the needs for existing and potential customers and ensure not only the development of new technology but also new concepts and business models that enable to exploit the shortcoming the space sector. The space sector

[2] Research & development

itself provides many opportunities in providing global connectivity or geoinformation services, space launches of cube-sats and mega-constellations but may lead even towards space tourism or space mining. This also has a spill-over effect on more traditional companies that are challenged by the New Space, but at the same time, they can adapt to a new ecosystem and seize new opportunities (Vernile, 2018, pp. xxv-xxx).

Practically speaking, for instance, in Singapore there were no space opportunities before the establishment of the Office for Space and Technology Industry (OSTIn) in 2013. However, since then, the space industry in Singapore grew rapidly. In 2019, global space tech funding reached the U.S. $5 billion into more than 30 companies. The interesting thing about Singapore remains the fact that the role of OSTIn is purely coordinative, Singapore managed the development of its space industry without any state-owned space agency or large state projects and still enabled the companies to emerge. For example, SpeQtral company aims to develop satellite-based communication using photons to send messages that would be immune to traditional methods of interception, thus, would have potentially commercial but also military implications (Kaushik, 2019). However, similar trends are also valid for major space players. In the United States, the New Space industry is focused in Seattle and Silicon Valley and includes companies such as Deep Space Industries and Planetary Resources that are asteroid mining or additive manufacturer Made in Space. In Europe, the European Space Agency (ESA) Business Incubation Centres supporting over 100 companies across Europe (Vernile, 2018, pp. 25-33). In China, private space companies reached 100 in 2020 in comparison to 30 in 2018, according to China Space News. The leading companies are OneSpace, LandSpace, LinkSpace and iSpace. Notably, the LinkSpace's third reusable test rocket reached 1,000 feet and landed successfully in western China in 2019. Nevertheless, the private companies aim to efficient, low-cost technologies like microsatellites, reusable rockets, and budget transport services since they do not dare to compete with governmental large military project and space missions. Still, the U.S. government-funded IDA Science and Technology Policy Institute estimated that investments in China's commercial space sector were between $600 million to $900 million in the years 2014–18 (Brown, 2000). While the New Space brought up new opportunities to space sector development, it also constituted new challenges, especially regarding the traffic safety, sustainability, protection of space environment or regulation issues (Paikowsky, 2017).

3.1. New Space Challenges

New Space creates a novel dynamic ecosystem that, however, has to face many constraints. Paikowsky (2017) noted that growing commercialization of space activity requires the demand for a secure and sustainable environment and responsible activity by both private and governmental actors. The rapid development of miniaturized space systems, small satellites, and mega-constellations poses a great challenge for the space environment and its sustainability. In connection to that, the amount of space debris is increasing and rising numbers of new systems multiplying the problem. Though the states put some efforts into dealing with existing issues, the international negotiations are often hindered or even stagnating due to the tensions between major players like the United States, Russia, and China but also less powerful countries. Luckily, the safety and sustainability of the space environment are also in the interest of commercial space actors. In my thesis, I will thus elaborate on the most striking issues that also have relevance and direct implications for space traffic management – (1) space legal regime; the crowded orbits, i.e. (2) the rapidly increasing number of space systems, especially with the connection to the development of small satellites and deployment of space mega-constellations; altogether with (3) the proliferation of space debris; and (4) relations of space powers. It should be noted the issues are interconnected in many aspects, but selected diversification enables to provide a general overview of the situation.

3.1.1. Space Legal Regime

The Cold War was a great struggle between the West and East that was underlined by the existence of nuclear weapons. The signs of rivalry between the United States and the Soviet Union were visible practically all over the Earth, and their activities reached even the planetary orbits. Their competition in outer space, often labelled as a "Space Race" gave birth to space exploration and constituted space law. Though the "Space Age" officially started in 1957 by sending Sputnik 1 in outer space, the concerns of space law and debate of uses of outer space as a common heritage of humankind were already raised in 1952 by Oscar Schachter, Deputy Director of the U.N. Legal Department. However, when the Soviet Union launched their first satellite, there were no objections about the violation of sovereign territories over the overflown states that allowed to establish the principle of non-sovereignty and freedom of exploration of outer space and the U.N. as an international body became a guarantee of security of peace. The U.N. General Assembly established institutions for space affairs such as the Committee on the Peaceful Uses of Outer Space (COPUOS) that was also represented by non-spacefaring nations from both developed and developing countries. That moved the debates and preparations for the draft proposals of the Outer Treaty that is considered to have started in 1958 with a resolution acknowledging the common interests in outer space for all humankind and emphasized its peaceful purposes (Jakhu, 2017, pp. 13-18) and formulation of Article I of the Outer Space Treaty claims: *"The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind."* (Johnson-Freese, 2017, p. 20)

Eventually, what we came to refer to as international space law is fundamentally five international treaties and five sets of principles governing outer space which have been developed under the auspices of the United Nations. Apart from that, states may have their own national legislation coordinating their space activities (Unoosa.org, 2020). The international treaties and agreements include:

1. *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Also known as Outer Space Treaty) (General Assembly resolution 2222 – XXI) from October 10, 1967;*
2. *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (General Assembly resolution 2345 – XXII) from December 3, 1968;*
3. *Convention on International Liability for Damage Caused by Space Objects (General Assembly resolution 2777 – XXVI) from September 1, 1972;*
4. *Convention on Registration of Objects Launched into Outer Space (General Assembly resolution 3235 – XXIX) from September 15, 1976;*
5. *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (General Assembly resolution 34/68) from July 11, 1984 (Matignon, 2019).*

The additional principles adopted by the General Assembly include:

1. *Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, adopted on December 13, 1963 (General Assembly resolution 1962 – XVIII);*

2. *Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting, adopted on December 10, 1982 (General Assembly resolution 37/92);*
3. *Principles Relating to Remote Sensing of the Earth from Outer Space, adopted on December 3, 1986 (General Assembly resolution 41/65);*
4. *Principles Relevant to the Use of Nuclear Power Sources in Outer Space, adopted on December 14, 1992 (General Assembly resolution 47/68);*
5. *Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries, adopted on December 13, 1996 (General Assembly resolution 51/122) (Matignon, 2019).*

Although it may seem that the treaties is plentiful, the only extensive and all-embracing source of space law is the Outer Space Treaty. The Outer Space Treaty is the foundation stone and primary source of the international space law that remains relevant until today. Nevertheless, during the Outer Space Treaty negotiations, the number of spacefaring nations was restricted basically to the U.S. and Soviet Union that had limited opportunities for outer space exploitation. However, the current motions in space security are characterized by the more conflictual relations between major space powers and by the rising number of space actors which include the emergence of New Space companies that seek to exploit outer space for profit (Doboš and Pražák, 2019, pp. 219-223). Moreover, as Schrogl (2016, pp. 1-2) pointed out, diplomacy is currently overlapping with international relations and is influenced by the rise of non-state actors and their impact on the international system. Space diplomacy and negotiations are strongly affected by this shift that is typical for what we call New Space. Thus, treaties and space law became arguably outdated. Moreover, states do not wish to be restrained in the prospects of their space exploitation. For example, the last of the ratified treaties, Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (or just the Moon Treaty), was ratified only by a small number of states, excluding some of the major space powers such as the U.S., Russia, or China (Treaties.un.org, 2020), giving it only a little relevance.

The space companies are constrained by jurisdiction, control and liability for space activities by the private sector. Though the private actors were operating since the beginning of the space, the era of rapid innovations since the 2000s requires new control mechanisms and current legal framework, rules and regulations are insufficient. The current space legal regime is based on the Outer Space Treaty from 1967 and the space regime that was established during the Cold War and did not anticipate the recent increase of space companies and their competition. The space enterprise remains a risky business that lacks a formal framework that would, with certainty, comply with international treaties. The meanings and interpretations of current space law are divergent and do not provide accurate legal status. Still, the engagement of the private sector is allowed with the condition that states' are responsible for companies behaviour. For instance, according to the Liability Convention, only the state can be responsible for damage caused to outer space objects. That requires national legislation for private space actors that must be interpreted according to the unclear international space law. As a consequence, the companies may be limited in their activities and discouraged from new innovations. For support of the space development, the private sector should be provided with precise and specific regulations that would enhance the sector investments, exploit the benefits of outer space for the benefits of all humankind and at the same time ensure survivability and sustainability of space environment (Vernile, 2018, pp. 71-79).

3.1.2. Quantity of Space Systems

The principal concern for the viability of the space environment is the rapid increase of launched satellites. Rapid advancements in space technology since the 1990s increased the number of space actors and currently, there are about 8 000 systems from about 100 different nations, from which over 2 000 are operational satellites, with the highest proportion from the United States, followed by China and Russia (UCS Satellite Database, 2020; Sachdeva, 2017, p. 39). However, this number is far from finite. In 1999, Stanford University constructed satellites of 10x10x10 cm cubic units and set a standard for the small cube satellite. Many companies, scientists and governments adopted low weight and simplicity. The small satellites made space launches more affordable and cost-reductive and managed to substitute functions of much larger satellites. The market was thus opened to a much larger scale of space actors, and it is thus expected that the space sector will considerably expand (Quintana, 2017, p. 90). Nowadays, we recognize a broad range of small satellites (small-sats). Though the small-sats are generally considered satellites of lower weight than 500 kg, it is possible to divide several subcategories – (1) mini satellites (100 – 500 kg); (2) micro satellites (10 - 100 kg); (3) nano satellites (1 – 10 kg); (4) pico satellites (0,1 – 1 kg); and (5) fenito satellites (less than 100 g) (Konecny, 2004, p. 1; Straub, 2017, p. 78). In this connection, it is suitable to mention the planned deployment of satellites mega-constellations that are anticipated to be crossing soon and will consist of thousands of new space systems. For instance, Starlink mega-constellation by SpaceX that aims to provide global internet coverage should count about 12 000 satellites by mid-2020s (Skibba, 2020). However, SpaceX is not the sole example, and more actors follow. At the 2017 U.K. Space Conference, Martin Sweeting mentioned that by 2025 the orbits should be occupied by around 160 constellations comprising of 25 000 satellites (Quintana, 2017, p. 90). In comparison, in 2010, less than 1 000 satellites were orbiting Earth (Liemer and Chyba, 2010, p. 151), as of August 2017, there were 1 738 functional satellites in orbit (Grego, 2018), and in March 2020, the number was already 2 666 satellites (UCS Satellite Database, 2020) with expected sharp multiplying. Arguably, decades ago, satellites were perceived as something distinct for ordinary people; however, currently, Space X satellites in Low Earth orbit are visible with a mere eye (Rao, 2019) and attract the attention of the broader public. That makes the most congested regions – Low Earth orbit and strategic geostationary orbit – increasingly busy, possessing gradual collision risks.

3.1.3. Space Debris

Apart from functional systems, the space environment is burdened by dysfunctional systems and orbital debris. Since the start of the Space Age in 1957, there were about 5 600 successful space launches carrying about 9 600 satellites from which around 5 500 systems are still orbiting (counting both functional and obsolete systems) (European Space Agency, 2020b). Moreover, outer space is congested by the increasing number of space debris. The U.S. Space Surveillance Network (SSN) catalogue currently tracks about 23 000 pieces of debris. Nevertheless, SSN is able to track objects larger than 5-10 cm in Low Earth orbit and objects of 30 cm to 1 m at geostationary orbit. However, it is estimated that fragmentation events already generated over 750 000 pieces of orbital debris larger than 1 cm. The sources of space debris vary from in-orbit explosions to solid rocket-motor firings. The satellites in lower altitudes are usually torn down by atmospheric drag; however, objects in the altitudes higher than 800 km remain orbiting for decades if their removal was not considered. In 2009, the first break-up collision of satellites happened. The impact of American communication satellite, Iridium-33, and Russian military Kosmos 2251 satellite resulted in a proliferation of 2 300 trackable fragments. Above that, a single Chinese anti-satellite weapon test in 2007 increased space debris by 25%. Besides, the risk of collisions will be increasing, and by doubling the number of space objects will increase the collision risk by four times. The "Kessler syndrome" explains the regular collisions will have a multiplying effect even without further space pollution (Liemer and Chyba, 2010, pp. 151-152; European Space Agency, 2020a; Kessler and Cour-Palais, 1978).

Moreover, the availability of space launches and space technology attracted a rising number of private companies involved in space activities. In this connection, the number of space debris is gradually multiplying and may endanger space explorations and freedom of access to outer space. The Outer Space Treaty fails in dealing with all these issues and the mitigation guidelines that were adopted in 2007 serve only as non-binding norms (Sachdeva, 2017, pp. 36-40).

3.1.4. Relations of Space Powers

Major space powers are dependent on access to outer space, and space systems are a crucial element for securing their military operations. Hence, they are willing to protect their space assets. The states are developing advanced counterspace capabilities that range from kinetic ASAT and energy weapons to electronic and cyber means of warfare that may endanger space assets and space activities (Weeden and Samson, 2019). As Weeden and Samson pointed out "*[f]rom a security perspective, an increasing number of countries are looking to use space to enhance their military capabilities and national security. The growing use of, and reliance on, space for national security has also led more countries to look at the development of own counterspace capabilities that can be used to deceive, disrupt, deny, degrade, or destroy space systems."* (Weeden and Samson, 2019, p. viii) In the current military space operation, only non-kinetic capabilities are being used; however, the U.S., China, Russia and India have all successfully tested also kinetic direct-ascent anti-satellite weapons (Weeden and Samson, 2019, pp. viii-x).

The United States established Space Force as the sixth branch of the military in 2019 (The White House, 2019) and 2020 Defence Space Strategy openly claims that *"China and Russia each have weaponized space as a means to reduce U.S. and allied military effectiveness and challenge our freedom of operation in space."* (U.S. Department of Defence, 2020, p. 1) Various authors also emphasized Chinese space military efforts, e.g. Shabbir and Sarosh (2018, pp. 6-7), Tellis (2007, pp. 42-72), or Cheng (2012, pp. 55-77). The recent Russian A-235 PL-19 Nudol ASAT test was conducted on April 15, 2020, and was promptly condemned by the United States with a strong reaction. General John 'Jay' Raymond, the commander of U.S. Space Command and the Chief of Space Operations for the U.S. Space Force, stated that *"Russia's DA-ASAT test provides yet another example that the threats to U.S. and allied space systems are real, serious and growing. The United States is ready and committed to deterring aggression and defending the Nation, our allies and U.S. interests from hostile acts in space," and that "[t]his test is further proof of Russia's hypocritical advocacy of outer space arms control proposals designed to restrict the capabilities of the United States while clearly having no intention of halting their counterspace weapons programs."* (Maday, 2020) The Indian intentions in keeping pace with other space powers were suggested by the successful test of kinetic anti-satellite weapon (ASAT) on March 2019 (Foust, 2019). However, even the smaller space nations feel the need for enhanced protection of space systems. France declared deployment of Syracuse satellites bearing submachine guns or lasers by 2030 (Weitering, 2019).

Space diplomacy thus became more complicated with more conflictual nature. For instance, the Anti-Ballistic Missile Treaty (ABM) from 1972 that set restrictions on development and testing of anti-ballistic missile defence components was pronounced as irrelevant for the development of space-based capabilities by Reagan Administration already during Strategic Defense Initiative (SDI) in the 1980s, with complete withdrawal from the treaty by the U.S. in 2002 (Von Kries, 2002, pp. 175-178). Nevertheless, space conflict would most likely have a polluting effect on the space environment. The single Chinese ASAT test in 2007 resulted in an increase in space debris by 25% (European Space Agency, 2020a). The current talks about space weapons arms control got stuck on the Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT) which new draft was presented in the U.N. by Russia in 2014, supported by China but declined by the U.S. the treaty aimed to ban the space weapons; however, it does not provide sufficient characteristics or definitions on space weapons, setting restrictions on various kinds of space systems but allowing the proliferation of ground-based counterspace capabilities (Listner and Rajagopalan, 2014). Moreover, some space actors incline to conduct space hybrid operations that are *"intentional, temporary, mostly reversible, and often harmful space actions/activities specifically designed to exploit the links to other domains and conducted just below the threshold of requiring meaningful military or political retaliatory responses."* (Robinson et al., 2018, p. 3) An example can be the Russian Luch satellite that was monitored spying in geosynchronous orbit with latent destructive potential (Sciutto and Rizzo, 2016). Such operations make unclear the borderline of potential conflict and increase the insecurity of space actors that are seeking appropriate countermeasures to secure their space assets.

Moreover, the debate does not exclude the role of the private sector. For instance, Article 77 of China National Security Law states that citizens or organizations are obliged to *"[provide] public security organs, state security organs or relevant military organs with necessary support and assistance."* (国家安全法, 2015) In other words, all private companies have to be of assistance, if willing or not, to support national security by providing information or technological knowledge. In the U.S., in 2018, Space X company proclaimed they would willing to consider deployment of space weapons to support national security (Tucker, 2018). In 2020, Space X deployed GPS navigation satellites for Space Force, representing cooperation between the military and private company (Thompson, 2020).

4. Space Traffic Management

Space Traffic Management addresses the measures that target to mitigate the negative consequences of increased space congestion (Johnson, 2017, p. 40). Put simply, as was mentioned, collisions of space objects happen and are expected to be increasing, the aim of STM is to enhance the safety in the congested orbits to reduce the risk of unintentional accidents. Apart from mentioned Ailor's definition, which was chosen for its relative complexity suggesting the urgency to promote cooperation and regulation in the interferences issues, there are many definitions of STM from different authors and institutions (Moranta, Hrozensky, and Dvoracek, 2020, pp. 3-5) which makes its detailed meaning somewhat blurred and unclear. For instance, the U.S. Space Policy Directive-3 defines space traffic management as *"the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment,"* (The White House, 2018) or Cosmic Study on Space Traffic Management states STM is *"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."* (Contant-Jorgenson et al., 2006, p. 10) Basically, the definitions promote the safety and sustainability of outer space; however, it should be said, the newer White House definition arguably better reflects the increasingly contested and congested space environment and its challenges with the direct addressing the need for synchronization of activities and sustainable space environment.

Nevertheless, in practice, the experts have disagreements especially in the areas of regulation, enforcement and verification, role of the international framework, and distribution of roles and responsibilities (Moranta, Hrozensky, and Dvoracek, 2020, pp. 6-7). Still, it was agreed that workable STM should encompass three main functions. *(1) Space traffic monitoring* to ensure detection, identification, and traffic; *(2) space traffic regulation*, to provide definitions, rules for regulation, and verification and enforcement; and *(3) space traffic coordination*, to synchronize activities and information sharing about STM (Moranta, Hrozensky, and Dvoracek, 2020, p. 7).

The vital component for STM is space situational awareness that represents the ability to track and recognize space activities. It predicts moves and trajectories of space objects and also includes elements of space weather, characterization of objects or pre-planned manoeuvres. However, there is no established international regime of STM or SSA though some states are discussing further options. In 2010, the U.S. government started a program to inform about close approaches for satellite operators and some countries provide similar services for national entities. Other operators cooperate with third parties, such as the Space Data Association (Johnson, 2017, pp. 40-41). The importance of SSA was highlighted in 2019 by the U.S. military when outer space was proclaimed a warfighting domain due to the increased congestion and rivalry between nations. Followed the mindset shift from traditional SSA that was connected to the *"detecting, tracking, and identifying all artificial objects in Earth orbit"* to more comprehensive space domain awareness (SDA), that was defined as an *"identification, characterization and understanding of any factor, passive or active, associated with the space domain that could affect space operations and thereby impact the security, safety, economy or environment of our nation."* (Erwin, 2020) Accordingly, it can be concluded that the implications of STM are much broader and may also include military activities. There is an ongoing debate on how STM should be directed, whether, for instance, by national practice or regulated by international treaty. The example that could be followed is the air traffic control analogy with the International Civil Aviation Organization (ICAO); however, ICAO was established to unify existing national air traffic standards. Moreover, this would require national regulation even for non-spacefaring nations. Thus, it is also under consideration that major spacefaring nations should set up national STM regime that should be transferred into an international regime (Johnson, 2017, p. 41).

4.1. Space Objects and Disposal of Space Debris

As was mentioned for New Space, the elementary issue for STM is the space congestion and proliferation of space debris and obsolete systems. The Inter-Agency Space Debris Coordination Committee (IADC) that was established in 1997 coordinates the measures to limit the numbers of space debris. IADC designed the critical, most congested region for protection – (1) Low Earth orbit in the altitudes below 2 000 km and (2) geostationary in the altitude 35 786 km. Furthermore, they formulated space debris mitigation guidelines that, if complied with, should mitigate orbital debris. The satellite operators should (a) limit debris released during normal operations; (b) minimize the potential for on-orbit break-ups, including the risk of explosions; thus, the satellites should be eradicated of all sources of stored energy); (c) dispose of space hardware at the end of its mission. That means obsolete satellites and rocket launch stages should be de-orbited into a safe ocean area by controlled re-entry or moved into orbit where they will naturally decay within the prescribed time frame (usually 25 years). The satellites located in geostationary should then navigate into a graveyard orbit above protected regions, and (d) prevent on-orbit collisions with other systems and make provisions to decrease the probability of impact with untracked debris. Though the guidelines are voluntary and are not legally binding, they became a standard that was adopted in government regulation and captured in best practices and international standards. Furthermore, randomly re-entering objects should have low casualty expectations. In addition, controlled re-entry may have a significant impact area and violate the airspace of several countries, possibly even endanger aircraft traffic. Thus, new regulations would be required for the future. Apart from that, the satellites are still endangered by, for instance, confusing sensors and loss of communication during close approaches, radio-frequency interference, or laser energy damage that possess a risk of collisions. In the end, it must be noted that the need for precise STM will be escalating as the emerging space sector expands its services. Beyond already mentioned, STM will likely have to incorporate aspects of space tourism, debris salvages, asteroid mining services or even orbital factories and many other systems that are being considered for the future (Ailor, 2015, pp. 236-251).

As discussed in the previous section, the US SSN maintains the most extensive catalogue of space objects that is a crucial element of safe STM and is used by the Joint Space Operations Center located at Vandenberg Air Force Base in California. However, the unclassified version of the catalogue is also available for the general public. Unfortunately, despite its comprehensiveness, it still has many limitations. The data are collected periodically by radar and optical sensors and omits the position and manoeuvre information that is in control of the satellite operator with the most recent awareness about the satellite. Hence, it is impossible to ensure reliable predictions of close approaches. Furthermore, the publicly available catalogue does not include all the systems and is not the most accurate. Thus, other nations and space actors try to maintain their data about space systems. For keeping safe STM, it would be wise to maintain shared international space objects catalogue. The vital part is the exchange of information on existing data and utilization and standardized formats of sharing from which some have been already developed. Although there are some cooperative strategies between operators, it is necessary to apply best practices in satellites movements to avoid the risk of collision during close approaches and interference (Ailor, 2015, pp. 244-247).

4.2. Control Services

International Telecommunication Union (ITU) is responsible for allocation of global radio spectrum and satellite orbits and assigns new slots in congested geosynchronous orbit. Satellite operators are obliged to specify the satellite purpose, register desired orbits and define the broadcast frequency. Despite the measures, the radio-frequency interference and physical collision are still a threat. Satellite operators generally determine the choice of orbits and purpose of the satellite, and there is a national or international body that would be in charge. Moreover, no one can regulate the number of satellite launches. Thus, the variety of satellites and their launches are a result of technical, economic and political factors rather than a legal question. Fortunately, two traffic control services are currently available. The U.S. Joint Space Operations Center (JSpOC) using SSN data and advanced software to predict close approaches. As was mentioned, SSN data itself is not sufficient to ensure safety. However, JSsOC offers a free service for subscribers who provide information inputs to verify satellite manoeuvres to enhance data provided by SSN. Moreover, JSsOC informs about possible collisions, even non-subscribed operators. Still, operator-supplied data is insufficient and may lead to tracking inaccuracies. Thus, commercial operators Intelsat, Inmarsat, and SES established non-profit Space Data Association that unites operator-supplied data with JScOC information to provide safety in geosynchronous orbit. The association cooperates with 12 satellite operators and monitor 237 geosynchronous satellites, about 100 satellites in other orbits, and even NASA is using its services (Ailor, 2015, pp. 246-249).

Successful STM will require cooperation, collection of data and development of new software and tracking and monitoring capabilities. In addition to that, Ailor (2015) proposed the subsequent cooperation should broaden its spectrum of activities and should incorporate:

- *"Possible radio-frequency interference due to satellites that may be passing within an operator's sphere of influence*
- *Existing or planned physical presence of other satellites in nearby orbital regions that may pose threats to normal operations during the lifetime of the operator's satellite or constellation*
- *Space weather events that may require operator actions to prevent anomalies*
- *Satellites with periodic close approaches, enabling operators to develop cooperative approaches for minimizing interference."* (Ailor, 2015, p. 249)

The unification should allow the development of manoeuvring strategies and avoidance of unintended interference.

When discussing control services, governments must be included. They are operators of many satellites including the systems that are vital for national security whose information is not publicly disclosed; hence, their purposes remain unknown and cannot be stated in available catalogues, and STM service providers cannot process their data. That substantially complicates the safety and security of STM. Governments and organizations such as ITU also impose requirements on satellite providers about where and how the systems may operate to be sure the operators comply with regulations and agreements. For the near future, governments will likely be responsible for the protection of space tourists and their safety thus must be considered during launch, re-entry and time spent in outer space (Ailor, 2015, p. 249).

4.3. Legal and Policy Framework

The only legally binding international law concerning STM is the Outer Space Treaty and subsequent previously mentioned treaties; however, the relationship remains vague since the treaties do not address STM nor SSA. The articles of the treaty are only generally formulated and promote peaceful uses of outer space benefit of all humankind, encouraging cooperation and mutual assistance (Palanca, 2018, p. 3). Nevertheless, Article VI of "Convention on Registration of Objects Launched into Outer Space" provides a more specific claim:

"Where the application of the provisions of this Convention has not enabled a State Party to identify a space object which has caused damage to it or to any of its natural or juridical persons, or which may be of a hazardous or deleterious nature, other States Parties, including in particular States possessing space monitoring and tracking facilities, shall respond to the greatest extent feasible to a request by that State Party, or transmitted through the Secretary-General on its behalf, for assistance under equitable and reasonable conditions in the identification of the object. A State Party making such a request shall, to the greatest extent feasible, submit information as to the time, nature and circumstances of the events giving rise to the request. Arrangements under which such assistance shall be rendered shall be the subject of agreement between the parties concerned." (United Nations treaties and principles on outer space, 2008, p. 24)

The information about caused damage in outer space has a link to STM; however, the generality of the statements does not provide sufficient guidance and cannot construct STM prescription (Palanca, 2018, p. 3). Some other connections to STM can be found, for instance, Article IX of OST claims that *"States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose."* (United Nations treaties and principles on outer space, 2008, p. 6) The statement about avoidance of contamination can be potentially linked to STM; nevertheless, again, its vagueness does not allow to set specific guidance for STM. The international organization that promotes principles of the treaties maintains the international registry of space objects is the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) that makes OST high-level governing doctrine, yet, most space operations are guided on a national level (Palanca, 2018, pp. 3-4). Other sources of space law guiding STM principles are Registration Convention from 1962 that ensures proper registration and further identification of space objects and Liability Convention from 1972 that enacts to pay compensation by launching state due to its system failure (United Nations treaties and principles on outer space, 2008).

Unfortunately, as was suggested, the legal and policy framework of STM is outdated. Currently, many issues require to be addressed and recognized in the New Space environment. Firstly, (1) notification system and data exchange standards. That could involve elements similar to air control traffic to avoid interferences. Thus, there should be international standards and protocols for STM. Secondly, (2) framework for handling and protecting resident space object data. The satellite launches and their placement in orbits should be planned altogether with coordination of the movements and re-entries. Measures should also involve close approaches and frequency interference of the systems. Nowadays, the data are in possession of governments, satellite operators and launch service providers who protect their data. The framework should, therefore, encourage governments and private actors to share their information in, for instance, a sort of 'clearinghouse' which would supervise the data exchange and preserve privacy of actors. In addition to that, the concern of (3) addressing liability. While the risk of collision can be minimalized, it cannot be completely avoided. Thus, service providers are reluctant to order satellite operators to move their systems during conjunctions because they would bear at least partial responsibility from an eventual collision. Hence, the framework should set the rules that would promote cooperation and satisfy all parties; for example, the service provider would be sanctioned but also protected by governments. Finally, (4) internationally accepted space traffic control service provider. Arguably, there is a need for an internationally recognized entity to coordinate space traffic. Government agencies such as JSpOC could step into this role, but this could be problematic for the satellite operators since the state entity would be responsible for all the service and data protection even during unstable political situations. An alternative would be to set up a for-profit company; however, that means STM would become a business with all the market consequences. Therefore, another option would be the establishment of a non-profit company which are usually funded from the private or public sector or both. The board then could consist of representatives of both governments and the private sector. As an example of the Space Data Association showed, some cornerstone towards this system was already laid (Ailor, 2015, pp. 251-254).

5. Astropolitics of Space Traffic Management

As the thesis suggested, the implementation of functional space traffic management in the New Space environment is a difficult task since there are no standardized rules for STM. Politics and space international relations strongly affecting the STM negotiation efforts and determine the will of state actors to resolve this issue. As summarized by the report of global counterspace capabilities by Secure World Foundation, *"[t]he space domain is undergoing a significant set of changes. A growing number of countries and commercial actors are getting involved in space, resulting in more innovation and benefits on Earth, but also more congestion and competition in space."* (Weeden and Samson, 2019, p. viii) Thus, the next chapter will reflect STM problematics from the various astropolitical approaches that will clarify STM status and challenges that are important for the STM policy implications and analysis.

5.1. Neo-classical Astropolitics Perspective

From the realist perspective, satellites provide a wide scope of both civilian and military services that become indispensable for times of war and peace, and their protection is thus of vital national interest. As the U.S. representative, Jim Cooper pointed out, *"[w]e had naively hoped that our satellites were simply out of reach, too high to be attacked, or that other nations would not dare"* and *"[t]he risk of a space Pearl Harbor is growing every day."* (Harrison et al., 2019, p. iv) The U.S. 2018 National Defense Strategy argues that *"[n]ew threats to commercial and military uses of space are emerging, while increasing digital connectivity of all aspects of life, business, government, and military creates significant vulnerabilities. During conflict, attacks against our critical defense, government, and economic infrastructure must be anticipated."* (U.S. Department of Defense, 2018, p. 3) Space Threat Assessment by Center for Strategic & International Studies then explicitly mentions China, Russia, Iran and North Korea as a significant risk for the U.S. space security (Harrison et al., 2019, p. v). It should be noted that the U.S., China and Russia are all major global space players, and their disputes strongly determine the opportunities for solving outer space issues.

The disagreement is visibly illustrated during the negotiations in the bodies of the United Nations. In 2008 was firstly proposed draft "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects" (PPWT) in the Conference of Disarmament by Russia and China. The treaty would restrict the placement of weapons in outer space; however, the treaty has significant flaws and is thus vehemently opposed by the U.S. (Listner and Rajagopalan, 2014). Namely, the statement by European Union in the Disarmament Commission concluded that "*initiative in fact does not address the difficult issue of pertinently defining what a weapon in outer space is, which could easily lead a State to mistakenly assess that another State has placed weapons in outer space. We also remain concerned of the continued development of all anti-satellite weapons and capabilities, including terrestrially based, and underline the importance of addressing such developments promptly and as part of international efforts to prevent an arms race in outer space.*" (U.N. Disarmament Commission, 2018) The statement underlined two essential issues – definition of space weapon and continued development of ground-based counterspace capabilities. Regarding the STM, since a space weapon is not adequately defined, for instance, active debris removal (ADR) systems that will be vital for the preservation of congested space environment could be treated and misunderstood as space weapons. Furthermore, the treaty would not limit Russia and China in the development of space weapons that are not directly placed in outer space (Listner and Rajagopalan, 2014). Practically, the debate results in deadlock in the First and Fourth Committee in the General Assembly where the U.S. and its allies promote transparency and confidence-building measure, whereas Russia and its supporters ask for legal-binding measures[3] (United Nations, 2014; 2015). However, it should be highlighted that debate about space weapons is strongly politicized to fulfil ambitions of space powers. As a result, the major space powers accuse each other of provocative behaviour in outer space that disables further discussions and negotiations.

Furthermore, similar patterns can be observed even in perspectives on STM. The U.S. aims to develop a set of norms, best practices and standards to coordinate STM that would promote globally. Such cooperation could be also beneficial for Europe; however, there could withstand some issues regarding the European role and balanced positions between partners, again facing power struggles for a dominant role since it would be inconvenient to accept, for instance, coordination of STM managed solely by the U.S. or disproportional access to STM for the U.S. and European industry. On the other hand, China stressed that STM should be based on the international legal regime, and Russia similarly supported internationally-agreed mechanisms (Moranta, Hrozensky, and Dvoracek, 2020).

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[3] See also further press releases of the First and Fourth Committee on the space issues - https://www.un.org/press/en/advanced-search

Connected to the theoretical basis, Dolman (2002, pp. 154-155) promotes the establishment of free-market sovereignty in outer space. However, Dolman considers the U.S. will first achieve space dominance and thus will have complete control over Earth and space territory. The U.S. would then coordinate all the commercial, civilian and military space projects. As was discussed, the coordination of STM by one state agency would be possible, nevertheless, improbable under current conditions. Moreover, Dolman's scenario is unlikely to happen because, as outlined above, the U.S. is not in a position to take over all outer space territory. Moreover, realism in space diplomacy between crucial state-space actors complicating the construction of functional space regulations and mechanisms and increasing tensions between states. Thus, realism does not provide sufficient ground for establishment and security of STM.

5.2. Astroeconomics Perspective

Astroeconomics highlights the benefits of mutual cooperation in outer space. Outer space is a commercial area from which all actors can profit. Thus, the conflict is inconvenient, and even in during increased competition, the peaceful solution is the most reasonable. The stability of the system is ensured by the existence of international institutions that coordinate the activities and regulate the behaviour of the actors. However, the institutional setting of STM is scattered, and it does not seem it will be able to react to sharply rising numbers of space systems. Though there are some institutions for space traffic regulation that also produce some cooperative efforts, the STM is still divided between international institutions and national legislation that may significantly differ; furthermore, satellite operators often do not share the same opinions about STM with governments. Hence, the liberal point of view provides many explanations regarding STM, but it is questionable whether they can be implemented and how.

Nevertheless, there is one international institution that was not yet properly discussed. In 1959, The General Assembly of the United Nations established the Committee on the Peaceful Uses of Outer Space (COPUOS) that gave birth to the five treaties and five principles that are regulating the space law and promoting the cooperation, exploration and peaceful uses of outer space. During the years, the COPUOS became the platform where are discussed and reflected developments in outer space, including its rapid advancement and use of new technology (United Nations, 2020a). In 2018, COPUOS managed to negotiate a set of 21 guidelines for the long-term sustainability of outer space activities that are addressing policy and regulatory framework for space activities, the safety of space operations, international cooperation, capacity-building and awareness, and scientific and technical research and development (Committee on the Peaceful Uses of Outer Space, 2018) (see appendix no. 1).

As can be observed from this summary, the COPUOS guidelines managed to address issues that are related to STM and can provide a solid basis for the creation and implementation of STM rules. However, it should be noted that the discussion about the guidelines is relatively new since issues of sustainability of outer space were treated only separately and in isolation before 2010. In addition to that, as Martinez (2018, p. 2) pointed out, in 2010, there were separately at least three initiatives that were related to the security outer space – PPWT at the Conference on Disarmament, the Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities (under the First Committee of the U.N.), and the long-term sustainability of outer space activities (LTS) initiative in COPUOS (under the Fourth Committee of the U.N.). Still, LTS provides what we may perceive as a neoliberal institution that aims to successfully regulate the system and promotes cooperation between states.

After the Chinese test in 2007 increased the urgency of the problem. However, it took 8 years to negotiate 21 guidelines. Moreover, those guidelines are not legally binding, and their violation cannot be legally punished. The positive fact remains that the Committee is gradually extending and currently consists of 95 states and thus is likely to be widely recognized (United Nations, 2020b). However, some guidelines covering important issues, namely the peaceful nature of space activities, protection of terrestrial space infrastructure, active debris removal and intentional destruction of space objects, dealing with non-registered space objects, safe rendezvous and proximity operations, modification of the space environment, and cyber security, are still under consideration. Since geopolitical tensions and ideological division still influence even the discussion in COPUOS, it is difficult to reach consensus. Furthermore, Russia is dissatisfied with the current outcomes because some of its proposals were not approved and may withdraw from further negotiations. In the end, as Weeden and Samson (2018) pointed out, the guidelines resolved important topics but did not directly address STM. As the number of involved states extends, it may also be expected the opinions and interests of countries will be more divergent and an agreement will be hence difficult to reach.

5.3. Critical Astropolitics Perspective

Lastly, critical astropolitics emphasizes the discourse and historical process; and how social knowledge affects the understanding of interest and power. Havercroft and Duvall (2009, pp. 42-58) mentioned the altered perception of the state's sovereignty and territoriality. The dominant state could project its power over the world. Nevertheless, as I have described, there is currently no dominance by a single state, and the interests' of states are mixed. On the other, we can observe the territoriality and sovereignty of outer space differs since everything is in constant motion and satellites are orbiting freely over territories of many states without any violation of international law. However, when it comes to space traffic management, states were unable to negotiate any detailed rules and regulations. Thus, it should be noted whether the states' can fulfil this role. Looking into the discourse and historical development, we see the clash between the Old and New Space and space dynamics are centred around the development of the commercial space sector and increased tensions between states. The disagreements between space powers causing deadlock and slowing the negotiation process and are, thus, unable to react to the sharp emergence of the private sector. As a consequence, critically speaking, if we want to produce efficient STM, we should focus more on the dynamics in the private sector and try to understand its interests, powers it disposes and opportunities it brings, rather than expect changes in governmental talks.

5.4. Implications for Space Traffic Management

The outer space is a domain with own geographical limits, and even though it is by the general public often perceived as infinite, human activities are in reality restricted by its specific conditions and technological limitations. Thus, space actors have to adapt to a new environment and adjust their behaviour. STM must comply with these conditions and respect outer space chokepoints, lines of communication, or congested orbits. Realism claims that the reality of international relations is a power-based zero-sum game with self-interest actors that are trying to ensure their own survival and access to resources (Johnson-Freese, 2017, pp. 20-23). Accordingly, the neo-classical perspective suggests that space actors will struggle for limited or exclusive orbital slots for their satellites in the congested environment. Private actors will contest for profitable locations to provide services or to gain access to natural resources. On the other hand, astroeconomics would argue that cooperation is possible and can be mutually beneficial. Hence, it should be considered collaboration between space actors could be contributing for the establishment of efficient STM international regime from which can benefit commercial actors by the creation of STM norms and rules that will decrease the risk of conflict for gaining access to orbits and space resources. The implications from critical astropolitics schools are that space relations are, to some extent, socially constructed; thus, it is suitable to contemplate over how the STM should be established and by whom. Though the private sector is likely to lead technological development and space exploitation, the role of the state still remains critical and private actors depend on their support. However, the conflicts between major space powers can undermine peaceful uses of outer space and endanger private activities. Hence, the private sector has to be actively involved in building STM to enable further space penetration and make outer space profitable market that will not be hampered by unnecessarily power ambitions by major space powers. Notwithstanding, there is still a risk that the ideas will be shaped in the opposite direction with a threat of conflict (Johnson-Freese, 2017, pp. 20-23). Overall, the description and discussion over STM clearly suggested space actors are not sufficiently prepared for the New Space era and STM regime as exists today have to be reformed to ensure the sustainability of outer space. Thus, the hypothesis that contemporary space traffic management mechanisms do not suitably address the issues stemming from the emergence of New Space is deemed to be correct and primary research question – "Are the current space traffic management mechanisms sufficient for the sustainable and secured space traffic?" – have to be answered negatively. Thus, in the next final chapter, I will answer and elaborate on the secondary research question that is asking "how should the space traffic challenges be addressed and what are the proposals for the improvement of safety and security of the space traffic?"

6. Space Traffic Management Recommendations

The thesis illustrated the emergence of space has serious security implications for the safety of space traffic. Space traffic management is not mature nor embedded enough to be prepared for the upcoming sharp space congestions. In the final chapter, I will thus propose some policy recommendations that should be considered for the establishment of travel safety in New Space environment. Further on, I have decided to divide them into two sub-chapters to look in more detail on two specific issues. As was suggested in the previous chapters, the STM must consider both technical and non-technical (legal) issues. Hence, first, I will address the process of establishment of space traffic regime; who and what work should be done to allow further discussion, thus, discuss the actors and entities responsible for space traffic. Secondly, I will turn to the more technical side and elaborate on the crucial factors of space traffic that needs to be solved by the appropriate authorities for the effective and efficient space traffic management that will increase the safety in congested orbits.

6.1. Legal and Policy Issues of STM

As described above, legal and regulatory topics are solved based on the existing legal framework that is embedded in the Outer Space Treaty from 1967. However, space legal framework was established during the Cold War when the access to outer space was only limited, and the prime role had state actors. Space law and negotiations discussing the new regulations are thus conducted on the principles of "Old Space"; states are the one that leading talks and are responsible for space objects; however, they are burdened by geopolitical disputes and slow processes. As mentioned, "Old Space" is slow government-driven with large long-term projects, whereas New Space is fast-paced, led by private sector and companies; enterprises seek profit, not long discussions without uncertain outcome. Furthermore, though the cooperation takes place, it is only limited and can cope with the small number of space systems; nevertheless, it does not reflect the needs of the New Space environment. With the expected increase of the space systems, the low-level collaboration will not become viable.

The debate about the security of outer space is scattered. The security issues are divided into several bodies of the United Nations from which only COPUOS was able to reach some feasible conclusions. However, it still omits many essential issues, including specifics about space traffic management. Additional international initiatives included mostly International Code of Conduct for Space by the European Union; nevertheless, it was based on voluntarism and was never widely recognized (Weeden and Samson, 2018). Hence, it seems the COPUOS has the highest chances of the establishment of new rules for STM. Moreover, its advantage is the debate in COPUOS in rather technical and is thus less politicized than other United Nations bodies. Notwithstanding, the negotiations take decades to find appropriate solutions; thus, alone, it cannot provide sufficient responses to New Space needs. Moreover, security and traffic management issues in outer space that are directed by national legislative cannot be internationally applied and may collide with expectations and needs of satellite operators and the private sector.

Nevertheless, it is possible to observe some behaviour of both state and private actors that is trying to reflect the need for a sustainable space environment and space traffic management that could serve as an example for further development. On the governmental level, as mentioned, Singapore managed to develop prosperous space industry without any kind of state-owned space agency or large state project, just by funding and coordinative efforts enabled space business to flourish. Thus, it is evident that the private sector is capable of development without the unnecessary control of the government. The implication should then be that the role of the private sector must be considered even for the establishment of new rules and regulations. In 2018, Luxembourg established space agency with a particular focus on the development of space industry to attract new companies. The space industry of Luxembourg counts about 2% of GDP and already in 1985 was in Luxembourg establishment government-supported SES company – the largest satellite operator. Luxembourg Space Agency is moreover partnering with many organizations from all spheres, including University of Luxembourg, Technoport (business incubator), Groupement luxembourgeois de l'aéronautique et de l'espace (industry group for the aerospace sector), or Chamber of Commerce. Thus, the private and state sector is tightly connected that enables further rapid development for the benefits of all interested groups (Groupement luxembourgeois de l'aéronautique et de l'espace, 2020; Foust, 2018).

On the international level, COPUOS seems to be the most reliable platform for the exchange of proposals about the sustainability of outer space and discussion about space security. Again, to make the efforts effective, the private sector should be involved in the processes. The factor that would support this argument is that the companies are well-aware of the need for a sustainable space environment and appear to be willing and responsible enough to take this role. Agnieszka Lukaszczyk, senior director of the Planet, Earth-imaging company, stated that Planet company want to be an example of responsible behaviour in outer space and would like to the model to other space commercial actors, including those developing mega-constellations (Robinson et al., 2019, p. 23). Thus, further private companies engagement can lead to sustainable STM.

In addition to that, there are also considerations regarding SSA. The limitation in tracking and efficiently addressing what is happening in the orbits have far-reaching consequences beyond STM and possess danger to space security since the gaps in legal framework are being exploited by state actors for espionage or testing counterspace capabilities. For instance, between the years 2014 and 2019, Russian Luch satellite was scanning geostationary orbit near the various satellites with close approaches to lower than 36 km (Roberts, 2020).

To conclude, the first recommendation and crucial element of sustainable STM should be further incorporation of the private sector into discussions about STM and space law itself, since companies currently represent the driving of the development of whole space sector and understand and provide new technology that must be considered and implemented into STM. The opinions of space commerce could then constitute the groundwork for international bodies such as COPUOS that should respect and consider the visions are space industry. Involvement of the private sector could also enhance the negotiations by reducing the geopolitical deadlocks as the private sector is not interested in power-relations between states. Private actors could also take the role of international coordinator of space traffic, and the states could support these organizations that would not be affected by geopolitical environments but would be backed by governments to ensure their operability.

6.2. Technical Issues of STM

Apart from legal and policy issues, as the thesis suggested, STM is also hindered by technical deficiencies that require further addressing. The essential problem of the technical side of STM is the congestion of the space environment and the proliferation of space debris. IADC and some other studies and a considerable amount of national guidelines claim that the appropriate decay limit for dysfunctional satellites passing the Low Earth orbit is 25 years (Inter-Agency Space Debris Coordination Committee, 2007, pp. 9-10). However, Low Earth orbit is the most congested area in which will be placed the overwhelming amount of new systems and mega-constellations. Accordingly, new guidelines for de-orbiting of obsolete systems should be considered. When speaking of de-orbiting, the connected challenge is de-orbiting capabilities of satellites. The planned mega-constellations will consist of thousands of small satellites that will also become obsolete over time. As Alexander Reissner, CEO and founder of Austrian space tech company Enpulsion pointed out, small satellites usually do not have any propulsion systems and are limited in terms manoeuvres, flight formation and passive de-orbiting once they no longer serve their purpose. Moreover, they need to be replaced more often than regular satellites (The Community Research and Development Information Service, 2020). Luckily, the propulsion systems for the small satellites with weight lower than 500 kg are being developed. Accordingly, they should be implemented into to rules of STM about satellite de-orbiting capabilities.

Secondly, as was illustrated, in the congested space environment, the mitigation guidelines may not be sufficient to limit the amount of increasing space debris. Therefore, systems of ADR should be included in STM. Space debris and disposal of outdated systems are serious issues not only for the upcoming New Space satellites but also for the current status in the orbits. The number of space debris is increasing even without further congestion. Consequently, functional systems are endangered. Furthermore, debris also putting human lives at stake. International Space Station (ISS) is provided with information about close conjunctions and is prepared for avoidance manoeuvres. The crew is equipped with patch kits and is prepared evacuate when necessary. Though the cabin was not damaged, small hits with banging noise are registered, for instance, on solar arrays, radiators, or some truss (Forbes, 2019). Since 1999, ISS had to conduct already 25 manoeuvres to avoid debris collision (Liou, 2018). However, some of the close conjunctions are detected too late for avoiding, in 2012, the crew was even forced to hide into Soyuz return vehicle (Stubbe, 2018, p. 50). Hence, ADR *"aim to dislocate a dysfunctional system (piece of orbital debris) using another vehicle in the process. Therefore, the advantage of ADR is that it may be used for all kinds of objects disregarding previous consideration about their removal."* (Doboš and Pražák, 2019, p. 220). ADR can utilize a wide range of methods and can relieve the most congested space regions. Some of the methods, namely harpoon and capturing net, were already tested in the outer space environment. Accordingly, ADR can be a support and a tool of STM to enhance the security of space traffic and ensure the sustainability of the space environment.

Although the COPUOS guidelines are solving technical issues of space security, they do not provide sufficient tools nor guidance for space traffic. Thus, lastly, it is worth to emphasize the direction of the space sustainability debate. COPUOS or some substitutive entity must specifically address the regulatory elements of space traffic management. Furthermore, it must also include the questions of space situational awareness and enhanced monitoring of space activities. In hand with that, STM could be standardized for all actors and be under international regulation. Low Earth orbit and geostationary orbit are already congested and require international coordination in their occupation. The rules for assignment of orbital slots thus should not be left out. In the end, ADR must be implemented into space traffic regime, and effective application and utilization of ADR systems should be incorporated into STM and space traffic planning.

Finally, the enhanced systems and mechanism for control of SSA and SDA should be developed and implemented. Though there are efforts to monitor space activities, various entities dispose of a limited amount of information, and the global picture is missing. The recent example is close conjunction in January 2020 between Infrared Astronomical Satellite (IRAS) and the Gravity Gradient Stabilization Experiment (GGSE) 4 satellite. The probability of collision was counted by several sources with similar results. LeoLabs company estimated the chance of collision to 1-100 with final adjustment to 1-1000, considering the satellites will pass each other between 13 and 87 m. Because both systems were no longer operational, the space community could only wait for final outcomes without any options of changing systems' trajectory. Though this time the situation was favourable, it still raised serious concerns because models of similar collisions estimated the debris cloud would count thousands of objects between 5 and 10 cm and hundreds of thousands of debris larger than 1 cm, thus nontrackable but potentially lethal to space systems (Foust, 2020).

7. Conclusion

The thesis elaborated on the sufficiency of space traffic management in the context of the emergence of the New Space environment. New Space introduces new space actors and private companies that wish to exploit outer space for business and profits. However, new ecosystem brings new challenges that endanger space activities and sustainability of outer space and are connected to the unsatisfactory legal regime, congested orbits, increasing number of space debris, and deteriorating relations among major space powers. The thesis described current space traffic elements and mechanisms that were analysed from the perspectives of existing theoretical astropolitical approaches. The current status of space traffic management has significant deficiencies and requires substantial revitalization and reconsideration of norms. The primary research question supported the hypothesis that existing space traffic mechanisms do not suffice the needs of New Space actors and cannot ensure viable access to outer space and secured space traffic. Thus, the secondary research question was asking how to address space traffic challenges and proposed possible solutions for space traffic and future development of space traffic regime. States are still main actors in managing space activities, however, they are unable to push forward new rules to satisfy the needs of space of fast-paced New Space ecosystem. Hence, they should incorporate the commercial sector in negotiations to create new norms and legislative that would meet new space traffic requirements. Moreover, international bodies such as the United Nations Committee on the Peaceful Uses of Outer Space should take a leading position, and national legislation should be coordinated according to international standards. The private sector can also be contributing to the development of new technology that would enhance general space situational and domain awareness and solve technical deficiencies such as debris removal. Finally, international guidelines should be turned into generally respected rules that will secure the sustainability of an outer space environment.

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List of Appendices

Appendix no. 1: Guidelines for the long-term sustainability of outer space activities (summary)

A. Policy and regulatory framework for space activities

Guideline A.1: Adopt, revise and amend, as necessary, national regulatory frameworks for outer space activities;

Guideline A.2: Consider a number of elements when developing, revising or amending, as necessary, national regulatory frameworks for outer space activities;

Guideline A.3: Supervise national space activities;

Guideline A.4: Ensure the equitable, rational and efficient use of the radio frequency spectrum and the various orbital regions used by satellites;

Guideline A.5: Enhance the practice of registering space objects.

B. Safety of space operations

Guideline B.1: Provide updated contact information and share information on space objects and orbital events;

Guideline B.2: Improve accuracy of orbital data on space objects and enhance the practice and utility of sharing orbital information on space objects;

Guideline B.3: Promote the collection, sharing and dissemination of space debris monitoring information;

Guideline B.4: Perform conjunction assessment during all orbital phases of controlled flight;

Guideline B.5: Develop practical approaches for pre-launch conjunction assessment;

Guideline B.6: Share operational space weather data and forecasts;

Guideline B.7: Develop space weather models and tools and collect established practices on the mitigation of space weather effects;

Guideline B.8: Design and operation of space objects regardless of their physical and operational characteristics;

Guideline B.9: Take measures to address risks associated with the uncontrolled re-entry of space objects;

Guideline B.10: Observe measures of precaution when using sources of laser beams passing through outer space.

C. International cooperation, capacity-building and awareness

Guideline C.1: Promote and facilitate international cooperation in support of the long-term sustainability of outer space activities;

Guideline C.2: Share experience related to the long-term sustainability of outer space activities and develop new procedures, as appropriate, for information exchange;

Guideline C.3: Promote and support capacity-building;

Guideline C.4: Raise awareness of space activities;

D. Scientific and technical research and development

Guideline D.1: Promote and support research into and the development of ways to support sustainable exploration and use of outer space;

Guideline D.2: Investigate and consider new measures to manage the space debris population in the long term (Committee on the Peaceful Uses of Outer Space, 2018).

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Diploma thesis project

Security of Space Traffic Management in the New Space Environment

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Study programme: Mezinárodní vztahy

Year of project submission: 2019

Introduction to the topic

Outer space is after land, sea, air (and most recently cyber) the fifth strategic domain (Lonsdale, 1999, pp. 137-159). Recently, outer space development is characterized by two major shifts - the escalated relations of space powers raise concerns of space security and the emergence of the so-called New Space with the increasing numbers of commercial space actors and space assets (Dobos and Prazak, 2019, p. 218). Outer space has become congested, contested, and competitive domain. Contested due to the increased tensions between states and the proliferation of counterspace capabilities. Competitive because of the U.S. decrease in space global market and the rise of China as space power and, finally, congested since the numbers of both functional and dysfunctional space systems is significantly rising (Lynn, 2011, pp. 7-16). Statistically speaking, about half of the operational satellites are located in Low Earth Orbit in the altitude between 200 – 2000 km (Liemer and Chyba, 2010, p. 151). Overall, there are about 5 000 satellites orbiting around the Earth with about 1 950 still functioning. The threat is then constituted by the orbiting space debris. The U.S. Space Surveillance Network currently tracks approximately 22 300 junk objects and overall it was estimated that there is more than 34 000 objects larger than 10 cm and about 900 000 space debris larger than 1 cm. Worth noting, since the beginning of the space age in 1957 more than 500 in-orbit collisions and explosions resulting in fragmentation already took place (European Space Agency, 2019). Considering the commercial actors intend to place thousands of additional space systems in the near future (Grush, 2018), those numbers will grow and the need for advanced space traffic management and greater space situational awareness will be required. Therefore, in my thesis, I intent to describe the challenges of space traffic management in the New Space environment and evaluate the positions and approaches of space actors. Finally, I would like to propose ideas and solutions on how to address the congested space traffic and how to maintain safe and secured space environment.

Research target, research question

The thesis will be written as a case study with an emphasis on space situational awareness and space traffic management. Outer space is becoming increasingly congested and in the near future may easily become overcrowded. This requires a response to face challenges posed by increased space traffic. Thus, my research question states:

- Are the current space traffic management mechanisms sufficient for the sustainable and secured space traffic?

I believe the research question will unveil the challenges to space traffic management and its insufficiencies. Hypothesis states that contemporary space traffic management mechanisms do not sufficiently address the challenges stemming from the emergence of New Space and thus need to be reconsidered. If the hypothesis proves to be supported and match my predictions, I will ask the second research question.

The secondary research question that states:

- How should the space traffic challenges be addressed and what are the proposals for the improvement of safety and security of the space traffic?

Literature review

Several authors I intend to build upon have considered outer space as a contested strategic domain that could be exploited for the military operations and space warfare, however, same theoretical basis provide the information about orbital mechanics that is vital for satellite movement and space traffic management. In 1999, Everett Dolman (1999, pp. 83-106) published his article Geostrategy in the space age: An astropolitical analysis where he described the basic orbital principles for the space geostrategy. His research was then extended in his book Astropolitik: Classical Geopolitics in the Space Age (Dolman, 2002). Several authors followed Dolman and outlined their own space warfare principles. John J. Klein (2006) proposed his thoughts in the book Space Warfare: Strategy, Principles and Policy and Howard Kleinberg set the principles of space warfare in the article On War in Space (Kleinberg, 2007, pp. 1-27). I believe mentioned authors provide relevant insights about orbital mechanics and the theoretical basis for the satellite movements that are important for the understanding of space traffic management. Above mentioned authors often put space in comparison to other strategic domains. On the contrary, Mendenhall argues outer space should be approached individually and analogies to other domains may be misleading in constructing a governance regime in outer space (Mendenhall, 2018, pp. 97-118). Though I believe the analogies to other domains are especially useful when constructing the military principles of space warfare strategy, for the insights to space traffic management unique attributes of outer space domain must be considered. However, it should be noted that a complete rejection of connections to other strategic domains could be a mistake. Even Mendenhall omits many important details regarding other strategic domains and did not consider for instance cyberspace as a strategic domain.

Moreover, other authors describe the various schools of thoughts to outer space that contributes to the comprehension of space actors behaviour. Johnson-Freese (2007) or Moltz (2011) elaborated on the politics of outer space and discussed the different approaches of states to outer space. However, the drawback of mentioned works is that they were not put sufficiently into the perspective of emerging New Space as a new phenomenon. Nevertheless, it is important to point out their thoughts still remain highly relevant and should be taken into consideration. Above that, the new books such as Johnson-Freese's Space Warfare in the 21st Century: Arming the Heavens (Johnson-Freese, 2016) already acknowledged the emergence of New Space and incorporated it into their works. The concept of New Space was outlined namely by Quintana (2017, pp. 88-109) and Paikowsky (2017, pp. 84-88)) and both authors call for the reinforced space situational awareness and space traffic management. The recent development in New Space technology and its implications are then vital to consider. Regarding the space traffic management mechanisms, it is important to realize that there are no legally binding or internationally agreed space traffic norms and the current space traffic management is mostly linked to the Outer Space Treaty from 1967, to guidelines established by International Telecommunication Union and to Inter-Agency Space Debris Coordination Committee space debris guidelines (Larsen, 2018, p. 361). The legal framework is arguably outdated and insufficient when dealing with not only governmental but also non-governmental and private actors (Al-Rodhan, 2018). The U.S. Space Policy Directive-3, National Space Traffic Management Policy acknowledges the increase of space activities and calls for the new approach to space traffic management (The White House, 2018). Therefore, it is relevant to research and propose options for enhanced space traffic management.

Conceptual and theoretical framework, research hypotheses

Since space is an independent strategic domain, I intend to build upon the theories proposing various space strategies for asserting control over space orbits and outer space. Based on this knowledge, it is possible to describe the basics of orbital mechanics and movements that are relevant for understanding the importance of space traffic management and required enhanced space situational awareness. Despite the fact that these theories are often based on the 'hard' military security of space assets, the principles can be easily applied to the 'soft' security in the New Space environment. Outer space has its own physical principles and geographical boundaries that limit the space traffic and demands a specific attitude of states to ensure the peaceful uses of the space domain. Understanding the principles of orbital movement will then serve as a solid basis for recognition of space security challenges for the space traffic management. Albeit outer space seems like a vast openness without geographical limits, the satellite movements are in reality very limited for various reasons. Specific orbits are exploited for particular reasons and its congestion will have a significant impact on the safety and security of space traffic management.

Identification of space traffic challenges is an essential part of the thesis. Subsequently, it will be possible to determine how are these challenges addressed in the international space regime and if the international norms are well prepared for the emerge of New Space.

My hypothesis claims that the measures of space traffic management need to be revitalized and the states will have to reconsider the options for the enhanced space situational awareness to ensure the orbital space security of space assets.

My primary research question will be answered positively if we may conclude that the challenges of New Space environment are suitably incorporated in the norms of space traffic management. If I identify distinctive drawbacks in the rules of space traffic management, I will then propose the solutions on how to mitigate the deficiencies for the future.

Empirical data and analytical technique

The U.S. Space Policy Directive-3 defines space traffic management as *"the planning, coordination, and on-orbit synchronization of activities to enhance the safety, stability, and sustainability of operations in the space environment"* (The White House, 2018). However, many definitions of space traffic management may be given. For instance, Cosmic Study on Space Traffic Management defines space traffic management as *"the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference"* (Contant-Jorgenson et al., 2006, p. 10). Basically, both definitions promote the safety and sustainability of outer space, however, I will prefer the White House definition since it was formulated to better reflect the increasingly contested and congested space environment and its challenges. In this context, it is also appropriate to set a definition of space situational awareness that was defined by White House Directive as *"the knowledge and characterization of space objects and their operational environment to support safe, stable, and sustainable space activities"* (The White House, 2018).

In my thesis, I will first describe the principles of orbital mechanics and explain its importance for space systems. Secondly, I intend to outline the existing rules and norms for space traffic management. Subsequently, I will describe the New Space and its challenges for the future of outer space. Then, I will put the challenges in contrast to the existing space traffic management norms and evaluate its sustainability. Eventually, I will propose new mechanisms that should be applied for safe and secured space traffic.

Planned thesis outline

- Introduction to Space Traffic Management
- Methodology/ Conceptualization
- Principles of Orbital Mechanics and the Importance of Orbital Movement for the Space Systems
- The Norms of Space Traffic Management
- The Emergence of New Space and its Implications for the Space Traffic Management
- Future Challenges to Space Traffic Management
- Interpretation, Solutions for the Sustainable Space Traffic Management
- Conclusions

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