SPACE TRAFFIC MANAGEMENT: AN INESCAPABLE NECESSITY

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INTRODUCTION

The vast expanse of space, once considered infinite, is now witnessing an unprecedented surge in activity, propelling humanity into a new era of exploration and technological advancement. This surge, marked by a growing number of satellites, space missions, and debris orbiting the Earth, has underscored the critical importance of effective Space Traffic Management (STM). As space utilisation has significantly increased over the years, STM has become a crucial aspect involving the coordination and monitoring of objects in the Earth's orbit to ensure safe and sustainable space use.

Tracing the historical trajectory of space activities reveals a transformation from a race to the stars to a complex network of satellites serving various purposes. In the present day, the Earth's orbit is bustling with activity, with satellites reaching an all-time high due to technological accessibility, commercial interests and military deterrence. However, this surge poses multifaceted risks, including collisions, jeopardising operational satellites and contributing to the growing menace of space debris.

At the core of effective STM is Space Situational Awareness (SSA), which involves the continuous monitoring and tracking of space objects

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to predict and prevent collisions. Advanced SSA technologies enhance the understanding of the space environment and enable timely manoeuvres to avoid potential threats. Despite existing international and national regulations providing a foundation for responsible space activities, challenges persist in their implementation and enforcement, highlighting the need for a dynamic regulatory framework as space activities evolve.

Technological solutions play a pivotal role in pursuing effective STM, with advanced tracking technologies and autonomous collision avoidance systems on the horizon. As humanity ventures further into space, responsible space use and safeguarding the orbital environment become prerequisites for a sustainable and prosperous future. The resounding call to action is to unite in navigating celestial highways responsibly, ensuring that the inescapable necessity of STM is met with diligence and foresight. This article explores various nuances of SSA and STM, looking towards the future.

EVOLUTION OF SPACE ACTIVITIES

The journey into space began with the launch of Sputnik 1 in 1957, marking the start of a space race between the United States and the Soviet Union. This era witnessed significant space exploration, including the Apollo 11 Moon landing in 1969 and ongoing ventures into our solar system. Satellites became essential for communication, Earth observation, and scientific research, reflecting technological advancements and international collaboration.

However, the success of space exploration gave rise to concerns about space debris. The collision of the Cosmos 2251 and Iridium 33 satellites in 2009 highlighted the potential dangers. It led to the recognition of the Kessler syndrome, where debris generates more debris, making certain orbital regions hazardous for generations. This realisation prompted efforts to mitigate and manage orbital debris to ensure the sustainable use of space.

The international community established regulatory frameworks in response to the challenges posed by rapid space expansion. The Outer Space Treaty of 1967 set principles for peaceful space use, followed by agreements like the Liability Convention and Registration Convention, reinforcing the legal foundation for responsible space activities. Collaborative initiatives, such as the Inter-Agency Space Debris Coordination Committee (IADC) and guidelines from the United Nations Office for Outer Space Affairs (UNOOSA), reflect the collective commitment to ensuring the orderly and sustainable use of outer space as space activities evolve.

CURRENT SPACE TRAFFIC

In the present era of space exploration, there is an extraordinary increase in space activity and innovation. The count of operational satellites in the Earth's orbit has increased over two-fold in the last decade. As per the RAND Brief, "As of December 2022, space traffic included approximately 6,900 active satellites, more than 36,500 pieces of trackable debris that are 10 cm or larger, and approximately one million objects that range in size from 1 cm to 10 cm."[1] This surge is due to contributions not only from traditional space-faring nations but also from a growing private space sector, including companies like SpaceX, OneWeb, and Amazon. A notable trend is the emergence of satellite constellations, where thousands of small satellites work together to provide services like the global internet and Earth observation. This shift signals a new way of using space, challenging our traditional approaches to managing space traffic.

This steep rise exemplifies a space boom; it signifies an upsurge in endeavours that introduce both opportunities and risks to the outer limits of the cosmos. Once an unobstructed expanse, the Earth's orbit is currently transforming into a congested thoroughfare. Space debris is a rapidly expanding cloud that consists of a growing quantity of spent rocket stages, satellites, and the by-products of orbital disasters. This cosmic debris not only presents immediate risks to operational satellites but also gives rise to the Kessler syndrome, a situation wherein a self-sustaining debris field could

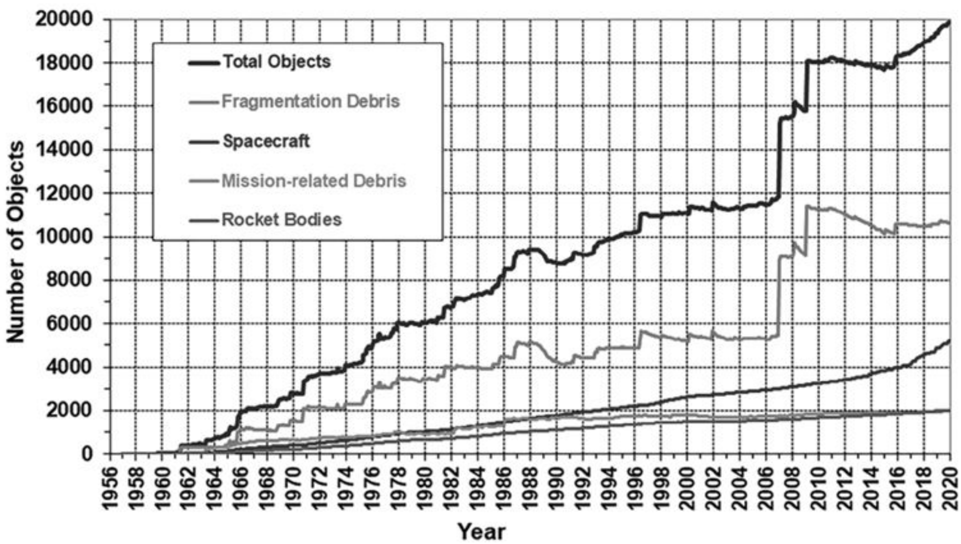
1. Bruce McClintock, et al., "The Time for International Space Traffic Management Is Now," RAND Corporation, https://www.rand.org/pubs/research_briefs/RBA1949-1.html. Accessed on December 8, 2023.

be generated by cascading collisions; this could render portions of the Earth's orbit impassable for generations.

In its 2020 annual report, the National Aeronautics and Space Agency's (NASA's) Aerospace Safety Advisory Panel has cited space debris as "a major safety issue" and identified it as two of the top three safety risks for the International Space Station (ISS). The ISS had to make three emergency manoeuvres last year to avoid catastrophic collisions, including a critical one in September 2022, when the astronauts were requested to move to the Russian segment.

Fig 1 depicts the number of objects being tracked in orbit that has seen a sudden spike after 2016, touching the 20,000 mark, while the total mass of all objects in orbit has also steadily increased and currently exceeds 8,100 metric tonnes. This includes active satellites, those that are dead or lost, the ISS, rocket stages, and even nuts and bolts left behind by astronauts.

Fig 1: Increment in Number of Objects Being Tracked in Orbit



Source: "Aerospace Safety Advisory Panel", Annual Report for 2020, p. 34, https://oiir.hq.nasa.gov/asap/documents/2020_ASAP_Report-TAGGED.pdf

This surge in space activity also brings challenges. The Earth's orbit is getting crowded, increasing the risk of collisions between satellites and space debris. This congestion poses immediate threats to operational satellites. Moreover, the rapid increase in space traffic raises concerns about the long-term sustainability of the Earth's orbital environment. This highlights the urgent need for effective STM systems that can navigate the complex network of satellites, prevent collisions, and sustainably regulate the growing traffic in space.

The current state of space traffic demands our attention, and our ability to navigate it safely will determine the future of space exploration and utilisation. Dealing with these issues is not just a technical requirement; it is essential for ensuring the ongoing viability and sustainability of our activities beyond the Earth's atmosphere.

To tackle these challenges, comprehensive STM frameworks are crucial. The current state of space traffic demands our attention, and our ability to navigate it safely will determine the future of space exploration and utilisation. Dealing with these issues is not just a technical requirement; it is essential for ensuring the ongoing viability and sustainability of our activities beyond the Earth's atmosphere.

IMPORTANCE OF SPACE TRAFFIC MANAGEMENT

Collision Risks: In the vast expanse of space, where the distances between celestial bodies seem infinite, the potential for collisions may appear remote. However, as the activities in the Earth's orbit burgeon, so does the risk of unintended encounters among satellites and space debris. The consequences of such collisions are profound and multifaceted.

Collisions in space can render operational satellites inoperative, disrupting critical services such as communication, Earth observation, and navigation. The 2007 incident involving the Chinese anti-satellite missile test, which generated thousands of fragments and threatened the functionality of other satellites, serves as a stark reminder of the real-world impact of collision risks. Furthermore, the debris from such incidents contributes to the growing menace of space debris, amplifying the challenges of space traffic management.

Debris Mitigation: Effective STM plays a pivotal role in debris mitigation. By providing accurate and timely information about the trajectories and potential collisions of space objects, STM systems enable satellite operators to execute manoeuvres that avoid collisions and reduce the risk of debris generation. This proactive approach is essential for preserving the long-term sustainability of the Earth's orbital environment.

In addition to collision avoidance, STM contributes to debris mitigation by implementing guidelines and practices for responsible satellite operations. There include measures such as designing satellites with propulsion systems for controlled de-orbiting at the end of their missions and minimising the creation of space debris during satellite deployments. As we navigate the celestial crossroads, effective STM emerges as the lynchpin for ensuring the safety, sustainability, and responsible use of space for future generations.

Technological Solutions

In the realm where the cosmos meets technology, the challenges of STM find innovative solutions through the relentless pursuit of cutting-edge technologies. As humanity's ventures into space proliferate, the demand for advanced tracking and collision avoidance technologies has never been more pronounced. Target monitoring is the fundamental technology for space-based Space Situational Awareness (SSA) in decision-making. The ultimate objectives are to provide timely and precise warnings and to prevent collisions. The following are a few of the forefront technological solutions, exploring the ingenuity that is shaping the future of space object tracking and autonomous collision avoidance. It is broadly classified into advanced tracking and autonomous collision avoidance technologies.

Advanced Tracking Technologies

Ground-Based Radar Systems: Ground-based radar systems lie at the foundation of space object tracking. These systems utilise radio waves to detect and track the positions of satellites, space probes, and space debris. Advancements in radar technology, including phased-array antennae and digital signal processing, have enhanced the precision and efficiency of ground-based tracking, enabling more accurate monitoring of objects in the Earth's orbit.

Optical Telescopes: Ground-based optical telescopes play a crucial role in tracking space objects, particularly those in higher orbits. These telescopes capture the reflected sunlight from satellites and provide valuable optical tracking data. Innovations in adaptive optics technology mitigate the distortions caused by the Earth's atmosphere, enabling astronomers to observe and track fainter objects with unprecedented clarity.

Space-Based Sensors: The deployment of sensors in space, either as dedicated satellites or payloads aboard operational satellites, represents a paradigm shift in space object tracking. Space-based sensors offer continuous monitoring without the limitations imposed by the Earth's atmosphere. Initiatives like the Space-Based Space Surveillance (SBSS) system and commercial constellations equipped with tracking payloads contribute to the expansion of space-based tracking capabilities.

Onboard Transponders: Consideration could also be given to investigating onboard transponders. Any space object can mount a minuscule, autonomously powered device capable of transmitting position data of Global Positioning System (GPS) quality. The device can provide the position and identity for active satellites, akin to the idea and use of maritime transponders and aircraft. Even if the host spacecraft malfunctions in "debris mode," it can continue performing this function for decades.

Machine Learning and Data Fusion: The integration of machine learning algorithms and data fusion techniques revolutionises space object tracking. By analysing vast datasets from diverse tracking sources, machine learning algorithms can identify patterns, predict object trajectories, and distinguish between operational satellites and space debris. This adaptive approach enhances the accuracy and efficiency of tracking systems.

Servicing satellites equipped with robotic arms or capture mechanisms can actively manoeuvre and relocate non-operational satellites or debris to safer orbits. This proactive approach contributes to space sustainability by reducing the density of objects in high-traffic orbital regions.

Autonomous Collision Avoidance

Onboard Sensors and Propulsion: Autonomous collision avoidance systems in aircraft like the Tactical Air Navigation Systems (TACAN) rely on onboard sensors, such as cameras and Light Detection and Ranging (LiDAR), to detect potential collisions. Paired with propulsion systems, these technologies enable satellites to autonomously adjust their orbits to avoid close approaches with other space objects. The integration of compact and efficient propulsion systems such as ion thrusters, enhances the manoeuvrability of satellites for collision avoidance.

Artificial Intelligence (AI) Algorithms: AI algorithms play a pivotal role in autonomous collision avoidance. These algorithms process real-time data from onboard sensors and external tracking systems, assessing collision risks and determining optimal manoeuvring strategies. The ability of AI to analyse complex scenarios and make split-second decisions enhances the autonomy of collision avoidance systems.

Collaborative Collision Avoidance: Collaborative collision avoidance systems come into play in scenarios involving satellite constellations or multiple cooperating satellites. These systems facilitate communication and coordination among satellites within a constellation, allowing them to plan and execute collision avoidance manoeuvres collectively. This collaborative approach minimises the risk of interference within satellite groups.

In-Orbit Servicing: The emerging field of in-orbit servicing introduces new dimensions to autonomous collision avoidance. Servicing satellites equipped with robotic arms or capture mechanisms can actively manoeuvre and relocate non-operational satellites or debris to safer orbits. This proactive approach contributes to space sustainability by reducing the density of objects in high-traffic orbital regions.

Emerging Technology in STM

Emerging technologies in Space Traffic Management (STM) represent a critical step toward ensuring the sustainability and safety of activities in the Earth's orbit. By leveraging advanced analytics, automation, coordination platforms, enhanced surveillance, and international collaboration, these technologies contribute to a more efficient and secure space environment. As the space industry continues to evolve, the development and implementation of these technologies will play a vital role in managing the complexities of space traffic.

Space security relies heavily on space-based situational awareness, a comprehensive capability encompassing threat knowledge, analysis, and decision-making. Numerous systems for space situational awareness have been developed and deployed.

The safety of spacecraft in orbit is now gravely endangered due to the proliferation of space debris, which has caused severe congestion in the space environment. Space security relies heavily on space-based situational awareness, a comprehensive capability encompassing threat knowledge, analysis, and decision-making. Numerous systems for space situational awareness have been developed and deployed. Significant contributions are made by key technologies, including data acquisition, target recognition, and monitoring, while numerous advanced algorithms are under consideration as technical support. Nevertheless, exhaustive evaluations of these technologies and particular algorithms are uncommon. It impedes the development of situational awareness in space in the future. India, being among the rapidly developing countries in the field of space, will inevitably be required to establish its own space-based surveillance systems. The following section highlights some critical and essential global technologies being developed and operational. Deep Space Advanced Radar Capability (DARC) and Space Fence are the two most essential technologies that India must develop as soon as possible.

Deep Space Advanced Radar Capability: A significant milestone was reached at the end of 2023 with the successful completion of the DARC. In 2021, the DARC programme underwent its initial successful technology demonstration with the DARC-TD. The endeavour served as an initial assessment by the Enterprise Corps and Special Programmes Ground Radar portfolio of the Space Systems Command. Its purpose was to validate that the system's underlying technology remained operational and could be effectively implemented in a novel application.[2]

Fig 2: Global Deep-Space Defence Tracking Network

Source: newatlas.com https://newatlas.com/military/aukus-partners-global-deep-space-defense-tracking-network/

2. Space Systems Command (Office of Public Affairs), United States Space Force, "DARC Technology Demonstrator Test a Success," December 22, 2021, https://www.ssc.spaceforce.mil/Portals/3/DARC%20Technology%20Demonstration%20test%20a%20success.pdf. Accessed on December 8, 2023.

At the defence technology hub of the United States military, Australia, United Kingdom, United States (AUKUS) defence commanders convened to discuss potential avenues of collaboration concerning the utilisation of advanced technologies in the military. These dialogues took place in accordance with the AUKUS trilateral agreement. The agendas encompassed progressive collaborations in deep space surveillance, artificial intelligence, and quantum computing systems, aiming to fortify their armed forces individually and collectively against escalating worldwide challenges, with particular emphasis on the expanding influence of China's capabilities in the Indo-Pacific.

An extraordinary consequence of the deliberations was the introduction of the DARC initiative. The continuous, all-weather capabilities of DARC are anticipated to enhance the capacity of the AUKUS nations to characterise celestial bodies situated at a depth of 22,000 miles (36,000 km) from the planet. A worldwide network comprising three ground-based radars will be incorporated. It will aid in administrating critical space traffic and contribute to the global surveillance of deep space satellites.[3]

The distinctive geographical locations of the United States, the United Kingdom, and Australia enable DARC to offer worldwide coverage, which encompasses the detection of potential risks to military or civilian space systems. By 2026, the initial Western Australian-built radar will be operational, and by 2030, the remaining radars will be completed. According to British Secretary of State for Defence Grant Shapps, DARC will "provide us with the capability to see beyond the clouds" and will be "more sensitive, more accurate, more powerful, and more agile than anything that has come before it."[4]

3. Ministry of Defence and The Rt Hon Grant Shapps, MP, Government of UK, "New Deep Space Radar will Transform UK Security," December 2, 2023, https://www.gov.uk/government/news/new-deep-space-radar-will-transform-uk-security. Accessed on December 4, 2023.
4. Ruth Comerford, "AUKUS: Radars will Help Counter Threat of 'Space Warfare'," BBC News, December 3, 2023, https://www.bbc.com/news/uk-67603379. Accessed on December 4, 2023.

As of March 2020, the Space Fence had been deemed operational. It is a ground-based radar system primarily utilised in low Earth orbit to track satellites and space debris.

SPACE FENCE

The United States Space Force operates the US$ 1.5 billion Space Fence, a second-generation space surveillance system designed to monitor and track space debris and artificial satellites in the Earth's orbit. In 2014, contracts were awarded to Lockheed Martin for its development and construction. As of March 2020, the Space Fence had been deemed operational. It is a ground-based radar system primarily utilised in low Earth orbit to track satellites and space debris. It operates from the initial Space Fence facility on Kwajalein Island in the Republic of the Marshall Islands, situated 2,100 miles southwest of Hawaii. It has an alternative location for a radar site in far Western Australia.

Fig 3: US Space Force's Space Fence on Kwajalein Atoll in the Marshall Islands

Source: Lockheed Martin.

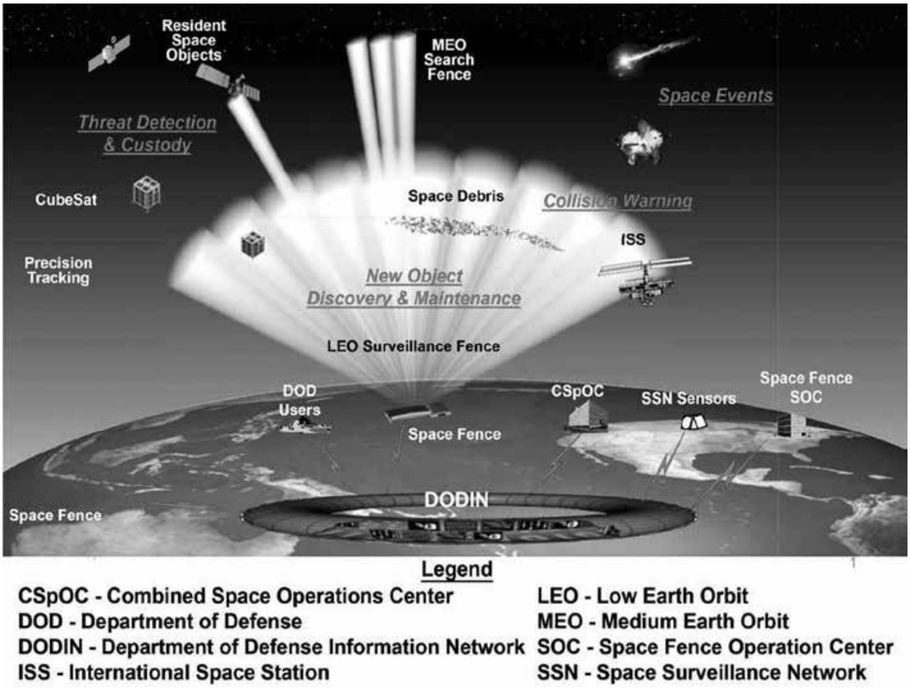
The Space Fence can detect and monitor minuscule objects, even as minuscule as a marble. Additionally, it offers a search function that can locate objects in higher orbits.

The Space Fence is anticipated to exchange data with a minimum of seven nations and 44 corporations. Australia, Japan, Italy, Canada, France, South Korea, and the United Kingdom will receive assistance from the US Air Force (USAF) in establishing space situational awareness. The organisation also partners with the European Space Agency and Eumetsat, the European weather satellite organisation. The Space Fence is an S-band radar that is superior to its previous generations in its ability to track a greater quantity of small objects owing to its shorter wavelength. The original equipment manufacturer states that it is capable of monitoring "approximately 200,000 objects and conducting 1.5 million observations per day, which is approximately ten times the number" reported by the Air Force Space Surveillance System. Furthermore, its functionality extends to the precise detection, tracking, and measurement of space objects in orbit.

The Space Fence can detect and monitor minuscule objects, even as minuscule as a marble. Additionally, it offers a search function that can locate objects in higher orbits. The solid-state S-band radar allows the detection of closely spaced objects, fragmentation occurrences, manoeuvres, launches, conjunction assessments, and expended rocket boosters. The Space Fence will provide data to the military's Space Surveillance Network. Chief of Space Operations General John Raymond underscores the importance of this revolutionary technology, "Space Fence is revolutionising the way we view space by providing timely, precise orbital data on objects that threaten both manned and unmanned military and commercial space assets."[5]

5. Sandra Erwin "Space Fence Surveillance Radar Site Declared Operational", *SpaceNews*, March 28, 2020, https://spacenews.com/space-fence-surveillance-radar-site-declared-operational/ Accessed on December 29, 2023.

Fig 4: Global Deep-Space Defence Tracking Network



Source: Wikipedia. https://en.wikipedia.org/wiki/Space_Fence#/media/File:Space_Fence.png

The earlier system's design inspired the concept of a fence: a narrow beam that generates an alert when an object flies through it. In contrast, this system has the ability to be steered electronically. Actively guided arrays can rapidly generate an orbit determination for subsequent monitoring while aiding in the effortless tracking of the object. The fence has strengthened the surveillance system that includes a satellite, radar, and telescopes. Reportedly, tens of thousands of transmitters and receivers comprise the new S-band phased array radar, supported by structures that can withstand seismic activity. The receiver portion of this edifice accommodates an exceptionally voluminous S-band array, surpassing all others in size by 7,000 sq ft. The square footage of the transmitter is 2,000 sq ft.[6]

6. Roger Mola, "How Things Work: Space Fence", *Air & Space* magazine, February 2016, https://www.smithsonianmag.com/air-space-magazine/how-things-work-space-fence-180957776/ Accessed on December 30, 2023.

The Space Fence is an integral part of a space surveillance network that includes the Space Surveillance Telescope in Australia and a Space-Based Space Surveillance satellite that gathers data on particles and objects in orbit from an altitude of 390 miles. It functions as the initial phase of a data transmission line that supplies information to the Joint Space Operations Centre located at Vandenberg Air Force Base in California. Upon detecting an object in the Earth's orbit, the radar transmits a signal to the computers, which define the object and devise its trajectory. A new object is tracked until its orbit can be estimated. At this point, it is appended to the catalogue; if the item matches an existing one, its record is then updated. The Space Fence is a significant contributor to the US Special Force's (USSF's) Space Domain Awareness (SDA), which supplies the Space Force with the data required to protect critical assets in orbit and make informed decisions and actions. The surveillance network receives data from telescopes, satellites, and fences, facilitating prompt notifications regarding potential collisions between space debris and the International Space Station (ISS) or satellites operating in Low Earth Orbit (LEO).[7]

INDIA'S EFFORTS SO FAR

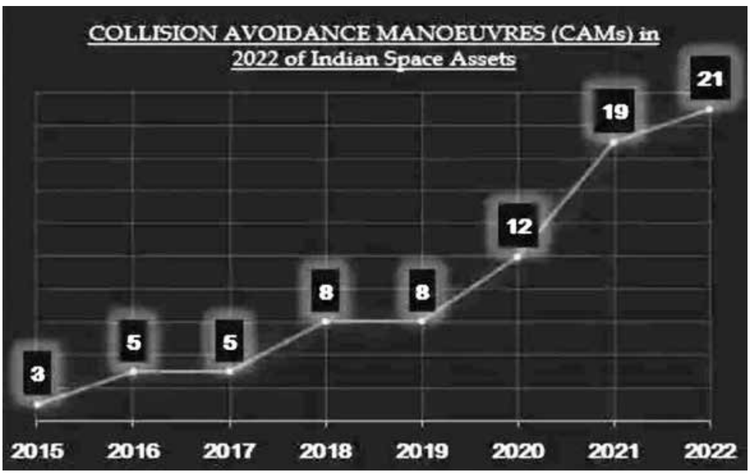
Space Object Proximity Analysis (SOPA): Space assets are of paramount importance for national security, defence, and socio-economic progress of a country. An increasing number of space objects has resulted from diversifying space activities and the rapid pace of technological progress. The Indian Space Research Organisation (ISRO) conducts routine analyses as part of the SSA and STM to forecast the proximity of other celestial bodies to Indian space assets. Internal SOPA generated approximately 14,000 alerts for close approaches within 1 km in 2022. Approximately 13,000 close approach alerts were also received from the United States Space Command. Collision Avoidance Manoeuvres (CAMs) are necessary to protect operational spacecraft during critical approach situations. In 2022, a total of 22 CAMs were implemented. The CAMs

7. Ibid.

implemented over the years are depicted in Fig 4. The plot suggests that space is becoming increasingly congested. Regular Orbit Manoeuvres (OMs) are implemented to ensure that ISRO satellites remain in their designated orbits. The outcomes of SOPA were utilised to prevent the satellites from approaching any nearby space objects while undergoing routine OMs immediately following the manoeuvre.[8]

As shown in Fig 5, the highest number of on-orbit payload deployments occurred in 2022, reflecting the increasing interest of emerging entities, especially the private sector, in space activities. The current trend is anticipated to persist. The penalties associated with CAMs are also expected to increase, including fuel expenditures, operational overheads, payload operation disruptions and frequent synchronisation with external operators. Presently, there is no firm framework for STM that is universally accepted. In the future, it is anticipated that resolving multiple conjunctions between operational satellites will further increase operational complexity.[9]

Fig 5: Collision Avoidance Manoeuvres from 2015 to 2022



Source: ISRO.

8. "Indian Space Situational Assessment for the Year 2022", ISRO, Department of Space, April 3, 2023, https://www.isro.gov.in/Indian_Space_Situational_Assessment_2022.html. Accessed on December 28, 2023.
9. Ibid.

IS4OM and NETRA: The establishment of the ISRO System for Safe and Sustainable Operations Management (IS4OM) in 2022 was a component of ISRO's comprehensive strategy to ensure the safe and sustainable utilisation of outer space for the benefit of the nation. The primary objectives of IS4OM are to protect the organisation's space assets and enhance adherence to globally acknowledged standards regarding the enduring viability of outer space operations. IS4OM is responsible for conducting SSA and STM activities, which include oversight and detection of potential threats, risk assessment and mitigation, collaboration, and object characterisation and cataloguing, as well as processing observations for orbit determination.[10]

In order to achieve comprehensive coverage of the space objects that are dispersed across different orbital regimes, an extensive network of observational facilities that are geographically dispersed is necessary. The ISRO Network for Space Objects Tracking and Analysis (NETRA) project is presently establishing a space surveillance and tracking network utilising radars and optical telescopes.[11] In order to monitor the active and passive satellites in orbit and track the debris, ISRO relied on the data provided by the North American Aerospace Defence Command (NORAD). ISRO's inability to access real-time data as a non-NORAD member led to a reduction in accuracy, precision, and time efficiency in the space debris's location. Therefore, to facilitate the sustainability, security, and autonomy of India's space programme, ISRO has established the Directorate of Space Situational Awareness and Management (DSSAM).[12]

To carry out the activities related to SSAM, the Space Situational Awareness Control Centre (SSACC) has been established in Bengaluru. The objective is to organise and coordinate all space-related research and development. Additional capabilities of the SSA include a Multi-Object Tracking Radar (MOTR) in Sriharikota and a radar in the northeastern region

10. Ibid.
11. Ibid.
12. Deepak Halan, "India's Anti-Satellite Programme: New Opportunities For Industry", Elecronicsforu.com, November 26, 2022, https://www.electronicsforu.com/technology-trends/indias-anti-satellite-programme-new-opportunities-for-industry. Accessed on December 29, 2023.

ISRO's Project NETRA (Network for Space Object Tracking and Analysis) monitors satellites in LEO to safeguard them from potential collisions with space debris or space weather occurrences. NETRA will ultimately be integrated into the worldwide system designed to monitor, alert, and alleviate the impact of space debris.

of India, as well as a long-range Indian Astronomical Observatory comprising a 2.01-metre optical-infrared Himalayan Chandra Telescope (HCT) and a High-Altitude Gamma Ray (HAGAR) telescope situated at Hanle near Leh. Furthermore, optical-infra-red observatories can be found in Bengaluru, Pune, Mount Abu, and Nainital. The nation's largest interferometry observatory is the Giant Metre Wave Radio Telescope Observatory in Pune. It consists of approximately 35 radio telescopes, each with a diameter of 45 metres, for a total base diameter of 25 km.[13]

ISRO also cooperates with nations including Australia, France, the United States, and Japan through exchanging information and data. ISRO's Project NETRA (Network for Space Object Tracking and Analysis) monitors satellites in LEO to safeguard them from potential collisions with space debris or space weather occurrences. NETRA will ultimately be integrated into the worldwide system designed to monitor, alert, and alleviate the impact of space debris. In addition, several new facilities are being constructed, including telescopes, radars, data processing centres, and a control centre, to detect, track, and catalogue objects as small as 10 cm and as distant as 3,400 km.[14]

RECOMMENDATIONS

A few of the recommendations that could help go a long way in space traffic management globally are given below:

13. Pushpinder Bath, "Space Situational Awareness (SSA): An Essential Strategic Requirement", Vivekananda International Foundation, December 17, 2020, https://www.vifindia.org/article/2020/december/17/space-situational-awareness-ssa-an-essential-strategic-requirement Accessed on December 30, 2023.
14. Halan, n. 12.

Establishment of an International Space Traffic Management Organisation (ISTMO): By now, adequate study has been done, and awareness about space traffic mitigation has garnered international consensus in the space fraternity. However, now is the time to walk the talk. As per one of the study reports by the RAND Corporation, similar concerns have been raised. Such urgency may be underlined by the statement, "The goal should be an international STM convention within the next five years that sets specific milestones for implementation within the next ten years."[15]

Regional circles of trust, which consist of alliances or nations with similar objectives, have the potential to serve as crucial input nodes in the development of an ISTMO.

Action on UN Resolution 75/36: Prominent stakeholders in the space domain may employ the UN Resolution 75/36[16] process to initiate a global dialogue, and transition from sub-level to international discussions, thereby avoiding criticism of inadequate coordination or regional prejudice. Major space-faring nations, crucial regional stakeholders, and representatives from industry, academia and non-governmental organisations could participate in the discussions. Regional circles of trust, which consist of alliances or nations with similar objectives, have the potential to serve as crucial input nodes in the development of an ISTMO. This would ensure the continued involvement of nations that might otherwise be hesitant to participate independently due to resource constraints or concerns about being marginalised by other multinational blocs.

15. McClintock, et al., n. 1.
16. "Report of the Secretary-General on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviours (2021)," United Nations, Office for Disarmament Affairs. "By resolution 75/36, the General Assembly encouraged Member States to study existing and potential threats and security risks to space systems, including those arising from actions, activities or systems in outer space or on Earth, characterize actions and activities that could be considered responsible, irresponsible or threatening and their potential impact on international security, and share their ideas on the further development and implementation of norms, rules and principles of responsible behaviours and on the reduction of the risks of misunderstanding and miscalculations with respect to outer space", https://disarmament.unoda.org/topics/outerspace-sg-report-outer-space-2021/#:~:text=By%20resolution%2075%2F36%2C%20the,could%20be%20considered%20responsible%2C%20irresponsible. Accessed on December 7, 2023.

Creation of Experts' Cadre: All space-faring nations are at the crossroads of the technology and governance framework in the space sector. Somehow, the regulatory frameworks and governance policies are lagging behind the technological pace in the space domain. One of the visible causes is the inadequacy of a cadre of technical space experts. There is a need to create such a cadre at the military, academic, and industry levels in the concerned countries and internationally. In the absence of adequate knowledge, nations, and potential ISTMO members are prone to disregard, or show indifference to, ISTMO decisions, processes, and rules.

Hooking on to the DARC Global Network: The finalisation of the DARC programme in December 2023 comprised the appropriate time for the emerging market of aerospace in India. India can leverage its positive image amongst the AUKUS nations to be part of the upcoming DARC network of radars. It is also technically sound to plug the gap between the UK and Australia to cover most of the globe with the network.

Indigenous Space Fence: ISRO and the Defence Research and Development Organisation (DRDO) have come a long way in radar technology. Developing an indigenous Space Fence could prove to be a remarkable achievement towards maintaining effective SSA and STM. It is time that a dedicated lab for research, development and production of space sensor assets was established. Somehow, Indian technological efforts lag behind contemporary global technological developments. Indian efforts must catch up with the emerging technology at the earliest. Initial collaboration with global manufacturers and, thereafter, relying on indigenous technological accomplishments in this field must be the way ahead.

CONCLUSION

The escalating pace of space activities, characterised by a proliferation of satellites, space missions, and debris, underscores the unequivocal necessity for effective STM. As the Earth's orbit transforms into a bustling thoroughfare, the risks of collisions and the exponential growth of space debris demand immediate attention and coordinated action. The pivotal role of SSA in predicting and preventing collisions, coupled with existing and futuristic firm international regulatory frameworks, forms the foundation for responsible space activities. Technological solutions are propelling STM into a new era of efficiency and precision. From advanced tracking technologies that expand our observational capabilities to autonomous collision avoidance systems that rely on artificial intelligence and collaborative strategies, these innovations are crucial for navigating the complexities of the Earth's orbital environment. As humanity's presence in space continues to grow, the fusion of technological prowess and space governance becomes essential for a future where the celestial pathways are navigated with precision and responsibility. The recent achievement of DARC marks a significant milestone, showcasing the continuous efforts to enhance global space surveillance capabilities. The call to establish an ISTMO, action on UN Resolution 75/36, creation of an experts' cadre, and the opportunity for India to hook onto the DARC Global Network emerge as crucial recommendations for navigating the complexities of space traffic on a global scale.