



A Review Paper on Space Traffic Management

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Abstract- Space has always fascinated humanity, driving curiosity, innovation, and technological advancement. From early satellite launches to modern space missions, human exploration beyond Earth has expanded rapidly. However, this progress has introduced a serious and often overlooked problem—space debris. As more satellites, rockets, and missions are launched, non-functional objects and fragments accumulate in orbit, especially in Low Earth Orbit (LEO), posing significant risks to operational spacecraft and future exploration. Space Traffic Management (STM) has been developed to monitor and regulate space activities, aiming to reduce collisions and manage orbital congestion. Despite these efforts, the increasing rate of technological development and frequent space missions have made existing systems insufficient. However, This growth has also created a serious issue called debris, threatens not only space infrastructure but also the long-term sustainability of space operations. This project focuses on analyzing the causes and impact of space debris in Earth's orbit. It examines current management systems and identifies their limitations. Furthermore, it explores effective methods and strategies to control and reduce space debris, ensuring safer and more efficient use of space for future generations.

Keywords: Space Traffic Management (STM),Low Earth orbit(LEO)Constellations(LEOC),Space Situation Awareness(SSA).

I.INTRODUCTION

Space is the vast, mostly unexplored expanse beyond Earth's atmosphere that has fascinated humanity for centuries. For much of human history, it remained mysterious and unreachable. This changed in 1957 with the Sputnik 1 launch, when the Soviet Union successfully launched the first artificial satellite, Sputnik 1. It was a small metal sphere equipped with radio transmitters, designed to orbit Earth and send signals. This achievement, led by Sergei Korolev.

In the present era, space activities have increased significantly, leading to a rapid rise in the number of objects orbiting Earth.

Currently, space traffic includes approximately 16,900 active satellites, over 36,500 trackable debris objects larger than 10 cm, and nearly one million smaller fragments. This dramatic increase has resulted in growing congestion in Earth's orbital environment. The accumulation of these active satellites and debris is referred to as space traffic, which poses serious challenges to the safety and sustainability of space operations.



space debris has led to a buildup of junk and inactive materials in Earth's orbit, especially in low Earth orbit. This interferes with signals like GPS. The major risk is collision—either between active and inactive satellites or between two inactive ones—creating even more debris. This growing congestion poses future hazards for space missions and rockets.

Space Traffic Management (STM) emerged as a response to increasing space activities, formally defined by the International Academy of Astronautics in 2006. It aims to ensure safe access to space by preventing collisions, especially as debris and satellite congestion threaten critical systems like GPS. STM is globally managed by international organizations, national agencies, and private entities to ensure sustainable space operations.

The purpose of this project is Space Traffic Management (STM). This project is important because STM helps prevent collisions caused by space debris, which is essentially orbital junk. Through this project, we will also explore how AI can be used in STM. Furthermore, this will help ensure that major incidents that occurred in the past will not happen in the future. We are going to prevent collisions and also examine how we can clean up debris in space. This is the purpose.

II. LITERATURE REVIEW

Why STM is important-

STM is an institution that is highly important, not just from a human perspective, but for everyone, because STM works as Space Traffic Management. It mitigates the risk of space debris collisions and actively works to prevent them. As a result, it can prevent large-scale collisions, which is why STM is important.

Development of STM

Space Traffic Management (STM) began with early ideas in the 1930s and gained momentum by the 1980s. Today, it relies heavily on Space Situational Awareness, tracking objects in orbit. The U.S. Space Force and other national agencies, along with commercial providers, now coordinate to prevent collisions. With increasing orbital congestion, STM is still evolving, but there's no global authority—so cooperation remains crucial.

Major Satellite Failures and Orbital Debris Generation

The rapid expansion of space activities in recent decades has significantly increased the number of artificial objects orbiting the Earth.

Satellites are essential for communication, navigation, weather forecasting, and scientific research; however, their growing population has also resulted in the accumulation of space debris. This debris includes defunct satellites, fragments from collisions, and remnants of rocket stages. Past accidents and subsequent mission failures have worsened this problem, making the orbital environment more congested and hazardous.

One of the most notable accidental events is the Iridium 33–Cosmos 2251 collision that occurred in 2009. In this incident, an operational satellite collided with a defunct Russian satellite at a very high velocity. The collision generated more than 2,000 trackable debris fragments, along with thousands of smaller pieces that are difficult to monitor. The growing frequency of satellite incident in low earth orbit has intensified the risk of collisions.



Another major event contributing to space debris was the Fengyun-1C anti-satellite test conducted in 2007. In this case, a weather satellite was intentionally destroyed using a missile. The resulting explosion produced over 3,000 trackable debris fragments, many of which remain in orbit for extended periods.

This incident significantly increased the density of debris and continues to pose a long-term threat to active satellites and space missions.

Uncontrolled re-entry of satellites has also created serious concerns. A well-known example is the Kosmos 954 nuclear satellite crash in 1978. This satellite, powered by a nuclear reactor, re-entered the Earth's atmosphere in an uncontrolled manner and dispersed radioactive material over parts of Canada. The incident raised global concerns about the safety risks associated with nuclear-powered space systems and emphasized the need for controlled deorbiting mechanisms.

Similarly, the Skylab reentry in 1979 demonstrated the risks associated with large space structures. The space station, developed by NASA, lost orbital stability and eventually re-entered the Earth's atmosphere. Debris from the station fell over parts of Australia.

Although no casualties were reported, the event highlighted the potential danger posed by uncontrolled re-entries of large objects.

In addition to collisions and re-entries, non-functional satellites remaining in orbit represent a persistent hazard. The Envisat satellite failure serves as a significant example. After losing communication, the satellite became one of the largest inactive objects in orbit. Its presence increases the risk of a potential collision, which could generate a large amount of additional debris and further worsen the orbital environment.

Another incident illustrating spacecraft malfunction is the Progress M-27M spacecraft failure in 2015. The spacecraft lost control shortly after launch and began spinning uncontrollably in orbit. Although it eventually burned up during re-entry, the incident demonstrated how technical failures can quickly lead to unstable and potentially hazardous situations in space.

The accumulation of debris from such incidents has significantly increased the risks associated with space operations. Objects in orbit travel at extremely high velocities, often exceeding several kilometers per second, which means even small fragments can cause severe damage upon impact. This growing concentration of debris has led to concerns regarding the Kessler Syndrome, a theoretical scenario in which collisions between objects generate more debris, leading to a chain reaction of further collisions.

Kessler syndrome concept

Kessler Syndrome is a situation where the number of objects in Earth's orbit becomes so high that collisions create more debris, which then causes more collisions in a continuous chain reaction.

Which is proposed by Donald j Kessler in 1978.

How It Work-

1. Satellites and debris already exist in orbit
2. Two objects collide
3. Thousands of fragments are created
4. These fragments hit other satellites Chain reaction continues (cascade effect).

Some incidents-

Iridium 33- Cosmos 2251 collision. Created thousands of debris pieces.
That incident proved concept is real, not just theory.

*Worst case= Low Earth orbit becomes unusable.

Manage conflicts using existing legal frameworks.

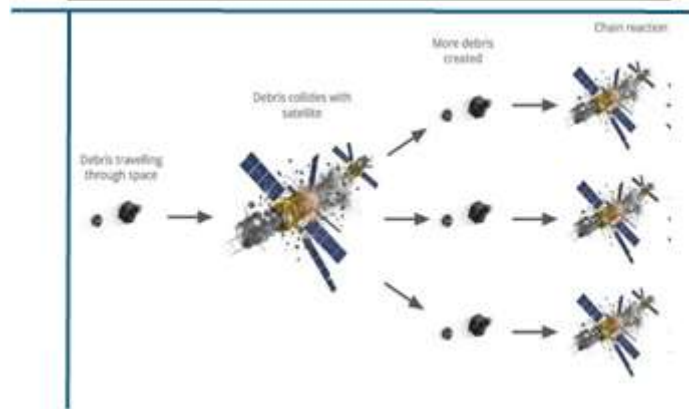


Fig.2.1 Kessler syndrome chain reaction

III. METHODOLOGY

Space traffic management system design for Protect man-made space vehicles. Minimize risk of collision.

Reduce physical & electromagnetic interference.

Minimize space weather impact.

Key points

1. Monitoring & Tracking Services:

A global network of sensors used to track satellites and space debris in real time.

2. Data Management Services:

A shared database containing information about the location of all space objects, radio frequencies in use, and space weather updates.

3. Operation Services:

A consulting service that helps space agencies plan safe launches and orbital maneuvers to avoid collisions and ensure safe mission operations.

4. Warning Services:

An automated system that alerts operators about collision risks, radio interference, or solar storms.

5. Conflict Management Services:

A legal and regulatory service that helps resolve disputes between countries or organizations regarding space activities.

Data collect from internet-

Category	Number
First satellite .	Year 1957(sputnik-1)
Total satellites launched(all time)	~25,000+
Satellites still in orbit.	~16,900+
Active satellites. Inactive satellites	~11,700-13,000. ~3,000-4,000



Total satellites launched(2025)	~15,000
Expected by 2030	40,000-100,000

*policy and legal issues-The study also includes analysis of international legal frameworks (1963–1996) to evaluate their relevance to current space traffic management challenges.

IV. PAST LAWS AND METHODOLOGY

This study adopts a qualitative analytical approach to examine the political and legal framework of Space Traffic Management (STM). Key international legal principles such as the 1963 Declaration of Legal Principles, 1982 Satellite Broadcasting Principles, 1986 Remote Sensing Principles, 1992 Nuclear Power Sources Guidelines, and 1996 International Cooperation Declaration are reviewed.

The methodology includes: Identification of key stakeholders: governments, space operators, and service providers

Analysis of legal frameworks (1963–1996) for satellite regulation, safety, and data sharing

Evaluation of their role in STM objectives such as collision avoidance and sustainability

Examination of limitations like weak enforcement and national conflicts

Comparison of past legal principles (1963–1996) with current space activities

Assessment of the need for updated global regulations

V. DISCUSSION

Increasing debris and satellite-

Many countries and private companies are launching satellite for communication ,internet,weather tracking and other servies.Due to that satellite grow is increasing day by day.So,that's why not only satellites but also debris can increasing.

Major sources of space Debris-

Space debris refers to all non-functional, human-made objects orbiting the Earth, and it has emerged as a critical challenge for modern space operations. A significant portion of this debris consists of defunct satellites, which have lost communication or exhausted their fuel and now drift uncontrollably in orbit, acting as potential collision targets. In addition, rocket body remains—such as discarded boosters and upper stages—represent some of the largest debris objects and pose severe risks due to their size and mass.

Another major category is fragmentation debris, which is generated when satellites or rocket bodies collide or explode. These events produce thousands of high-speed fragments, making this type of debris the most dangerous and difficult to track. Smaller particles, including paint flakes and metallic fragments, also contribute significantly to the debris environment; despite their tiny size, their extremely high orbital velocities allow them to cause damage comparable to high-impact projectiles. Furthermore, explosion debris caused by leftover fuel or battery malfunctions in aging spacecraft continues to add to the problem, highlighting gaps in design and end-of-life management.

Intentional destruction of satellites, such as in anti-satellite (ASAT) tests—including the case of Fengyun-1C—has further worsened the situation by creating long-lasting debris clouds. In addition, operational activities contribute to debris accumulation through tools lost by astronauts during spacewalks and abandoned mission-related objects such as bolts, insulation materials, and protective covers. Although individually small, these objects collectively increase the density of debris in orbit.

The scale of the problem is alarming: it is estimated that over 130 million debris pieces exist in space, the majority of which are too small to track. Traveling at speeds of approximately 28,000 km/h, even debris as small as 1 cm can cause damage equivalent to a bullet impact. This growing concentration of debris significantly increases the likelihood of collisions and raises concerns about cascading effects such as the Kessler Syndrome.

Therefore, effective mitigation strategies and coordinated global efforts are essential to ensure the long-term sustainability of space activities.



Fig.5.1 Increasing space debris.

From picture it shows that debris increasing very fast. This is major problems that occurs. That why STM is important.

Analysis of Orbital Congestion and Debris proliferation-

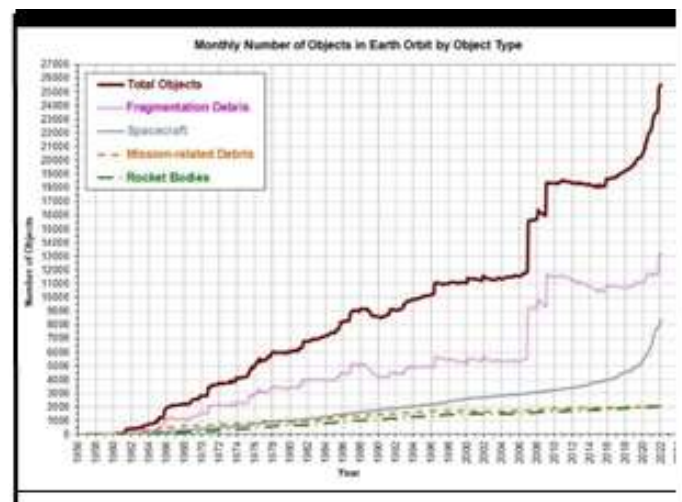


Fig.5.2 Graph Analysis



The observed data highlights a clear and concerning escalation in the number of objects in Earth orbit, particularly after the year 2000, with a dramatic surge post-2015. This growth is not uniform but driven primarily by fragmentation debris, which consistently represents the largest share of orbital objects. The sudden spikes in debris population, especially around 2007–2009, indicate the occurrence of major fragmentation events such as anti-satellite tests and in-orbit collisions.

These events demonstrate that space debris is not only a byproduct of space activity but also a self-generating problem, where collisions create further debris, increasing the likelihood of additional collisions.

Furthermore, the sharp rise in active spacecraft in recent years reflects the rapid expansion of commercial satellite constellations, significantly contributing to orbital congestion. In contrast, rocket bodies and mission-related debris show relatively gradual growth, indicating that they are not the primary drivers of the current debris crisis. The overall trend suggests a transition into a high-density orbital environment, where the probability of collision is significantly increased. This supports the growing concern regarding the onset of a collision cascade scenario, commonly referred to as the Kessler Syndrome. Therefore, the data strongly emphasizes the urgent need for effective space traffic management, stricter debris mitigation policies, and active debris removal strategies to ensure the long-term sustainability of space operations.

The process for stopping collisions we observe-

The current state of Space Traffic Management (STM) is more accurately described as Space Situational Awareness (SSA), which refers to the basic capability of tracking and identifying objects in Earth's orbit. At present, global actors such as governments and private organizations monitor space objects and provide collision warnings to satellite operators when the probability of collision exceeds certain thresholds, typically around 1 in 1,000.

However, collision avoidance is not centrally controlled. It is ultimately the responsibility of individual satellite operators to decide whether and when to perform maneuvers. This decentralized approach creates coordination challenges and increases the risk of miscommunication.

Merely knowing the position of spacecraft and space debris is no longer sufficient. As the number of satellites continues to grow rapidly, especially in low Earth orbit, there is a critical need for a shared global framework that enables active management and coordination of space activities.

Without such coordination, the increasing density of space objects significantly raises the probability of collisions, which can generate large amounts of debris and threaten the long-term sustainability of space operations, as well as critical global services that depend on satellites.

In this process, we have explained the current STM method of how collisions is controlled. However, now I need to say that this process is no longer sufficient because of the increased amount of debris. We need to use an advanced method or technology.

VI. CHALLENGES

Space Traffic Management (STM) faces several critical challenges due to the rapid expansion of space activities. One major issue is limited data sharing, as countries and private companies often restrict access to orbital information for security and competitive reasons, resulting in incomplete tracking and increased collision risks. Additionally, integrating data from diverse sources is difficult because different systems use varying technologies and formats. The lack of global standardization further complicates



communication and coordination between organizations. Policy and regulatory differences between nations also act as barriers, preventing effective international cooperation. At the same time, the growing number of satellites, especially large constellations, is placing significant pressure on existing STM systems. This problem is worsened by the increasing presence of space debris, which raises the likelihood of collisions. Moreover, current tracking systems have limitations in detecting smaller debris, which can still cause serious damage.

Together, these factors contribute to system overload and highlight the urgent need for more advanced and coordinated STM solutions.

VII. SOLUTION

First, at a global level, international regulations must be established by governments to manage space traffic effectively. Prioritizing cleanliness in space operations is essential, ensuring that debris is minimized and deorbiting procedures are enforced. Second, satellites must be designed to prevent corrosion and to enable direct satellite-to-satellite communication, reducing reliance on ground infrastructure. Integrating AI is crucial: AI can automate monitoring and control systems, saving manpower and time, enabling AI to directly detect and address risks. Furthermore, it is essential to actively collect existing particles in orbit using advanced satellites, ensuring that leftover rocket fragments disappear after launch.

Future innovation, like nanotechnology in satellite design, could be a game changer, but this requires significant investment and continued international collaboration.

VIII. FUTURE SCOPE

In the future, new materials such as diamond-based or carbon nanotube composites could be used to create lightweight yet extremely durable satellites. AI-driven signal processing will automate tracking and control, reducing the need for manual labor. Moreover, quantum communication technology could emerge, providing secure data transfer in space. These advancements, along with nanotechnology in satellite design, could revolutionize aerospace and communication, but they will require significant investment and international collaboration.

Another key point is the use of space-based data analytics. By gathering large-scale data and applying AI-driven analysis, we can quickly identify potential risks. This allows satellites and missions to respond faster and more effectively, making operations in space safer, more advanced, and able to adapt in real time.

IX. CONCLUSION

space is immense, and humanity's drive to explore it has been boundless. Consequently, we have launched a vast number of satellites. After the first satellite, many more followed in subsequent years. Some satellites are now inactive, while others remain operational, leading to a large buildup of orbital clutter. To address this, space traffic management organizations were established; however, they still cannot fully prevent the growing congestion. Therefore, we must identify a range of solutions, as outlined in this research paper. Alongside these, we need to implement measures to restrict how many satellites private companies and others can launch. In doing so, we will keep low Earth orbit secure, preventing future incidents like those of the past, ensuring a cleaner, safer space environment.



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