Interagency Operations Advisory Group

Space Operations Sustainability (SOS) Working Group

A Subcommittee Under the Interagency Operations Advisory Group

Issue A

Ref.: IOAG.SOSWG.RPT.2021.v1
Date: March 02, 2021

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1. INTRODUCTION

1.1. PURPOSE

The Interagency Operations Advisory Group (IOAG) established the Space Operations Sustainability Working Group (SOS WG) because its member space agencies were sharing the same concerns on the evolution of the operations in Space:

- There is a rapid increase in the population of operational satellites, in particular on the non-institutional side, with new types of operations (cubesats, constellations, maneuvering satellites, …), and
- There is a growing population of debris in Space and the catalogues will contain smaller and smaller debris, and
- There is a need to assess the new risks on the operations conducted in Space (including collisions, spectrum, space weather, proximity operations, …) and to evaluate if the existing processes and coordination are sufficient to deal with these new paradigms.

In a meeting of the governing body of the IOAG, the Interoperability Plenary (IOP-4), held in Oberpfaffenhofen, Germany on 18~20 December 2018, the IOP delegates recommended that the IOAG:

a. evaluates the relevant issues and potential threats related to sustainable space operations and its implications for space traffic management initially in the vicinity of the Earth.
b. deals with the technical and operational perspective.
c. produces a situational report including recommendations on mitigation measures.

The IOAG has therefore formed the Space Operations Sustainability Working Group (SOS WG), with this Charter.

Therefore, the SOS WG is to respond to actions that have been received from the IOAG in the technical and operational domain of Sustainability of Operations in Space in order to produce a report that will include recommendations on possible improvements and on the potential future role of the IOAG.

1.2. MOTIVATION

The objective of the SOS WG is to analyze the situation of how operations are conducted in Space and the trends related to the new users and the new usages of Space, to:

- Verify the understanding of what the new or increasing risks are to be taken into account in various domains of the operations in Space (disposal operations, collision avoidance, maneuver coordination, space weather, re-entries, spectrum, interferences, in orbit servicing, proximity operations, etc...);
- Identify the international organizations that already address at least part of these challenges;
- Analyze what they adequately cover or what could be improved;
- Formulate recommendations/requests for endorsement by the IOAG, that could be addressed to
  - such identified organizations, or
  - standardization organizations, as required, or
  - the IOAG itself who could adopt and promote messages in Space Operations fora;
- Propose what role the IOAG could play in the future with respect to the SOS issues.

The SOS WG may coordinate activities addressing those risks with other international organizations such as the IADC, the SFCG or the ITU, or any other relevant community.

The decision on how to convey the SOS WG recommendations/requests, as will be endorsed by the IOAG, to external international organizations, is left to the IOAG who may decide to use formal interfaces, to rely on the Agencies representatives in such organizations or to use liaison interfaces, as will be found most appropriate.

1.3. STUDY SCOPE AND METHODOLOGY

To meet the objectives assigned by the IOAG, the SOS WG has elected to initiate a study on each of the following domains of concern:

- Space Debris and Collision avoidance
- End of life activities
- Spectrum and interferences
- Space Weather
- Manned flights (TBC)
- NEO's (TBC)
- Proximity operations, in-orbit services (TBC/TBD)

For each domain, new and growing risks to the sustainability of Space Operations were identified; these risks require measures to be taken by corresponding national and international entities. Such entities were identified and specific recommendations were directed to them by the WG. Before issuing the final report, these recommendations were discussed and improved upon with domain-specific experts. The experts were either members of the IOAG Agencies or of other international organizations.

As the domains explored by the SOS WG cover a wide range of expertise, they could not be addressed and completed in the same time frame. It was then agreed that the report would be incremental and some domains would be included later. Any version available on the public website of the IOAG, even if only completed for only a few of the domains, is assumed to be approved by the SOS WG Members and endorsed by the IOAG.

The recommendations contained in this study often increase in usefulness and value as more organizations chose to implement them. Although this report has been developed by multiple civilian space agencies, many of the concepts apply to all space asset organizations, including:

- Civilian Space Agencies
- Government military space organizations
- Commercial satellite organizations
- Independent research and club satellite organizations
- Academia – including University and even High School satellite developers
- Launch operators

Catalogs or registries of orbiting objects, for example, are only as valuable as the collection of information available from the missions (although many objects can be independently identified).

Awareness across the broad satellite community, and not just within government space organizations, is essential for the sustainability of operations in Space and this idea drives the formulation of the study recommendations. Whereas the SOS WG considers it is beneficial to achieve adherence to the outlined recommendations by as many operators as possible it is essential that future policies, plans, and procedures take into account the variety of satellite organization types and ability to comply.

1.4. REPORT STRUCTURE

Each of the following sections provides, for each of the domains, the findings of the working group in the analysis of the risks and the recommendations formulated by the SOS WG and directed to the various actors of the domain. In Annex A to the present report, the same recommendations are presented per actor.

The last sections of the report show:

- an analysis on the standards already in place to help mitigate the risks and issues identified in the various domains of interest. The objective of this analysis was to identify the specific needs for improvements or the missing standards. Annex B to the present report provides the list of the standards that were considered in this analysis;

- a cross-analysis of the findings of the SOS WG and the best practices recommended by the Space Safety Coalition (SSC) who conducted an analysis in 2019 with a scope similar to that of the SOS WG.

2. DOMAIN OF SPACE DEBRIS AND COLLISION AVOIDANCE (COLA)

The WG has collected inputs from its participants on the concerns their Agency may have on the evolution of the Operations in Space, with respect to the proliferation of Space Debris and the need to perform more

frequent collision avoidance maneuvers. As these concerns were shared by the participants, they were consolidated into the following findings and, from the discussion, recommendations were elaborated for each of these findings. There is no logical order in the presentation of findings and recommendations below; they are just listed in the order they were collected.

Finding 1. Proliferation
Introduction of the domain: risks increase due to the increase of the numbers of objects due to the short term vision of some new comers (short term benefit; short lifetime), due to their small investments (e.g.: no propulsion; low reliability) and their lack of experience or of awareness.

General statement
The IOAG/SOS WG adheres to the IADC guidelines and to the ISO standards, and invites all satellite operators to comply with them.
However, the IOAG/SOS WG recognizes improvements are needed to streamline the utilization of Space and the practices of the new operators in Space

Finding 2. Harmonization of risk assessment methods and manoeuver decisions
As much smaller debris will be detected, together with the increase on non-maneuverable satellites, there is a good chance that the number of collision avoidance maneuvers will increase and may reduce the mission execution for the most expensive satellites.
In this context it becomes more urgent to harmonize and define common approaches
- on the input data used to forecast the level of the risk; Providers with known data quality and employing standard formats are to be sought i.e. CDM from the U.S. Space Force's 18th Space Control Squadron (18 SPCS) (not TLE), EUSST, data base DISCOS
- on the calculation methods (algorithm; probability)
- on the minimum decision thresholds (lethal risks and object size; probability threshold; specifics for manned flights; decision timeline)

Moreover, as the database volumes will become huge, the catalogue size will be more difficult to maintain and there should be more analysis on some specific questions such as:
- should the catalogue be centralized to avoid divergence between catalogues?
- should methods be developed to fuse data from different catalogues?
- which data types/formats need be harmonized / standardized across catalogue output products?

Recommendation to Maintainers of Catalogues
The IOAG/SOS WG recommends that the catalogues
- be easily available for access of products by COLA operators
- use standardized product formats to distribute conjunction information
- provide auxiliary information supporting avoidance maneuver decisions (e.g. expected time of next update, object size estimates)

Recommendation to operators of satellites
The IOAG/SOS WG recommends that operators start sharing the full details as much as possible
- on the calculation methods (algorithm; configuration parameters; probability)
allowing mutual cross-verification,
- on the minimum decision criteria and thresholds (lethal/environmental risks and object size; probability threshold; specifics for manned flights; decision timeline)

Recommendation to national and international regulators
The IOAG/SOS WG recommends that national and international regulators standardize, harmonize and define common approaches, as soon as possible
- on the calculation methods (algorithm; configuration parameters; probability)
allowing mutual cross-verification,
- on the minimum decision criteria and thresholds (lethal/environmental risks and object size; probability threshold; specifics for manned flights; decision timeline)

Finding 3. Best practices / regulations on utilization of Space
Poor reliability and non-maneuverability of satellites increase the risks of collisions in some special orbit regimes of particularly high value; this applies to the orbits of manned missions (e.g.: ISS), of large-constellations (intra and extra constellation), of Earth Observation or to the Geo Arc. Moreover, the cubesats and smallsats are often launched as opportunity co-passengers of bigger satellites with which they will share the same orbit regimes for very long durations. Multiple non-maneuverable smallsats may also share the

same orbit while they cannot perform any manoeuver to avoid collision among them (collision reaction chain).
Authorizations for launch of such satellites should include a number of criteria so as to protect the high value orbits and to mitigate the risks on any orbit regime.
Depending on the satellite and the target orbit, such pre-launch criteria could include:
- reliability requirements satisfied or not
- mandatory propulsion system
- orbit sharing (short / long term) forbidden with identified co-passengers (big ones or non-maneuverable ones)
- use of a qualified Conjunction Analysis (CA) service (can be internal or external to operator and possibly include avoidance maneuver recommendation) and have some sort of validation of the COLA process.
Failing to meet such criteria, the satellites in this case should only be authorized to use certain orbits (e.g. below 400 km if no propulsion) far from the highest value orbits (e.g. ISS or other ones to be identified).
All satellite operators and their launching systems should acknowledge such best practices.

Recommendation to research, academia, IADC
The IOAG/SOS WG recommends that studies be conducted and that best practices be elaborated to identify the “highest value orbits” and the ways to protect them, e.g. by developing methods allowing to assess the risks added by a planned spacecraft to the sustainable use of these orbits and deriving criteria or thresholds on the risk of collision and its consequences.
This may also result in new avoidance decision criteria and thresholds for avoidance maneuvers, e.g. related to potential fragment cloud sizes and lifetimes.

Note: Special focus should be given to the potential increase of human spaceflight activities in LEO and its consequences on collision avoidance needs. Research should investigate whether the typically stricter criteria on collision avoidance maneuver thresholds may require dedicated protection measures, such as protected orbital regimes (sub-regime within LEO) in which unmanned spacecraft may have to satisfy special requirements.

Recommendation to national and international regulators
The IOAG/SOS WG recommends that authorizations for launch address a number of criteria so as to protect the high value orbits and to mitigate the risks on any orbit regime, such as:
- reliability requirements satisfied or not
- compulsory propulsion system
- orbit sharing (short / long term) forbidden with identified co-passengers (big ones or non-maneuverable ones)
- use of a qualified “COLA service” (can be internal or external to operator) and have some sort of validation of the COLA process.
Failing to meet such criteria, the satellites in this case should only be authorized to use certain orbits (e.g. below 400 kms if no propulsion) far from the highest value orbits (e. g. ISS or other ones to be identified) or orbits for which their risk impact is acceptable.

Finding 4. Uncontrolled satellites after bankruptcy of operators
Following bankruptcy or transfer of ownership of a satellite operator company, there is a risk that some satellite systems remain unattended and uncontrolled. Such cases should be addressed, through international agreements, so that there is always an obligation of continuity of control, even if there is no continuity of mission for such satellite systems, to be ensured somehow (e.g.: insurance, initial deposit, state guarantee…). Obligation of active debris removal could also be considered at least for satellites with long orbital lifetime.

Recommendation to national and international regulators
The IOAG/SOS WG recommends that regulations address the issue of continuity of control (not necessarily the mission) including the final disposal, so that it is ensured by insurance, initial deposit, state guarantee or the like, in particular to cope with the cases after bankruptcy of operators or transfer of ownership of a satellite operator company.

Finding 5. Information sharing between operators and catalogue maintainers on planned manoeuvers
The organizations maintaining catalogues of objects and their orbit may have difficulty predicting and confirming close approaches for the maneuvering satellites, as there may be orbit changes after the last known orbit bulletin.

A coordination, between satellite operators with the surveillance systems operators, on orbit control and candidate avoidance maneuver plans should be added to an improved coordination on orbit parameter exchanges, so as to mitigate the risk of receiving conjunction assessments based on invalid data.

Recommendation to operators of satellites
The IOAG/SOS WG recommends that a coordination, between satellite operators and the surveillance systems operators, on orbit control as well as candidate avoidance maneuvers, be added to an improved coordination on orbit parameter exchanges, both in the planning stage as well as after maneuver execution (or cancellation), so as to mitigate the risk of receiving conjunction assessments based on invalid data. This shall be assisted by contact information database(s) and standardized data exchange mechanisms.

Recommendation to Maintainers of Catalogues
The IOAG/SOS WG recommends that the maintainers of catalogues include in their close approach assessment process up to date information received from the operators of satellites using standardized data exchange mechanisms allowing an improved coordination via orbit parameter exchanges, on orbit control as well as candidate avoidance maneuvers (pre-maneuver plans and post-maneuver result)

Recommendation to Space Agencies
The IOAG/SOS WG recommends that space agencies promote the need for an improved exchange of orbit and maneuver information and jointly play an active role in defining and facilitating such exchanges.

Findings 6. Need to educate the new operators
New Space operators and other new comers need be educated to further improve their awareness of the risks as well as, their knowledge on their obligations and of the possible mitigation measures.
New conferences?
Dedicated conferences?

Recommendation to Space Agencies
The IOAG/SOS WG recommends that Space Agencies be active in educating New Space operators and other newcomers on the collision avoidance operations.

Recommendation to national and international regulators
The IOAG/SOS WG recommends that national and international regulators be more active in educating New Space operators and other newcomers on their obligations and of the possible mitigation measures.

Findings 7. Satellite design
Satellite designers should be prepared to embark enough fuel to cope with an increasing number of COLA maneuvers (also see End of Life for fuel budget).

Satellite designers may need to plan for continuity of the mission during the collision avoidance maneuvers.

Recommendation to satellite designers
The IOAG/SOS WG recommends that satellite designers be prepared to embark enough fuel to cope with an increasing number of COLA maneuvers.

Recommendation to satellite designers
The IOAG/SOS WG recommends that wherever practical satellite designers plan for continuity of the mission payload operations during the execution of collision avoidance maneuvers.

Findings 8. Orbit changing satellites
Certain categories of frequently orbit changing satellites need a special coordination with other satellites sharing orbits in their vicinity, both to inform of their short term predictions (models?) and to be updated on the other satellites accurate data.
This applies, among others, to:
- low-thrust propulsion
- electric propulsion
- autonomous orbit control
- proximity operations
- end of life operations

Recommendation to operators of satellites

The IOAG/SOS WG recommends that the operators of satellites changing orbit frequently (e.g.: low-thrust propulsion; electric propulsion; autonomous orbit control; proximity operations …) provide the maintainers of catalogues with propagation models, near term predictions (e.g. ephemeris data) and / or real time information, so as to mitigate the risk of receiving conjunction assessments based on invalid data.

Recommendation to Maintainers of Catalogues
For satellites changing orbit frequently (e.g.: low-thrust propulsion; electric propulsion; autonomous orbit control; proximity operations …) the IOAG/SOS WG recommends that the Maintainers of Catalogues adapt their trajectory and uncertainty predictions to take into account up to date information received from the operators of satellites.

Findings 9. Launches with multiple satellites
For multiple satellite launches, not being able to identify an object by a surveillance system poses a risk of mission loss to the newly launched spacecraft in case the concept of operations relies on the availability of catalogue data e.g. for ground station pointing.
Finding novel satellite identification methods or determining the most appropriate methods is an active research area.

Recommendation to launch service providers
The IOAG/SOS WG recommends that, in the case of launches with multiple satellites, the separation sequence and the trajectory plans are properly designed and communicated in advance to the surveillance service providers to be able to identify and track each object by a surveillance system shortly after separation. This is necessary for an improved collision avoidance process.

Recommendation to satellite designers
The IOAG/SOS WG recommends that, in the case of launches with multiple satellites, satellite designers implement devices, such as beacons and satellite identifiers, to overcome the difficulty of object identification and help mitigate the risk of collision at launch. Such devices should be designed to also ease the tracking of small satellites during routine operations.

Note: This may also be relevant in case the concept of operations relies on the availability of catalogue data e.g. for ground station pointing.

3. DOMAIN OF END OF LIFE ACTIVITIES

The WG has collected inputs from its participants on the concerns their Agency may have on the evolution of the Operations in Space, in particular when missions get close to their end. As these concerns were shared by the participants, they were consolidated into the following findings and, from the discussion, recommendations were elaborated for each of these findings. There is no logical order in the presentation of findings and recommendations below; they are just listed in the order they were collected.

Findings 1: Proliferation
Introduction of the domain: risks increase due to the growing population of satellites with insufficient preparation of their end of life operations. Guidelines and regulations in this respect exist, while they may still be further developed, but the key factor is clearly that they are applied by all users of Space.

General statement
The IOAG/SOS WG adheres to the IADC guidelines and the statement on Large Constellations of Satellites in Low Earth Orbit and to the ISO standard 24113, and invites all satellite operators to comply with them.

Recommendation to the IADC:
The IOAG/SOS WG recommends that the IADC establishes a top-level reporting on the status of the guidelines and reporting on their implementation globally where possible.

Recommendation to satellite operators:
The IOAG/SOS WG recommends that the end of life operations be prepared and resources be planned from the design phase, to be able to adopt and comply with the latest IADC guidelines and ISO standards on matters such as lifetime in Space, graveyard orbits, risks of casualties or reliability of disposal operations.

Finding 2: Application of the existing rule of 25 years on end of life operations of LEO satellites

These guidelines could be improved to identify when reducing further the lifetime should be recommended, also clarifying definitions and calculation methods; they could also take into account the status of the satellite at the time of end of life operations.

Recommendations to IADC:
The IOAG/SOS WG fully supports the existing guidelines. The IOAG/SOS WG recommends that studies are conducted to develop specific guidelines on the conditions when the rule should be different from 25 years for LEO satellites and from the 90% successful disposal objective, for instance:
- to differentiate how the 25 years should be counted (e.g.: ISO:24113:2019 counts from injection if not maneuverable)
- to relate allowed decay time to duration of active mission
- to relate allowed decay time to the consequence on the orbital environment of an unsuccessful disposal of the satellite (long and short term)
- to revisit the required probability of successful disposal accordingly
- to take into account the reliability and tolerance conditions for ageing missions and their hardware capabilities

Recommendations to ISO:
The IOAG/SOS WG recommends that standard ISO 27852 on the orbit lifetime estimation be improved to better specify how to compute the estimated lifetime and the associated uncertainty (e.g. varying drag area for tumbling spacecraft), and to provide criteria to validate the tools for the lifetime estimation.

Finding 3: Selection of disposal orbits
It is not always clear, in particular for new comers or for old satellites in LEO, in which conditions are the disposal operations safer for other satellites, for instance if elliptical orbit (lower perigee) or if circular orbit should be used. The best approach may be hardware or capability dependent (e.g.: sensors at very low altitude). Experience is available from many different Agencies / Operators and lessons learned could now be formulated into guidelines.

Recommendations to Space Agencies:
The IOAG/SOS WG recommends sharing past experiences and developing specific guidelines on the best practices on disposal operations for different spacecraft configurations and capabilities. Workshops or conferences should be used to identify which best practices could be established as new standards.

Finding 4: Satellite status information
There is a need to establish and maintain a data base with the status of the known satellites: dead or active, maneuverable or not, … and some characteristics are included (e.g.: radius). There are attempts to make such information available, but whenever available (e.g.: Space-Track, DISCOS) this information is not kept up to date by the operators.

Recommendation to Space Agencies
The IOAG/SOS WG recommends that space agencies promote the need for a data base to be established and maintained for sharing more effectively the status of satellites, especially, after a failure or their end of life operation.

Recommendations to satellite operators:
The IOAG/SOS WG recommends that each satellite owner input data into a data base of satellite status, to share more effectively if satellites are maneuverable or passivated, especially, after end of life operation. This should be done as soon as there is a known change of the status of the satellite.

Finding 5: Application of the 2019 ISO standard 24113
It has been observed that a great number of missions have experienced failures during extended life phase with no possibility of executing their EOL disposal plans. The third edition of the ISO standard 24113 published in 2019 requires a non-conditional probability of successful disposal greater than 0.9 by design in terms of reliability of the subsystems needed for disposal.
It also requires the assessment of the risk that a space debris impact will prevent a spacecraft from being disposed of.

Recommendations to satellite operators:
The IOAG/SOS WG recommends that the probability of successful disposal is continuously monitored during the operation phase for continued compliance and that corrective actions are applied if degradation is observed.

Recommendations to satellite operators:
The IOAG/SOS WG recommends continuously conducting the assessment of the risk of a space debris impact on the execution of disposal operations during mission lifetime to avoid compromising the success of the disposal.

Recommendations to national and international regulators:
The IOAG/SOS WG recommends that national and international regulators require license for mission extension demonstrating required Post Mission Disposal success.

Finding 6: Launcher bodies, risks of collision and re-entries
it is not clear if the good practices recommended by IADC are well applied by new / emerging launcher organizations.

Recommendations to satellite operators:
The IOAG/SOS WG recommends that the satellite operators encourage the new / emerging launch operators to comply with the IADC requirements applying to launchers from their launch to their re-entry operations.

Recommendations to national and international regulators:
The IOAG/SOS WG recommends that regulators force the new / emerging launch operators to comply with the IADC requirements applying to launchers from their launch to their re-entry operations.

4. DOMAIN OF SPECTRUM AND INTERFERENCES

To be completed in a later issue.

5. DOMAIN OF SPACE WEATHER

To be completed in a later issue.

6. DOMAIN OF MANNED FLIGHTS (TBC)

To be completed in a later issue.

7. DOMAIN OF NEO'S (TBC)

To be completed in a later issue.

8. DOMAIN OF PROXIMITY OPERATIONS, IN-ORBIT SERVICING (TBC)

To be completed in a later issue.

9. SPECIAL FOCUS ON STANDARDIZATION

Annex B to the present report provides the list of the standards that were identified by the WG and considered relevant for the discussion. In the first issue of the report, that list is informative only. At a later stage and for a next issue of the WG report, a thorough analysis will be conducted by the WG with the objective to identify the standards to be improved or the standards to be developed, i.e. those needed to support the recommendations in the previous sections.

ANNEX A: SOS WG RECOMMENDATIONS SORTED OUT BY ACTORS OF THE DOMAINS OF CONCERN

A1.1 – RECOMMENDATIONS IN THE DOMAIN OF SPACE DEBRIS AND COLLISION AVOIDANCE (COLA)

The IOAG/SOS WG adheres to the IADC guidelines and to the ISO standards, and invites all satellite operators to comply with them.
However, the IOAG/SOS WG recognizes improvements are needed to streamline the utilization of Space and the practices of the new operators in Space.

To operators of satellites

- The IOAG/SOS WG recommends that operators start sharing the full details as much as possible
  - on the calculation methods (algorithm; configuration parameters; probability) allowing mutual cross-verification,
  - on the minimum decision criteria and thresholds (lethal/environmental risks and object size; probability threshold; specifics for manned flights; decision timeline)

- The IOAG/SOS WG recommends that a coordination, between satellite operators and the surveillance systems operators, on orbit control as well as (tentative) avoidance maneuvers, be added to an improved coordination on orbit parameter exchanges, both in the planning stage as well as after maneuver execution (or cancellation), so as to mitigate the risk of receiving conjunction assessments based on invalid data. This shall be assisted by contact information database(s) and standardized data exchange mechanisms.

- The IOAG/SOS WG recommends that the operators of satellites changing orbit frequently (e.g.: low-thrust propulsion; electric propulsion; autonomous orbit control; proximity operations …) provide the maintainers of catalogues with propagation models, near term predictions (e.g. ephemeris data) and / or real time information, so as to mitigate the risk of receiving conjunction assessments based on invalid data.

To Maintainers of Catalogues

- The IOAG/SOS WG recommends that the catalogues
  - Be easily available for access of products by COLA operators
  - Use standardized product formats to distribute conjunction information
  - Provide auxiliary information supporting avoidance maneuver decisions (e.g. expected time of next update, object size estimates)

- The IOAG/SOS WG recommends that the maintainers of catalogues include in their close approach assessment process up to date information received from the operators of satellites using standardized data exchange mechanisms allowing an improved coordination via orbit parameter exchanges, on orbit control as well as on candidate avoidance maneuvers (pre-maneuver plans and post-maneuver result).

- For satellites changing orbit frequently (e.g.: low-thrust propulsion; electric propulsion; autonomous orbit control; proximity operations …) the IOAG/SOS WG recommends that the Maintainers of Catalogues adapt their trajectory and uncertainty predictions to take into account up to date information received from the operators of satellites.

To Space Agencies

- The IOAG/SOS WG recommends that Space Agencies be active in educating New Space operators and other newcomers on the collision avoidance operations.

- The IOAG/SOS WG recommends that space agencies promote the need for an improved exchange of orbit and maneuver information and jointly play an active role in defining and facilitating such exchanges.

To satellite designers

- The IOAG/SOS WG recommends that satellite designers be prepared to embark enough fuel to cope with an increasing number of COLA maneuvers.

- The IOAG/SOS WG recommends that wherever practical satellite designers plan for continuity of the mission payload operations during the execution of collision avoidance maneuvers.
- The IOAG/SOS WG recommends that, in the case of launches with multiple satellites, satellite designers implement devices, such as beacon and satellite identifiers, to solve the difficulty to differentiate the objects and so, to mitigate the risk of collision at launch. Such devices should be designed so as to also ease the tracking of small satellites during routine operations.
  Note: This may also be relevant in case the concept of operations relies on the availability of catalogue data e.g. for ground station pointing.

To launch operators:

- The IOAG/SOS WG recommends that, in the case of launches with multiple satellites, the separation sequence and the trajectory plans are properly designed and communicated in advance so as to be able to identify and track each object by a surveillance system shortly after separation. This is necessary for an improved collision avoidance process.

  Note: This may also be relevant in case the concept of operations relies on the availability of catalogue data e.g. for ground station pointing.

To IADC, research, academia

- The IOAG/SOS WG recommends that studies be conducted and that best practices be elaborated to identify the “highest value orbits” and the ways to protect them, e.g. by developing methods allowing to assess the risks added by a planned spacecraft to the sustainable use of these orbits and deriving criteria or thresholds on the risk of collision and its consequences. This may also result in new avoidance decision criteria and thresholds for avoidance maneuvers, e.g. related to potential fragment cloud sizes and lifetimes.

Note: Special focus should be given to the potential increase of human spaceflight activities in LEO and its consequences on collision avoidance needs. Research should investigate whether the typically stricter criteria on collision avoidance maneuver thresholds may require dedicated protection measures, such as protected orbital regimes (sub-regime within LEO) in which unmanned spacecraft may have to satisfy special requirements.

To national and international regulators

- The IOAG/SOS WG recommends that national and international regulators standardize, harmonize and define common approaches, as soon as possible
  - on the calculation methods (algorithm; configuration parameters; probability) allowing mutual cross-verification,
  - on the minimum decision criteria and thresholds (lethal/environmental risks and object size; probability threshold; specifics for manned flights; decision timeline)

- The IOAG/SOS WG recommends that authorizations for launch address a number of criteria so as to protect the high value orbits and to mitigate the risks on any orbit regime, such as:
  - reliability requirements satisfied or not
  - compulsory propulsion system
  - orbit sharing (short / long term) forbidden with identified co-passengers (big ones or non-maneuverable ones)
  - use a qualified “COLA service” (can be internal or external to operator) and have some sort of validation of the COLA process.

  Failing to meet such criteria, the satellites in this case should only be authorized to use certain orbits (e.g. below 400 kms if no propulsion) far from the highest value orbits (e. g. ISS or other ones to be identified) or orbits for which the impact is acceptable.

- The IOAG/SOS WG recommends that regulations address the issue of continuity of control (not necessarily the mission) including the final disposal, so that it is ensured by insurance, initial deposit, state guarantee or the like, in particular to cope with the cases after bankruptcy of operators or transfer of ownership of a satellite operator company.

- The IOAG/SOS WG recommends that national and international regulators be more active in educating New Space operators and other newcomers on their obligations and of the possible mitigation measures.

A1.2 – RECOMMENDATIONS IN THE DOMAIN OF END OF LIFE ACTIVITIES

Recommendation to satellite operators:

- The IOAG/SOS WG recommends that the end of life operations be prepared and resources be planned from the design phase, to be able to adopt and comply with the latest IADC guidelines and ISO standards on matters such as lifetime in Space, storage orbits, risks of casualties or reliability of disposal operations..

- The IOAG/SOS WG recommends that each satellite owner input data into a data base of satellite status, to share more effectively if satellites are maneuverable or passivated, especially, after end of life operation. This should be done as soon as there is a known change of the status of the satellite.

- The IOAG/SOS WG recommends that the probability of successful disposal is continuously monitored during the operation phase for continued compliance and that corrective actions are applied if degradation is observed.

- The IOAG/SOS WG recommends continuously conducting the assessment of the risk of a space debris impact on the execution of disposal operations during mission lifetime to avoid compromising the success of the disposal.

- The IOAG/SOS WG recommends that the satellite operators encourage the new / emerging launch operators to comply with the IADC requirements applying to launchers from their launch to their re-entry operations.

Recommendations to Space Agencies:

- The IOAG/SOS WG recommends sharing past experiences and developing specific guidelines on the best practices on disposal operations for different spacecraft configurations and capabilities. Workshops or conferences should be used to identify which best practices could be established as new standards.

- The IOAG/SOS WG recommends that space agencies promote the need for a data base to be established and maintained for sharing more effectively the status of satellites, especially, after a failure or their end of life operation.

Recommendations to IADC:

- The IOAG/SOS WG recommends that the IADC establishes a top-level reporting on the status of the guidelines and reporting on their implementation globally where possible.

- Recommendations to IADC:
- The IOAG/SOS WG fully supports the existing guidelines. The IOAG/SOS WG recommends that studies be conducted to develop specific guidelines on the conditions when the rule should be different from 25 years for LEO satellites and from the 90% successful disposal objective, for instance:
    - to differentiate how the 25 years should be counted (e.g.: ISO:24113:2019 counts from injection if not maneuverable)
    - to relate allowed decay time to duration of active mission
    - to relate allowed decay time to the consequence on the orbital environment of an unsuccessful disposal of the satellite (long and short term)
    - to revisit the required probability of successful disposal accordingly
    - to take into account the reliability and tolerance conditions for ageing missions and their hardware capabilities

Recommendations to ISO:

- The IOAG/SOS WG recommends that standard ISO 27852 on the orbit lifetime estimation be improved to better specify how to compute the estimated lifetime and the associated uncertainty (e.g. varying drag area for tumbling spacecraft), and to provide criteria to validate the tools for the lifetime estimation.

Recommendations to national and international regulators:

- The IOAG/SOS WG recommends that national and international regulators require license for mission extension demonstrating required Post Mission Disposal success.

- The IOAG/SOS WG recommends that regulators force the new / emerging launch operators to comply with the IADC requirements applying to launchers from their launch to their re-entry operations.

A1.3 – RECOMMENDATIONS IN THE DOMAIN OF SPECTRUM AND INTERFERENCES

A1.4 – RECOMMENDATIONS IN THE DOMAIN OF SPACE WEATHER

A1.5 – RECOMMENDATIONS IN THE DOMAIN OF MANNED FLIGHTS (TBC)

A1.6 – RECOMMENDATIONS IN THE DOMAIN OF NEO'S (TBC)

A1.7 – RECOMMENDATIONS IN THE DOMAIN OF PROXIMITY OPERATIONS, IN-ORBIT SERVICES (TBC)

ANNEX B: STANDARDS IDENTIFIED BY THE SOS WG

ISO 24113 THIRD EDITION 2019-07

"Space systems — Space debris mitigation requirements"

6.2 Avoiding break-ups in Earth orbit

6.2.3 Accidental break-up caused by a collision

6.2.3.1 A spacecraft that will operate in the GEO protected region shall have a recurrent maneuver capability.

6.2.3.2 A spacecraft that will operate in Earth orbit with a recurrent maneuver capability shall be designed and operated to actively manage collision risk until the end of life.

6.2.3.3 For a spacecraft with the capability to actively manage collision risk, if the risk of collision with other space objects is assessed to be above the corresponding risk threshold set by an approving agent then collision avoidance maneuvers shall be conducted to reduce the risk of collision below the threshold.

OTHER ISO TC20/SC14 REFERENCES

WG3 Operations

16158.1 Avoiding collisions with orbiting objects [Tech Rep] PUBLISHED
16164.1 Disposal of satellites operating in or crossing Low Earth Orbit - PUBLISHED
16699.1 Disposal of orbital launch stages – PUBLISHED
23339.1 Unmanned spacecraft residual propellant mass estimation for disposal maneuvers - PUBLISHED
24330.1 Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) — Programmatic Principles and Practices - DIS - 8/16/2021 Pub - 8/16/2022
26872.2 Disposal of satellites operating at geosynchronous altitude - PUBLISHED
26900.2 Space data and information transfer systems — Orbit data messages DIS - 12/11/2019 Pub - 12/11/2020 (with SC13)
27852.2 Estimation of orbit lifetime - PUBLISHED
27875.2 Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages – PUBLISHED
27875 Amd1 1 Re-entry risk management for unmanned spacecraft and launch vehicle orbital stages — Amendment 1 [for Edition 2] FDIS - 11/22/2020 Pub - 5/22/2021

WG7 ORBITAL DEBRIS

11227.1 Test procedures to evaluate spacecraft material ejecta upon hypervelocity impact - PUBLISHED
11227.Amd1 1 - Test procedures to evaluate spacecraft material ejecta upon hypervelocity impact — Amendment 1: Oblique impacts and Annex C update - DIS - 12/14/2019 Pub - 12/14/2020
16126.1 Assessment of survivability of unmanned spacecraft against space debris and meteoroid impacts to ensure successful post-mission disposal PUBLISHED
16126. 2 Survivability of unmanned spacecraft against space debris and meteoroid impacts for the purpose of space debris mitigation DIS - 11/13/2021 Pub - 11/13/2022
16127.1 Prevention of break-up of unmanned spacecraft PUBLISHED
18146.2 Space debris mitigation design and operation guidelines for spacecraft [Tech Rpt] DTR - 1/10/2021 Pub - 1/10/2022
20590.1 Debris mitigation design and operation guidelines for launch vehicle orbital stages [Tech Rpt] PUBLISHED
20893.1 Detailed space debris mitigation requirements for launch vehicle orbital stages DIS - 3/24/2020 Pub - 3/24/2021
23312.1 Detailed space debris mitigation requirements for spacecraft DIS - 3/20/2020 Pub - 3/20/2021
24113.3 Space debris mitigation requirements PUBLISHED

CCSDS BLUE BOOK ON CONJUNCTION DATA MESSAGES (ALSO UNDER ISO TC20/SC13 REFERENCES)

NAVIGATION WG DATA MESSAGES

- Conjunction Data Message 5 Year Review Revision Blue 508.0-B-2 Approved On Schedule First draft circulated to WG 01/14/2019 12/31/2021
- Orbit Data Message (ODM) 5 Year Review Revision Blue 502.0 Approved On Schedule Second draft circulated to WG 04/16/2015 2/28/2022
- Tracking Data Message (TDM) 5 Year Review Revision Blue 503.0 Approved On Schedule RID Resolution 2 10/09/2013 5/15/2020
- Tracking Data Message Version 3 Blue 503.0-B-3 Approved On Schedule First draft comments due

05/06/2019 11/30/2024
- Attitude Data Message (ADM) 5 Year Review Revision Blue 504.0 Approved On Schedule Second draft circulated to WG 04/16/2015 4/30/2022
- Navigation Data Messages XML Specification Five Year Revisions Blue 505.0 Approved On Schedule Second draft comments due 07/13/2016 10/31/2021
- Navigation Events Message Blue 507.0 Approved On Schedule First draft comments due 11/07/2017 11/30/2022

ECSS-U-AS-10C Rev.1 3 December 2019

"Space sustainability
Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements"

CEN JTC5 WG2 "Space Situational Awareness Monitoring"

EN 16604-30-03 Space - Space Situational Awareness Monitoring - Part 30-03: Observation System Data Message (OSDM)
EN 17350 SCM - Scheduling and Commanding Message

This WG plans on adopting the CCSDS (ISO SC13) standards: CDM, ODM, TDM, ADM, XML for Nav.

Recommendations/Guidelines International-level

IADC
https://www.iadc-home.org/

"IADC Space Debris Mitigation Guidelines" 2002/2007/2020

"Support to the IADC Space Debris Mitigation Guidelines" Rev 5.7, published 25/05/2020

"IADC Statement on Large Constellations of Satellites in Low Earth Orbit"

IADC also collects external guidelines

UN COPUOS

"Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space"
http://www.unoosa.org/pdf/publications/st_space_49E.pdf

"Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space"
https://www.unoosa.org/oosa/en/ourwork/topics/long-term-sustainability-of-outer-space-activities.html

UNCOPUOS also has a "Compendium of space debris mitigation standards adopted by States and international organizations"
http://www.unoosa.org/oosa/en/ourwork/topics/space-debris/compendium.html

Recommendations/Guidelines State/Agency-level

European Space Agencies
"European Code of Conduct for Space Debris Mitigation"
http://www.unoosa.org/pdf/spacelaw/sd/2004-B5-10.pdf

National Aeronautics and Space Administration
"NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook" (December 2020)
https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf

FRANCE
Decree concerning the technical regulation regarding the decree N° 2009-643 of 9th June 2009 concerning licenses issued pursuant to the Act N° 2008-518 of 3rd June 2008 relating to Space Operations.

RECOMMENDATIONS/GUIDELINES PRIVATE

SPACE SAFETY COALITION
"Best Practices for the Sustainability of Space Operations"
https://spacesafety.org/best-practices/

SATELLITE INDUSTRY ASSOCIATION
"Principles of Space Safety for the Commercial Satellite Industry"
https://sia.org/space_safety/