UK SPACE AGENCY REPORTING OF THE SPACE ENVIRONMENT SUSTAINABILITY ASSESSMENT (SESA) STUDY OUTCOMES

Jennifer Barry(1), Ian Christensen(2), Hugh G Lewis(3), Yui Nakama(2), Megan E Perks(3), Massimiliano Vasile(4)

(1) UK Space Agency, Didcot, Oxfordshire, United Kingdom, Email: jenny.barry@ukspaceagency.gov.uk
(2) Secure World Foundation, Massachusetts Ave. NW Washington, DC, United States, Emails: ichristensen@swfound.org; yuin@gwmail.gwu.edu
(3) University of Southampton, University Road, Southampton, United Kingdom, Emails: h.g.lewis@soton.ac.uk; megan.perks@soton.ac.uk
(4) University of Strathclyde, Richmond Street, Glasgow, United Kingdom, Email: massimiliano.vasile@strath.ac.uk

ABSTRACT

Currently, there is no globally accepted consensus view on the acceptable state for the outer space environment or an agreed model/metric to measure the impact of space activities, despite the acknowledged importance of space sustainability at all international fora. Noting the importance of evidence-based approaches for international agreements, a key element in understanding whether future space activities are sustainable is the development of a framework which is agreed and incorporated into global approaches.

This study, led by UK Space Agency's (UKSA) Office of the Chief Engineer (OCE), supported the development of threshold-based models and began to evaluate their potential incorporation into existing and new frameworks for space governance/regulatory coordination. The following paper provides a review of the research perform alongside initial recommendations and findings which will be used to inform potential future policy considerations.

1 INTRODUCTION

The United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) defines Long Term Sustainability (LTS) as

"the ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, in order to meet the needs of the present generations while preserving the outer space environment for future generations" [1],

however with increasing orbital use of up to 100,000 satellites estimated by 2030 [2], global efforts should be made in finding and understanding the changing landscape of the space environment through continued activities. Currently, there is no globally accepted consensus view on the acceptable state/threshold for the outer space environment or an agreed model/metric to measure the impact of space activities, despite the acknowledged importance of space sustainability at all international fora. Noting the importance of evidence-based approaches for international agreements, it is felt that a key element in understanding whether future space activities are sustainable is the development of a threshold-based framework which could be agreed and potentially incorporated into global approaches for space governance/regulatory coordination.

The recently conducted study on Space Environment Sustainability Assessment (SESA) aimed to:

- Establish a high-level plan for potentially incorporating a threshold-based model into governance/regulatory coordination frameworks.
- Identify, evaluate and support the development of threshold-based models to be used in assessing the sustainability of the space environment, including development of UK models.
- Assess the technologies that may be needed to achieve a sustainable space environment.
- And promote the need for a threshold-based framework internationally.

The basic research performed under SESA does not represent UKSA policy but provides valuable initial insight into the type of metrics, technologies and governance structures which could be considered if a metric-based approach was to be considered.

2 MODELLING WORKSTREAM

A core component of the work performed in the study was to identify different space sustainability/ environmental metrics and assess the benefits to different modelling approaches. The workstream included a critical review of existing literature, with 89 papers

Proc. 9th European Conference on Space Debris, Bonn, Germany, 1–4 April 2025, published by the ESA Space Debris Office
Editors: S. Lemmens, T. Flohrer & F. Schmitz, (http://conference.sdo.esoc.esa.int, April 2025)

evaluated, covering 38 metrics and thresholds, such as within the Inter-Agency Space Debris Coordination Committee (IADC). The findings on categories of metrics are displayed in Fig. 1. It is noted that whilst in the classification of the models there is a distinction between Risk-based and Risk-severity, there is limited difference to differentiate between probability-only metrics, and risk which contains severity. This was mainly due to a function of explicit parameterisation of probability and severity in papers.

The critical review of metrics found that risk-severity metrics were by far the most common type of metrics used in the context of space sustainability. In terms of scope, these metrics tend to be at mission level, needing an aggregation method to be applied at larger scales. However, risk-severity metrics usually require normalisation, as the values they return are very small, which then removes the direct meaning of the numbers. Setting a threshold on these metrics also typically requires a bottom-up approach, where the threshold is limited by feasibility rather than environmental effects. It was also noted that a formal connection between global sustainability impact and mission-level sustainability can be analysed through network based models, but might not be so obvious to study via aggregation of mission level metrics.

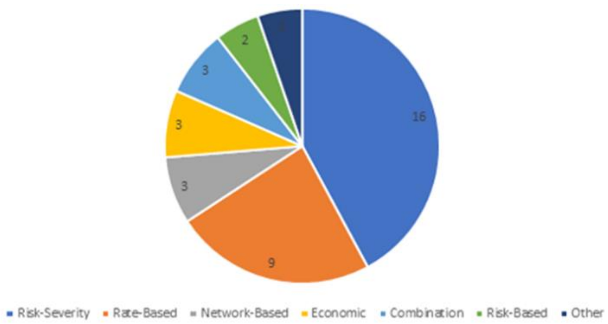

Figure 1: Analysed Metric Types

To compliment the review of existing metrics, UKSA initiated initial bread-boarding of models with a few academic consortia. Note that due to timescales, the models were anticipated to only be at a prototype or functional level by the end of this project phase.

As part of the study University of Strathclyde furthered their metrics work which was initially conceived as a project with ESA looking at modelling the space environment as a multi-layer temporal network of connected components [3][4][5]. Within this, each node of the network represents an object or a group of objects of a given type and with a given function, and links represent their relationships, as shown in Fig. 2. The physical, or space, layer of the network models the interaction of space objects in orbit. Other layers model their functions and services and the link with launch and re-entry activities. As part of SESA, the work from the University of Strathclyde focused on the development of the space environment layer and related indicators, and integration with a Life Cycle Sustainability model which similarly include the socio-economic impact and other impact categories. Within this model, the fragility of the space environment is measured by the degree of connectivity of the equivalent network and the rate at which the consequences collisions and explosions spread across the environment. The network representation provides a powerful way to capture the complexity of the relationships that drive the short- and long-term evolution of the space environment. Furthermore, the integration with Life Cycle Sustainability allows evaluating the combined effect on the space and Earth environment, including the socio-economic impact, of future policies and management actions.

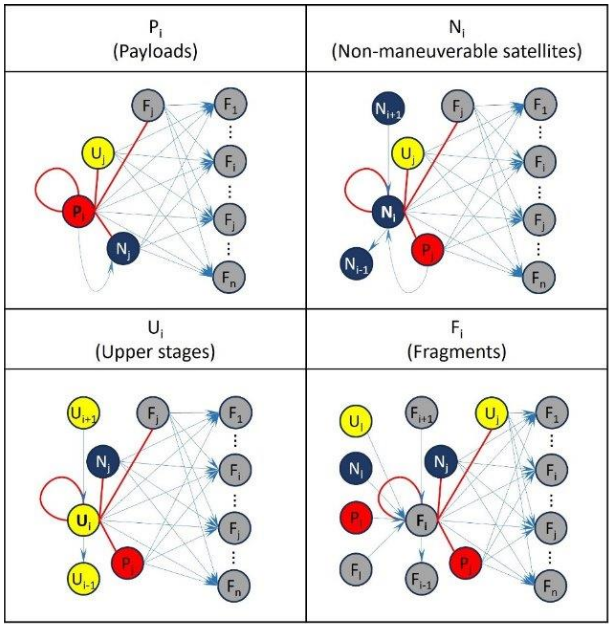

Figure 2: NESSY - illustration of part of the network model, where four classes of space objects are considered: Payloads (P), Upper stages (U), Fragments (F) and non-manoeuvrable satellites (N)

As part of the study the University of Southampton proposed a systems dynamics model EMISSARY, the guiding framework for which is shown in Fig. 3, which aims to provide a synthetic representation of the systems associated with use of the space environment in which an understanding of the role of individual factors or indicators can be gained, and predictions at the larger macroscopic scale can be made, which guide decisions where trade-offs may exist between two or more regulatory actions. These trade-offs arise from the interconnection in the system, whereby actions may produce conflicting results when multiple aspects of sustainability are considered. These trade-offs are an important consideration for achieving space sustainability in a holistic context. Holistic sustainability

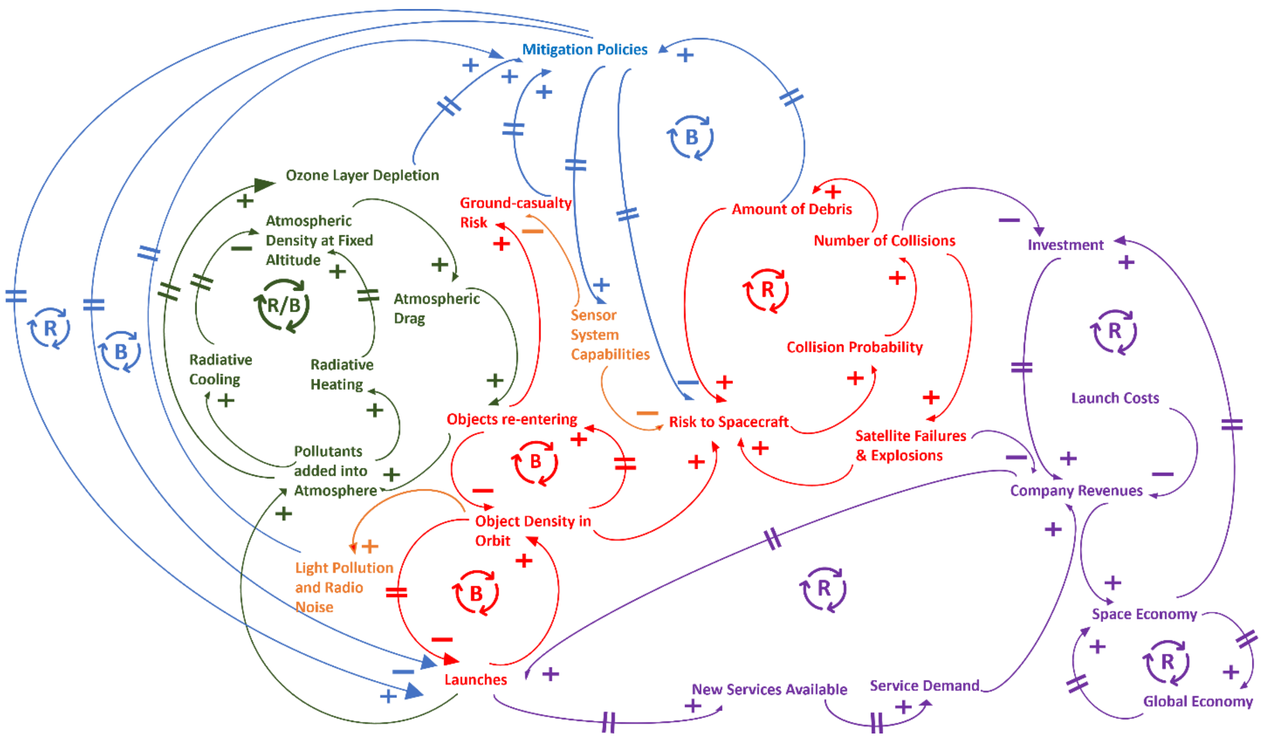

Figure 3:illustrative causal loop diagram showing the proposed framework as a system of Earth and human systems (adapted from [6]) which represents the framework for EMISSARY

in the University of Southampton work refers to the inclusion of perspectives beyond satellite operators alone, beyond the physical orbital environment alone and how each of these perspectives are linked to one another.

Whilst both models supported as part of the SESA project have different approaches to their development, some conclusions can be read across. The flexibility of the models to consider different use cases and understand the impact of future policy decisions is a critical factor in model development. Similarly, it is noted that validation of the whole systems model will be very difficult; there are no other models of the space system in the broad, holistic context that already exist in the literature to compare results against, and the model's production of highly complex, non-linear and emergent behaviour are unpredictable outside of simulation.

Both models support the idea that a single metric, (e.g. "orbital carrying capacity") would be insufficient to capture the required metrics to ensure a sustainable space environment. Ultimately, both models consider the management of the impact of the use of space systems most critical to understanding the sustainability of the space environment. Indeed, the use of a framework defining thresholds of acceptable conditions to be maintained in the system allows for the identification of a variety of management options to maintain sustainability. This switch in perspective from 'managing the use of the space system' to 'managing the impacts of the use of the space system' allows constraining the number of space users to become one of many possible management options.

3 REGULATIONS, GOVERNANCE, AND INTERNATIONAL WORKSTREAM

The first element of the study involved a critical review of similar domains that have implemented or considered environment and resource coordination. The work performed was undertaken by Secure World Foundation, generating case studies and lessons learnt on example governing bodies (and processes) and involved looking at case studies across International Spectrum Management, Climate Change Mitigation, Fisheries Management, and Deep Sea Mining. Each case study looked at the history of the issue, the current governance structure (including organisation, application, and challenges), and the applicability to the space environment.

Reviewing across these domains a series of key lessons learnt were identified and are provided in this section. The most effective structure appeared to be an approach in which thresholds are identified set in a scientific/technical body which is separate from a governance body. The implementation of measures to meet targets/thresholds are then performed at a national level, as outlined in Fig. 4. The research highlighted that balancing trade-offs between short-term economic/ societal benefits and long-term environmental values is a common challenge in implementation of threshold-based frameworks; as is in reconciling the interests of countries at different stages of development. Findings from the case studies also emphasised the need for adaptivity and multi-stakeholder involvement, and both the importance of and challenges to building transparency and accountability into threshold-based governance.

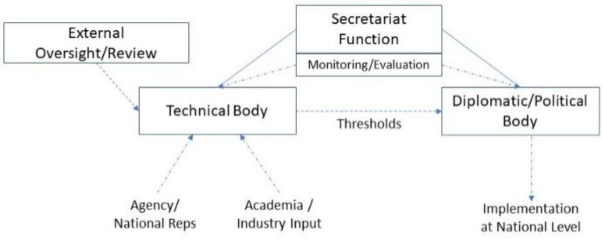

Figure 4: Notional Illustrative Structure for Space Environmental Threshold Governance

Additionally, UKSA held engagements with some global space regulators / space agencies were held to understand how they currently consider space sustainability, and document considerations for incorporating a threshold-based model for space environment sustainability into their regulatory frameworks. Through this, thought was given to a governance structure which could oversee the process of implementing and monitoring metrics for the space environment.

4 TECHNOLOGY AND STANDARDS WORKSTREAM

The third workstream initially investigated a selection of agreed space sustainability guidelines/standards, including the UNCOPUOS Long-Term Sustainability guidelines, ISO standards, IADC guidelines, Space Safety Coalition guidelines, and others to identify commonalities, differences, and gaps. The intent of this workstream would be that this would inform future work on metrics identifying the technological and behavioural levers that could be used to improve the environment. The workstream utilised sources of best practice for space sustainability to identify the critical technologies and approaches to achieve space sustainability across prevention, mitigation and remediation.

Some key findings from this study include the following:

- Technologies facilitating the detection and tracking of space objects were identified as key, having the broadest impact across the standards. Reliability analysis and design tools were seen to have the second largest contribution to meeting the standards.
- Active Debris Removal (ADR) capabilities and on-orbit servicing were also identified as a way of improving compliance with the standards and improving sustainability of the space environment. In the near term, compliance with space debris mitigation guidelines should be prioritised until ADR services are commercial sustainable.
- Other key gaps were identified where technologies would have a broad impact on improving space sustainability and were identified and assessed to have relatively low Technology Readiness Levels.

5 SOCIALISATION AND UN COPUOS STSC INPUT

To promote the work undertaken during the SESA project, a technical presentation was delivered at the 62nd session of the UN COPUOS Scientific and Technical Subcommittee (STSC). This provided the opportunity for the important topic of space sustainability and modelling of the space environment to be discussed with a number of member states.

Additionally, UKSA co-hosted a side event with United Nations Office for Outer Space Affairs (UN OOSA) to provide the opportunity for a more informal discussion on the topic. Opening remarks were made by the Director of UN OOSA and the Chief Engineer of UKSA, followed by a series of open questions to support discussion in the room. The discussion focused on strategic and political input to development of a metric, model, or governance structure that could inform space sustainability, as well as some specific technical development work such as evidence requirements.

Generally, it appeared that there was appetite for discussing this topic at an international level and agreeing a way to monitor the sustainability of the space environment. Fig. 5 shows that a significant proportion of attendees supported the idea of threshold-based metrics, with some attendees needing further discussion on the topic. Repeated through the event was the importance to consider all stakeholders, including operators/industry and politicians, and support capacity building efforts and communication to member states not yet actively involved in the discussion.

On a technical level, it was noted that an ongoing discussion is whether metrics and models should look at single spacecraft impact compared to the whole environment. Further, discussion was had around the possibility to have multiple models which could be used to cross-compare findings to improve confidence in results. It was noted models should be sufficiently flexible to consider aspects such as novel technologies.

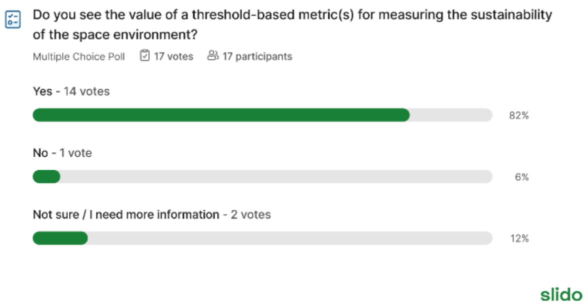

Figure 5: Anonymous poll taken on Slido at the end of the UKSA & UNOOSA side event from UN COPUOS STSC

6 CONCLUSION

Throughout the project the complexity of the problem was emphasised. On a technical level, modelling the space environment is complicated as it must address a multi-dimensional problem, and to assess the acceptable thresholds multiple contributing elements must be considered. In addition, the pathway to adopting thresholds for the management of activities in the space domain, at the international level, requires political will and buy-in from a significant number of states and commercial actors. Furthermore, the challenge of space sustainability continues to require consideration within multi-lateral forums such as UNCOPUOS to ensure appropriate and coordinated action can be taken. However, there are examples where targets or metrics can be internationally agreed and governed, and core lessons learnt have been determined.

Furthermore, the importance of engagements between a variety of stakeholders including governments, industry, academia, and regulatory bodies was also noted. Development of specific engagement strategies to target a variety of stakeholders and ensure buy-in was viewed as critical. Specifically noted was the importance of engaging with emerging space nations to improve transparency on these issues, as well as ensuring operators are consulted to build trust. Corresponding to this, thought was given to a governance structure which could oversee the process of implementing and monitoring metrics for the space environment.

Technical conclusions were drawn from a number of the workstreams on the models themselves. For example, the understanding of the need for validation of methodologies and access to data sources, and the limitations of these was raised across workstreams. Additionally, it was noted that thought had to be given to utilisation of quantitative vs qualitative metrics, with the benefit of numeric goals being potential ease of communication and clearer assessment of adherence to targets, however the challenge of staying current with rapidly changing technology and needs noted.

Aligning to the findings above, a set of recommendation on future work have been proposed and will be considered as further potential research in this area is planned. These recommendations include ensuring engagements across a number of key stakeholders, continued work to advance technical understanding of threshold methodologies and data sources, and a focused study on the needs and structure for a potential governing body. Recommendations have also been generated against each workstream individually in more depth for potential future work. It is hoped that some of these findings can feed into the important research being perform by the Inter-Agency Space Debris Coordination Committee (IADC).

Ongoing work at the UKSA is considering how sustainability fits within our regulatory processes for licensing future orbital activities. The basic research performed under SESA does not represent UKSA policy but has provided valuable initial insight into the type of metrics, technologies and governance structures which could be considered if a metric-based approach was to be considered. Overall, all workstreams reached the conclusion of the value of a potential metric, or preferably metrics, which can be monitored and assessed against the sustainability of the space environment (and associated space activities). It was also highlighted that a metric agreed at a multilateral level, would be beneficial to preserving outer space. Furthermore, awareness and coalition building efforts will likely be necessary to build consensus around a metric-based approach to space environment governance before the associated governance mechanisms can be agreed. The process to develop such a metric(s) would be a political, diplomatic, and technical one: a single focus on one of these workstreams would be insufficient to achieve global buy-in.

7 References

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