Foundations for a Debris Offset Market to Fund Remediation

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ABSTRACT

The growing space debris population represents a major threat to the long-term sustainability of space activities, yet current funding mechanisms for debris remediation missions remain inadequate. Guidelines and initiatives exist to try to prevent the creation of new debris however the remediation of debris is very expensive. This paper proposes a Debris Offset Market (DOM) solution designed to fund Active Debris Removal (ADR).

The DOM operates a "polluter pays" model, whereby entities are incentivised to offset their impact and financially support ADR. These contributions would be used to fund ADR operations targeting both large debris in Low Earth orbit (LEO), as well as smaller debris.

This market-based approach is structured to be transparent and equitable, with the removal priorities determined by those paying to offset, ensuring fair representation of stakeholder interests.

This paper outlines the foundational structure of the DOM that can evolve in collaboration with the global space industry.

1 INTRODUCTION

Space sustainability is going through a revolution with the aim to create a responsible industry that can achieve a net zero impact of its operations. Much focus is given to the mitigating processes to try to prevent creation of future debris. These mitigation processes come in many forms from Post Mission Disposal (PMD) and engineering design practices [1] to life extension servicing [2] and in the long term there is interest in creating a circular economy in space [3]. Adoption of guidelines in the area of debris mitigation has been widespread through international forums, such as the IADC, and there is a business case for satellite life extension and servicing, as it will postpone or prevent the need to design, build and launch a new satellite[4]. However, these processes will never be 100% successful, meaning that some debris will always be added to the existing base. Unfortunately, the viability of the market behind debris remediation is not so easy to justify. This hinges on the fact that debris removal is too expensive for individual entities outside of international governments, therefore requiring collective funding. Legal and liability mechanisms behind Active Debris Removal (ADR) are yet to be fully developed and there is a lack of incentive for commercial companies to fund it. [5] This is where an offset market comes into play as a means for the space industry to collectively fund ADR missions and it offers an opportunity for incentives to be associated with a known mechanism.

Numerous initiatives and guidelines are being developed for space sustainability that a Debris Offset Market (DOM) is designed to work in conjunction with and incentivise the use of. The following report explores an initial view of how the DOM can be structured and how stakeholders interact with it. This is written as a foundation upon which a fully functioning DOM can be built in collaboration with the wider space industry and associated stakeholders.

Markets like this must be built in a manner that is transparent to participants while also recognising the financial viability needs of the entities involved. The management of funds flowing through the market, via a trust-based system, must be handled by an entity that is demonstrably trustworthy and operates with full transparency in fund allocation and oversight. To maintain confidence in the system, it is envisioned that the DOM operator undergoes periodic review, for example, every 10 years, ensuring that other qualified entities have the opportunity to compete for the management role.

To uphold neutrality and legitimacy, the selection of the DOM Market Operator (MO) should be overseen by an independent oversight body under the auspices of a neutral international forum, such as the United Nations Office for Outer Space Affairs (UNOOSA). This structure ensures that all nations have a voice in the selection process, reinforcing trust, accountability, and democratic governance. The specific selection criteria and governance mechanisms should be developed in collaboration with industry stakeholders prior to the initiation of the DOM, ensuring that the system aligns with the needs of both regulators and market participants.

The targets for debris removal must be decided by those that are paying to offset, with no one entity having more influence than another. This report presents a means to achieve that via a register of objects, and foresees a requirement to enable funds to be allocated to ADR technologies targeting very small debris (<10cm) as well as large debris. It is expected that there will be separate

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markets, similar in operation, for LEO and GEO, as their interests are wholly different. This report focuses on a LEO market, but we anticipate that most of it can be adapted to a GEO market.

2 THE MARKET PROCESS OVERVIEW

Firstly, as mentioned in the introduction, the MO will be selected through a competitive process, overseen by an independent international body to ensure transparency and industry confidence. This governance structure will undergo periodic reviews to maintain trust in the market's operation.

The market is designed such that those paying to offset their space-based operations are able to follow a coherent process. It is intended to be a voluntary process, incentivised by government initiatives. This is discussed later in this report.

Those expected to use the offset market are the direct contributors to the debris population in space, as is expected in a 'polluter pays' model. It is recognised that there are indirect contributors to debris, such as downstream data users and manufacturers, however the means of estimating their contribution to debris in the same manner as is possible for direct contributors is very difficult in comparison. This may be an option for expanding the market in future, however it is expected that offset costs will be partially passed on to indirect contributors by those paying offsets.

The beginning of the process is the approach of a Satellite Operator or Launch Provider, hereby known as the 'Offset Payer' to the MO to express their intent to offset. The MO will encourage the Offset Payer to obtain sustainability standards or scoring to inform their offset calculation, without which a calculation can still be made, however the offset cost is likely to be higher than the 'Average Satellite'. The average satellite would be defined in terms of historic mass to various orbits and aligning this to debris mass increase. The Offset Payer is then required to provide details on the spacecraft or rocket to be launched, such that it can be compared to the aforementioned Average Satellite and an offset cost is then communicated to the Offset Payer.

The offset cost is then paid in to the Offset Trust, managed by the MO. Upon receipt of the agreed offset cost, the MO will confirm receipt and log the offset on a register that is viewable by the relevant authorities, such that they can deliver incentives associated to offsetting. The associated incentive is then received by the company that has offset its impact and is clear to continue its operations in orbit.

The money that accumulates in the trust is then used to pay for ADR missions to remove objects from a debris removal register. The order in which objects are removed is decided upon by those paying to offset. This will be done by enabling submission of removal preferences, such as low-cost targets or those that pose risk to particular orbits, by those paying to offset. These preferences will be used to order the Debris Removal Register (DRR) in a manner that is therefore fair to all those using the commons of space. The DRR will be populated by debris objects that have been submitted by debris owners or relevant international governments and as such highlighted as "Open to Removal" by suitable ADR operators.

When mission targets are decided, the object removal mission will be released as an Invitation To Tender (ITT) to ADR operators, such that they can bid and compete for the mission. The winning bid will be decided by an independent panel convened by the MO. Following contract award, the ADR operator will carry out the mission in a transparent manner and when the object is verified as removed, the MO can confirm the successful completion of the process. Those that have paid to offset will be informed of the successful mission and the MO will periodically report on the overall progress and effect of the DOM.

3 ALIGNMENT WITH WIDER INDUSTRY INITIATIVES

New initiatives focusing on sustainable space are being developed regularly. Some of these have common processes or stakeholders and, in some instances, similar aims and outputs. A DOM could be seen as similar to other initiatives, considering the potential financial outputs of debris bonds or insurance markets, however it is important to highlight its differences and how it is designed to operate alongside those financial mechanisms, amongst others, to enhance sustainability funding.

3.1 International Guidelines

Numerous global entities publish guidelines on space sustainability and acceptable practices. These are expected to be adopted by space actors much more commonly in future and which guidelines are used will depend on the jurisdiction in which the actor intends to register themselves. It is not envisioned that any future operator of the DOM will define these guidelines other than to encourage the adoption of an offset market as a means to achieve Net Zero Debris. As such, a DOM sits separate to, but in support of, international space sustainability guidelines and is agnostic to whichever are being used but must accept that those adopting less stringent guidelines will likely pay higher offset costs.

What should be recognised is that the sustainability guidelines focus on PMD and deorbit mechanisms reduce future debris, they do not address existing debris populations or new debris created despite following guidelines. The DOM ensures that the space industry collectively funds debris remediation, complementing existing sustainability practices rather than replacing them.

3.2 Space Sustainability Standards and Scoring Mechanisms

Sustainability standards, such as those being developed by the Earth-Space Sustainability Initiative (ESSI) [6], and scoring systems, such as the EPFL Space Sustainability Rating (SSR) [7], should be incorporated in to offset cost calculations. It is expected that those obtaining these standards or scores will be able to prove they are less likely to contribute debris to the space environment and will therefore pay lower offset costs. The MO will not be expected to validate these scores, instead relying on the applicant to provide the appropriate certification to prove SSR score, ESSI Mark or similar. In doing so, by offering lower offset costs to those utilizing initiatives like these, a DOM incentivises their use. As such, a DOM again sits separate to but in support of, sustainability standards and scoring mechanisms, instead using their output to inform its own operations.

3.3 Debris Removal Funding Mechanisms

Insurance and Space Debris Bonds (SDB) are the current front runners when it comes to conversations regarding funding of debris removal missions. These are means for space actors to protect themselves against loss and also ensure their satellite or rocket body may be de-orbited in the event of failure. These therefore operate very closely to an envisioned DOM, however they target future debris mitigation instead of legacy debris remediation. An SDB would be closely related to a DOM, however the DOM would not be expected to remove an object covered by an SDB, instead targeting objects that have no PMD plan as well as debris created by future failures and collisions. An SDB contributes to the targets of mitigating debris and it cannot guarantee Net-Zero Debris, given that it will not account for any minor contribution of debris from a successful satellite mission. The DOM enables Net-Zero Debris, as it is designed solely to account for the debris that is generated in the operation of all objects on orbit.

Insurance premiums are dependent on the risk posed by debris in space and would be expected to reduce if the risk reduces. A DOM or SDB would therefore reduce insurance premiums, as they lower risks in space, and their usage would expect to be supported by insurance companies. Insurance may also be a potential means of incorporating an offset cost as part of their premium, considering an insurance premium is more of a 'known cost' to the space industry, whereas offsetting debris is wholly new.

A DOM is therefore closely tied to insurance and SDBs, however sits separate to them in its operation, as it targets debris not covered by insurance or an SDB. The MO would therefore encourage the use of insurance and SDBs as sustainable practices that influence the calculation of an offset cost.

A debris offset market is highly likely to be seen as comparable to a carbon offset market, which brings some negative views considering potential for greenwashing and market manipulation.[8] However, the DOM can be designed to be much simpler and more transparent. Unlike carbon markets, where offsets are frequently traded, the DOM is designed as a direct funding mechanism rather than a speculative financial instrument. In short, debris offsets will not be tradeable. Allowing offsets to be tradable could introduce risks such as price speculation, market manipulation, and misalignment with actual debris removal needs. Instead, the DOM ensures that contributions are allocated directly to ADR missions, providing a transparent and accountable funding pathway for debris remediation. This structure prevents financial actors from using offsets purely for profit motives without contributing to sustainability efforts. Furthermore, a fixed non-tradeable offset cost aligns better with regulatory frameworks and avoids unnecessary financial complexity.

Unfortunately, the risk of free-riding exists in any sustainability initiative [9], but the DOM is structured to make non-participation commercially disadvantageous. Operators that do not contribute to offsets will have no influence over the selection of debris removal targets, meaning high-risk objects that threaten their constellations may be deprioritised. Additionally, if a known current operator wants to enter an object into the removal register, they must be an active contributor to the DOM. This ensures that those who continue to operate in space share the financial responsibility for remediation rather than relying on the market without contributing. However, objects from defunct operators or abandoned space assets may still be included in the DRR if deemed high-priority by offsetting stakeholders. As the market evolves, international policy and regulatory mechanisms could integrate offsetting into compliance frameworks, further discouraging free-riding behaviour. In effect, participating in the DOM is not just a sustainability effort—it is an insurance mechanism against long-term liability risks

Another consideration is for satellite operators whose satellite fails and they do not have insurance and are not paid in to any potential SDB. Some may feel that offsetting does not aid them, considering they are still liable for their now uncontrolled asset. Liability for uncontrolled satellites remains a legal challenge under existing international space law, as nations retain ultimate responsibility under the Outer Space Treaty [10]. However, in practical terms, an offset market provides an indirect risk-mitigation strategy. Without a market, a failed satellite could remain an indefinite liability, increasing collision risk and insurance exposure. With an active DOM, there is at least a structured pathway for its prioritisation in remediation efforts. While offsetting does not remove direct legal liability, it increases the probability that a failed satellite will be removed in a shorter timeframe, reducing long-term financial and operational risks for the owner. The alternative - no offset market - ensures no such mechanism exists at all.

4 CALCULATING AN OFFSET

4.1 Initial Method for Calculating Offsets

The following description is of a potential means to calculate an offset and includes many assumptions and simplifications. It is expected that the final calculations will be decided upon in collaboration with industry, such that they are confident they best represent the interests of sustainability and an economically successful space industry.

For this discussion we focus on satellites in Low Earth Orbit (LEO), not rocket bodies or geostationary satellites, however they would also be covered in the scope of future calculations.

Each year an 'Average LEO Satellite' (ALS) would be created from the data of the year prior as a baseline against which LEO satellites are compared. This would be characterised in terms of its size, orbit and sustainability credentials. The increase in mass of debris in the space environment from the same year as the ALS data would then be used to calculate the average mass of debris generated by the ALS.

The costs of ADR missions would be averaged from data supplied by ADR operators for the requisite year of the ALS. This average cost would be divided by the average satellite mass in space and therefore generate an average cost per kg for debris removal.

When an Offset Payer approaches the MO to offset their mission, they will be asked for the relevant credentials of their mission compared to the ALS. As such they can have their mass of debris contributed to space estimated and the associated cost per kg of ADR applied to generate their offset cost. The scale of the cost to offset a satellite throughout its life is expected to be approximately 1% of the satellite through life cost. This is an average across LEO, however offset pricing will be determined using a tiered risk model, where mass, orbital density, and sustainability compliance influence the cost per satellite. Operators using higher-risk orbits or lacking PMD strategies will pay proportionally higher offsets to reflect their debris contribution potential.

4.2 Potential Offset Generation

To understand the potential of an offset market, a few baseline assumptions will be made.

- The period of focus will be 2030-35, as this represents a timeframe by which an offset market could be established.
- The launch rate of satellites in to LEO will follow the same trend as the timeframe 2025-30 at 14,000 new payloads per year. [11]
- The share of satellite masses launched is as shown in Table 1.
- Satellites will be required to have on-orbit insurance at approximately 1% satellite value per annum.
- Launch+1 year insurance is at 10% satellite value. [12]
- Operations cost is at 10% satellite cost per annum. [13]
- Launch costs are based on SpaceX Falcon 9 rideshare costs. [14]
- Satellite life and through life costs are as shown in Table 2.

Type	% Share of Launched Payloads	Launched Annually
Cube (0-10kg)	17%	2,411
Small (11-200kg)	8%	1,184
Medium (201-600kg)	2%	319
Large (601kg-1200kg)	2%	286
Megaconstellation	70%	9,800

Table 1. Share of satellite masses launched [15]

Type	Manufacture Cost ($M)	Launch Cost ($M)	Life (Yrs)	Thru life Cost ($M)
Cube	0.1	0.3	3	0.4
Small	1	1	7	2.8
Med	40	3.25	7	77.6
Large	100	7.5	10	226.5
MegaC	0.8	1	7	2.5

Table 2. Breakdown of Satellite Through Life Costs [16][17]

Based on the assumptions made and the data in Table 1 and 2, applying an offset cost of 1% satellite through life cost we can derive a potential income to a debris offset fund. This would be the offset cost multiplied by the through life cost of a satellite mass class multiplied by the number of satellites launched annually in that mass class. Assuming an uptake of a DOM at 10% of the global market, $93.9M could be added to the offset fund annually. This translates to between 5 and 10 ADR missions annually based on potential future ADR mission costs. [5]

5 USE OF OFFSET FUNDS

5.1 Allocation of Funds

Figure 1 offers an indicative view of how an offset fund allocates money. To manage the DOM some money will be taken from the offset trust to cover operational costs of the management company. This is expected to be a very small fraction of the trust, as this is an environmental cause so as much money as possible needs to be allocated to the aims of the offset. Those paying in to the offset trust will be able to choose to allocate some of their money to the remediation of small debris. The reason this is segregated is that the technology and costs associated differ greatly from large debris remediation. The money for small debris remediation would go to the continuous operation of lasers or other small debris removal technology to remove small debris. The remaining money in the trust is to go to the remediation of large debris and this would constitute the vast majority of the trust. ADR missions funded will be scrutinised to ensure costs are kept to a minimum and enable the remediation of as much debris as practicable.

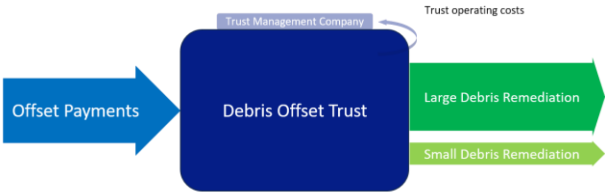

Figure 1. Indicative Debris Fund Allocation

5.2 Application of Incentives

It is expected that international governments are to introduce their own incentives for space sustainability. There is also scope for insurers to incentivise sustainability, especially considering they are interested in lowering industry risks. What these incentives are is yet to be decided, however they could come in the form of accelerated licensing or lower insurance premiums. The MO is not expected to influence the decisions of the governments regarding their offsets, rather it hopes that they recognise the potential of a DOM and choose to incentivise its use proportionately. There is scope for insurance companies to reduce premiums for those offsetting but, again this is for the insurers to deliberate.

5.3 Selecting Debris Targets

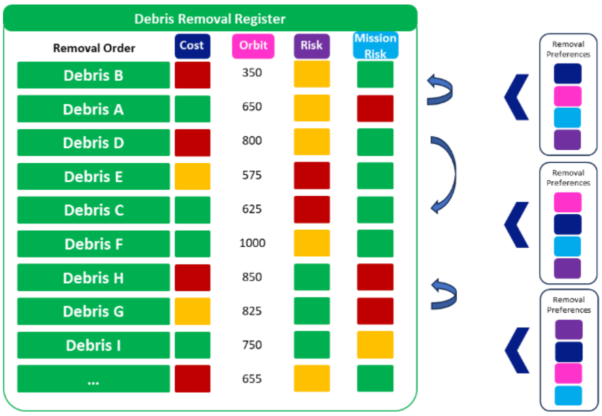

Figure 2. Function of the Debris Removal Register (DRR)

Sustain Space intends to utilise a DRR to display the order in which large debris targets will be removed. This will be populated by objects that have been highlighted as 'open to remediation' by their respective owners or responsible nations. Figure 2 illustrates how the DRR operates. It is a simplification of a register, considering definitions of costs and risks would need elaborating.

The way in which a debris owner submits an object to the register will be via a Debris Ticket that contains the identifier name of the debris, proof of ownership of the debris and a list of ADR operators or friendly nations they would accept an ADR mission bid from. This is so that there are not disputes from nations claiming their debris was removed by an unfriendly actor. Liability remains a significant challenge for ADR missions. To ensure legal compliance, the DOM will only fund removal of debris that is explicitly designated for remediation by its registered owner or an appropriate international authority.

Each object entered in to the register will have its associated data attached for cost of removal, orbital altitude it poses most risk to, risk to space operations in general and also the likelihood of ADR success.

The DRR will utilise a weighted voting system, with one vote per offsetting company, to ensure that removal priorities are decided transparently and fairly. This is done through making debris data variables accessible to those offsetting, as these variables are what they will be ordering in terms of preference as their 'vote' input to the register. Each order of preference submitted by those that have paid to offset will inform the order of the register such that the top item will be the first object targeted by the offset trust. Some will prefer the lowest cost of ADR mission be highest priority to enable most items to be removed, however it is likely that some will prioritise objects directly threatening their orbital altitude. This mechanism prevents large financial contributors from disproportionately influencing mission priorities, ensuring that both cost-effectiveness and risk reduction are considered in ADR target selection.

When the funds in the trust reach a suitable level to be able to fund ADR missions the top targets will be assessed against the market priorities. This is done instead of just taking the top item, as there is potential for multi-removal missions that can target objects local to each other. Where there is scope to use the fund to pay for a multi-object ADR mission that can be shown to be in the best interest of the offsetting stakeholders, this choice will be highlighted prior to publishing the mission ITT. If there is significant push-back from numerous offsetting companies to pay for a multi-mission then the top item in the register will have an ITT issued for it instead.

5.4 Selecting Active Debris Removal Operators

Bids against the ITTs are expected from international ADR operators and these will be judged by an independent panel, convened by the MO. There is scope for a nation to say it will only accept ADR operators from its own country, however this will likely cause that debris object to drop down the DRR, as the cost of removal increases and likelihood of mission success decreases with fewer ADR operator options.

ADR operators chosen to perform missions will be expected to operate transparently such that they can be trusted by the offset stakeholders. If they are seen to be operating DOM ADR missions in a manner deemed to be unexplainable or of a military manner, they will be removed from the list of companies able to perform ADR missions funded by the DOM until proven to be trustworthy from subsequent ADR missions for initiatives such as the SDB.

The outcome of missions and the effect of the DOM will be reported annually by the MO, such that stakeholders can be confident in its operation and choice of ADR operators.

6 CONCLUSION

This report has outlined the Debris Offset Market and the foundational processes upon which it’s operational rollout can be built. The application of the market will be such that numerous ADR missions to target current and future legacy debris can be funded in a manner that is transparent and trustworthy to those that offset their operations in space. This market will enable the space industry to tackle a major hurdle in achieving Net-Zero Debris in space.

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