Digital Currency Design for Sustainable Active Debris Removal in Space

Kenji Saito∗, Shinji Hatta†, Toshiya Hanada‡

Abstract

Orbital debris remains as an obstacle to further space development. While efforts are ongoing to avoid newly launched objects becoming debris, the number of debris would still continue to grow because of collisions. ADR (Active Debris Removal) is an effective measure, but building a sustainable economic model for ADR remains as a difficult problem.

We propose that the cost of removal can be paid by circulating digital currency tokens whose values may decrease and/or increase over time, issued by global cooperation (a consortium) of parties interested in space development, in exchange with proofs of ADR. The tokens pay their cost by themselves through contributions by the token holders, who are likely to be benefited by removal of debris. This scheme imposes virtually no cost to the consortium.

We evaluated the feasibility of our proposal through a simulation. We conclude that dynamic estimation of the economic values of each ADR and automated pricing of tokens that represent the orbital debris being removed are indeed possible. Actual prototyping of the proposed digital currency system is ongoing.

Keywords: Digital currency, Cryptocurrency, Blockchain, Orbital debris, Environmental remediation

1 Introduction

Orbital debris is a threat to active spacecraft and satellites. Efforts are ongoing to ensure that newly launched objects will be properly disposed from their orbits after their missions (PMD: Post Mission Disposal). However, the number of debris would still continue to grow even under ideal conditions of no new launches, no debris release or no explosions, because of collisions

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∗Keio Research Institute at SFC, Keio University
†MUSCAT Space Engineering CO., Ltd.
‡Department of Aeronautics and Astronautics, Faculty of Engineering, Kyushu University
among existing orbital objects including debris themselves. Therefore, for further development of space, it is mandatory for us to conduct ADR (Active Debris Removal). But building a sustainable economic model for ADR remains as a difficult problem.

We see that a possible solution may be to design an economic medium, learning from history.

Local currencies issued by local governments have been experimented in the past, in order to make use of under-utilized resources in the region, especially in times of depression. Well-known cases include experiments in Wörgl, Austria, in 1932, which made use of “stamp scrip” as a form of money whose value depreciates, which helped the local government to invest on public works at virtually no cost. This design may be a hint for us to implement works of public interest with limited budget.

The first author of this paper has extensively worked on possibilities of implementing and utilizing such currencies as digital media that can be used on the Internet.

Figure 1 shows the effects of depreciating (Reduction-Over-Time) currency tokens[7]. While it helps to reduce the debt of the token issuer, a game theoretic analysis showed that depreciating currency is likely to accelerate people’s spending. Being digital, such media can easily be reversed to obtain opposite effects. Figure 2 shows the effects of amplifying (Multiplication-Over-Time) currency tokens[6]. An analysis showed that this type of currency decelerates people’s spending. Applications of such currencies have also been studied, for example, for post-catastrophic disaster recovery[8].

Unfortunately, these ideas have not received wide acceptance. But situations are changing.

Bitcoin[5] is now well-known and an accepted digital currency. Another
example is Ethereum[1], under development and experimented widely, which make use of “blockchain”, the record-keeping foundation first developed for Bitcoin, as a platform of executing “smart contracts” as distributed applications. A blockchain, or a distributed ledger, is like a “promise-fixation device in the air” that keeps records of promises, which can withstand partial failures and churns. It can be used for implementing an unstoppable monetary system because money is essentially a promise that its recipient can also use it as money.

This paper proposes to utilize a new digital currency with planned depreciation to build a sustainable economic model for ADR.

Remaining of this paper is organized as follows. Section 2 gives background information on orbital debris and ADR. Section 3 shows the design of a digital currency that promotes ADR by imposing its cost to users of the monetary tokens. Section 4 evaluates the feasibility of the proposed design of the currency by simulating issuance of tokens based on the real estimations of collisions among orbital objects. Section 5 discusses potential societal influences and other applications of the same design. Finally, section 6 gives conclusive remarks.

2 Orbital Debris and ADR

The instability of the orbital debris (OD) population in low Earth orbit (LEO, the region below 2000km altitude), the “Kessler Syndrome”, was predicted by Kessler and Cour-Palais more than 30 years ago[3]. Recent modeling studies of the OD population in LEO suggested that the current environment had already reached the level of instability. Mitigation mea-
sures commonly adopted by the international space community, including those of the Inter-Agency Space Debris Coordination Committee (IADC) and the United Nations (UN), may be insufficient to stop the future population growth. In response to this new finding, an official IADC modeling study was conducted in 2008 to assess the stability of the current environment. Study participants were Agenzia Spaziale Italiana (ASI), British National Space Centre (BNSC, now UK Space Agency, UKSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA) and National Aeronautics and Space Administration (NASA). The goal was to investigate the stability of the current environment using the 1 January 2006 population as the initial condition. The 200-year future projection adopted a “best case” scenario where no new launches and no explosion beyond 1 January 2006 were allowed. At the conclusion, a follow-up study, based on an updated environment (including fragments from Fengyun-1C, Cosmos 2251, and Iridium 33), a more realistic future launch traffic cycle, and post-mission disposal implementation, was recommended. Finally, the IADC designated the follow-up study as an official Action Item (AI) 27.1, because of its potential significance. The objective of AI 27.1 was to investigate the stability of the future environment and reach a consensus on the need to use active debris removal (ADR) to stabilize the future environment. Participants included ASI, ESA, Indian Space Research Organization (ISRO), JAXA, NASA, and UKSA. Details of AI 27.1, its outcomes, and recommendations are summarized in [4].

In order to constrain the many degrees of freedom within IA 27.1, some reasonable assumptions were made. First, it was assumed that future launch traffic could be represented by the repetition of the 2001 to 2009 traffic cycle. Second, the commonly-adopted mitigation measures were assumed to be well-implemented. In particular, a compliance of 90% with the post-mission disposal “25-year” rule for payloads (i.e., spacecraft, S/C) and upper stages (i.e., rocket bodies, R/Bs) and a complete passivation (i.e., no future explosions) were also assumed. However, collision avoidance maneuvers were not allowed, as in the previous study. In addition, an 8-year operational lifetime for payloads launched after 1 May 2009 was uniformly adopted.

Each participating member agency was asked to use its official, or best, models for solar flux prediction, orbit propagation, and collision probability calculation for AI 27.1. Collision probability calculations were limited to 10cm and larger objects. The NASA Standard Breakup Model[2] was used by all participants for their future projections, as it was determined that participants did not employ any other fragmentation model. The participants were encouraged to conduct as many Monte Carlo (MC) simulations as time and resources allowed to achieve better statistical results. Finally, IA 27.1 conclusions were drawn primarily from the average results of each participating model, determined through MC simulations.

Figure 3 summarizes the projections of the OD population in LEO
Figure 3: Effective numbers of objects 10cm and larger in LEO predicted by the six different models. All models assumed no future explosion and 90% compliance of the commonly adopted mitigation measures.

through the year 2209, assuming no future explosion and a 90% compliance of the commonly adopted mitigation measures, from the six models. All models predict a future population growth. The average increase is 30% in 200 years. The short-term fluctuation, occurring on a timescale of approximately 11 years, is due to the solar flux cycle.

Figure 4 summarizes the cumulative number of catastrophic collisions happened within the 200-year projection period. Catastrophic collisions, such as the one between Iridium 33 and Cosmos 2251 in 2009, result in the complete fragmentation of the objects involved and generate a significant amount of debris. They are the main driver for future population growth. The steepest curve (UKSA) represents a catastrophic collision frequency of one event every 5 years, whereas the shallowest curve (ISRO) represents a frequency of one event every 9 years. Catastrophic collisions happened primarily at altitudes of 700-800km, 900-1000km.

The outcomes of AI 27.1 confirm the instability of the current OD population in LEO. They also highlight two key elements for the long-term sustainability of outer space activities. First, compliance of the mitigation measures, such as the 25-year rule, is the first defense against the future population growth. The need for a full compliance must be emphasized. The 90%-compliance assumption made in the simulations is certainly higher than the current reality. If the international space community cannot reach this level soon, future population growth will be far worse than the outcomes of AI 27.1, and it will certainly make future environment stabilization much
more difficult. Second, to stabilize the future environment, more aggressive measures, such as ADR, must be considered. Remediation of the environment after more than 50 years of space activities is complex, difficult, and will likely require a tremendous amount of resources and international cooperation. The international community should initiate an effort to investigate the benefits of environmental remediation, explore various options, and support the development of the most cost-effective technologies in preparation for actions to better preserve outer space for future generations.

3 Design of Digital Currency for ADR

3.1 Overview of the Design

We propose that the cost of ADR can be paid by circulating digital currency tokens that depreciate over time, issued by global cooperation (a consortium) of parties interested in space development, in exchange with proofs of ADR. We call the body of cooperation the consortium hereafter. We call a party that conducts ADR a remover. We call the monetary system we propose the ADR currency.

Figure 5 shows the overview of the design of the ADR currency.
3.2 Initial Token Value

Since the catalogue of all observed OD is available, we can calculate the risk of collisions. The consortium defines how the risk is calculated, representing the international space community. Probability of accidental collisions is calculated according to the defined function, and then the collision flux is translated into a monetary value.

In the translation, for example, the total cost of space development for the past 60 years can be used. The monetary value can be divided proportionally to the probabilities of collisions, which is iteratively re-evaluated as ADR proceeds.

The initial token value is decided by the consortium according to the following steps:

1. For each OD, the consortium periodically publishes the probability of collisions and the estimated token value with its depreciation schedule (the estimation expires after a certain duration of time).

2. A remover conducts an ADR (for the time being, a complete removal is assumed for the sake of discussion), to which the consortium issues a token.

3. For each OD, the consortium recalculates the probability of collisions.

- The issuer A is the consortium. The first token holder B is a remover.
- Depreciation in reality can be stepwise, such as yearly or monthly.
3.3 Depreciation

An ADR currency token depreciates as Figure 5 shows. We would like to accelerate removal and decelerate the space development while the number of debris is growing. Originally upon conceiving the idea of the ADR currency, we thought that the value of the tokens may be set to increase at first, to the extent allowed by the consortium, and when the number of debris stops growing, the token starts depreciating, thereby accelerating the industry.

However, the span for achieving the non-growth appears to be too long, such as 100 ∼ 200 years. Therefore, we have abandoned the idea of accelerating removal and decelerating spending by increasing the token values for the ADR currency (this idea is illustrated in section 6.3 for another application).

Instead, the tokens shall depreciate down to zero value over the duration of time the OD is estimated to cause harm, limited by, for example, 50 years.

3.4 Incentive Compatibility

For a given OD, the higher its probability of collisions is, the higher the initial token value would be when the ADR is performed. The longer the duration of time the OD would cause harm, the more slowly the corresponding token would depreciate. As a result, a remover would want to aim for removing an OD with higher probability of collisions that would stay for a longer time. The incentive provided by the currency design is compatible with our intention to make future space development safer and easier.

The tokens pay their cost by themselves through contributions by the token holders, who are likely to be benefited by the removal of the OD. This scheme imposes virtually no cost to the consortium.

4 Feasibility

Evaluation of the effects of the proposed currency design will involve how the industry and market react to this design, which is not objectively estimated. Instead, we evaluate the feasibility of the currency system by simulating issuance of tokens using the actual catalogue data and orbital projections.

For the matter of discussion, we chose 3,866 intact objects in LEO, i.e. uncrushed objects such as rocket upper fuselage or satellite platforms, from the catalogue data as of April 1, 2017. The objects include operational satellites, as we cannot distinguish between unused objects and ones in use, unless the intentions are confirmed.

1If we decide that the token value does not go down to zero, it will have to be redeemed by the consortium when the minimum value is reached. When this happens, the consortium will have to pay the value to the final holder of the token.
We divide space into \( \frac{10}{3} \)-kilometer cubes, and locate each object in a cube at a given time. Then we examine whether each object has any neighbors in the cube they are located or in any of the adjacent cubes (this means that we consider a 10-kilometer cube for each object). If such a neighbor is found, the collision flux is calculated according to the relative velocity of the objects. We iterate this procedure with one-day interval for 50 years in our simulated time to estimate the accumulated collision flux, or risk of collisions, for each object.

Figure 6 shows the initial distribution of accumulated collision flux.

![Figure 6: Initial Distribution of Accumulated Collision Flux](image)

We consider series of ADRs where an object with the highest accumulated collision flux is removed from the orbit at a time. We approximate the effects of an ADR by removing the corresponding item from the same catalogue data and recalculating the fluxes.

Figure 7 shows changes of the sum of collision fluxes of all objects and the highest collision flux by a single object (i.e. the flux of the removed object) over 50 iterations of ADRs as described above. We see monotonous decreases in both values.

For each orbital object, we assign an initial token value proportionally to its accumulated collision flux. To do so, we set the initial virtual budget of 3.2 trillion USD, referring to our estimation of the total cost of space development for the past 60 years, which is the debt the space industry and
the surrounding communities should be willing to repay over many years by taking the depreciating tokens as payments. For the first iteration of ADRs, we divide the budget proportionally to the accumulated collision flux of each object, assign the value as the initial value of the token representing the object.

We consider two different policies for pricing for later iterations.

**division policy:** We subtract the initial token value of the removed object from the budget, and recalculate in the same way. Over time, the sum of initial token values of removed objects will never exceed the initial virtual budget.

**coefficient policy:** We obtain the coefficient of translating the collision flux into a token value from the first iteration, and use the coefficient for later iterations. Over time, the sum of initial token values of removed objects may exceed the initial virtual budget.

Figure 8 shows the highest initial token values (i.e., the token values of removed objects) for the first 50 iterations of ADRs, calculated in these two different policies. Note that in this work, these tokens are valued for prototyping purposes only, and the resulted token values do not necessarily suggest how much each ADR should be valued.
Figure 8: Highest Initial Token Values

With division policy, we see that the highest initial token value may increase as contribution rate of the collision flux of the removed object against the whole may increase over time. With coefficient policy, on the other hand, the price monotonously decreases, as long as the highest collision flux keeps decreasing. For incentive reasons, monotonous decrease of highest initial token values is preferred, because it would not motivate removers to wait.

However, we should note that this simulation assumes no collisions happening (thus assuming no increase of objects), and in reality, the highest collision flux would not keep decreasing even with some ADRs. We may need more sophisticated policy to realize the monotonous decrease of prices.

5 Discussion

5.1 “Proof of Disposal” concept

In addition to physical or engineering aspect of OD including intact object described in section 2, the social aspect of OD and the proposed scheme is considered in this section.

Once an OD is produced, the risk diffuses thinly and broadly to all orbits that share the same space with the object. The responsible body for the object does not suffer any disadvantage except for the thinly diffused
risk. To make matters worse, the risk diffuses not only spatially but also temporally. The temporal spread of the risk is, in other words, a negative legacy from human space activity of the current generation to that of the future generations. Every time an OD is produced, human space activity of the current generation increases corresponding obligation to that of the future generations, and in consequence, human space activity of the future generations increases credit to that of the current generation (Figure 9).

\[ 
\text{Obligation} \quad \text{Credit} \\
\text{Production of Orbital Debris} \quad \text{Human Space Activity of Current Generation} \quad \text{Human Space Activity of Future Generations} \\
\text{Credit} \quad \text{Obligation} \quad \text{Production of Orbital Debris} \\
\text{Third Party} \quad \text{Digital Currency} \quad \text{ADR = Transfer} \\
\text{Human Space Activity of Current Generation} \quad \text{Human Space Activity of Future Generations} \\
\text{Time} 
\]

Figure 9: Obligation and Credit

It seems impossible for a creditor in the future to recover the credit from the current obligor. It is possible, however, for some third party to transfer the credit from the future creditor through a present-day activity, namely ADR. The third party to conduct ADR reduces the negative legacy through the environment remediation, and therefore, ADR is considered equivalent to transferring the credit from the future to today. The scheme is shown in Figure 10.

\[ 
\text{Obligation} \quad \text{Credit} \\
\text{Production of Orbital Debris} \quad \text{Human Space Activity of Current Generation} \quad \text{Human Space Activity of Future Generations} \\
\text{Credit} \quad \text{Obligation} \quad \text{Production of Orbital Debris} \\
\text{Third Party} \quad \text{Digital Currency} \quad \text{ADR = Transfer} \\
\text{Human Space Activity of Current Generation} \quad \text{Human Space Activity of Future Generations} \\
\text{Time} 
\]

Figure 10: Transfer of Credit from Future to Today

The transferred credit is a warranty for issuing a claim deed to be circulated as a digital currency token. The authors named this scheme for issuing digital currency “Proof Of Disposal (POD)”.

The scheme may be applicable for any kind of disposal of industrial or
war wastes. For establishment of POD, however, the corresponding disposal has to be performed under the witness of the whole community, in order to prevent an untrue statement of disposal. From this point of view, ADR is one of the most suitable cases for POD.

5.2 Related Work

In recent years, a way of funding from general public through the Internet has become a popular practice. It is called *crowdfunding*. However, crowdfunding is not necessarily a solution for implementing public works where sufficient money is unavailable, as it requires money to be gathered first. In the proposed scheme of POD, on the other hand, monetary medium is created on demand.

Another way of funding that is becoming a popular practice is *ICO (Initial Coin Offering)*, or a *crowdsale* of newly issued digital coins. Although both ICO and POD issue digital currency tokens, ICO is rather similar to crowdfunding, as it requires upfront money to purchase the coins. ICOs tend to attract more people more rapidly than crowdfunding, as people expect capital gains with an anticipation that the price of the coins will go up in the future. Because of this expectation, circulation as monetary medium is limited for the issued coins in ICO (spending is generally decelerated). Thus, the issued digital coins are not expected to help the community as a whole as means for payment among community members. Another point about ICO is that issued digital coins do not usually represent debt, so that ICO requires an external scheme for monitoring whether the proposed project is soundly ongoing or not.

5.3 Other Applications

POD is expected to work where disposal is observed publicly. Another possibly useful case is land mine clearing (Figure 1). This example uses both amplifying and depreciating features of digital currency tokens issued in return for disposal. First, the issued tokens amplify their values for both incentivizing early removal of land mines and decelerating spending. Depreciation is delayed until zero land mine is achieved in the defined area, after which the area can be reconstructed with accelerated spending.

5.4 Implementation and Prototyping

We believe that either Bitcoin or Ethereum can be used for implementing POD. However, both blockchain platforms are under a risk of being discontinued. If the price of the native token (bitcoin or Ether, respectively) goes down, the maintainers of the blockchain (often called *miners*) may have to leave the system, because the cost of maintaining the blockchain, which is
usually covered by rewards they receive in the form of native tokens, would be valued more than the rewards.

To ensure sustainability of the ADR currency, which would have to continue for many tens of years, we take part in developing BBc-1 (Beyond Blockchain One)\(^2\), a new open-source platform for record-keeping that can use either Bitcoin or Ethereum (and even dynamically switch between them) for proof of existence of transactions in its early stage (and later, it will become independent). We will prototype the ADR currency on top of this new platform.

## 6 Conclusions

We proposed that the cost of removal of OD can be paid by circulating digital currency tokens whose values decrease over time, issued in exchange with proofs of ADR. We have shown that managing such a currency system, the ADR currency, is indeed feasible.

We consider that OD is a kind of debt owed by the human race of existing generation to the future generations. The ADR currency has an effect of transferring the corresponding credit to the present-day.

This is also an implementation of a belief that creation of monetary amount should be warranted by some kind of value in the real world, as opposed by many cases of ICO. The authors hope that the scheme we proposed in this work will be considered as an alternative to crowdfunding or ICO for implementing public work under low budget conditions.

\(^2\)To appear at: https://github.com/beyond-blockchain/bbc1
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