Designing the International Framework for Active Debris Removal Operations

By Akiko OTSUKA,¹ Daisuke TSUIJITA,² Satomi KAWAMOTO,² Daisuke GOTO,² Naohiko KOHTAKE,³ Seiko SHIRASAKA³ and Yoshiaki OHKAMI¹

¹Koio University Graduate School of System Design and Management, Yokohama, Japan
²Japan Aerospace Exploration Agency, Tokyo, Japan
(Received July 31st, 2015)

The threat by the space debris in space activities has accelerating the necessity to take the measures against space debris, especially to remove the space debris, so-called, Active Debris Removal (ADR). The objective of this paper is to design the international framework to operate ADR from the systems engineering point of view, not only technical, but also economic, strategic, legal, or fairness etc. It is natural that ADR be operated under some international framework working together the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS) and/or the Inter-Agency Space Debris Coordination Committee (IADC). In order to urge many space faring countries and/or parties to support this framework, some mechanisms have been built-in to let them find the merit regarding responsibility, compensation and cost of ADR.

Key Words: Active Debris Removal (ADR), United Nations (UN), Committee on the Peaceful Uses of Outer Space (COPUOS), Inter-Agency Space Debris Coordination Committee (IADC), International Framework, Systems Engineering

1. Introduction

Throughout our space development and utilization activities since 1957, we have left many man-made objects in space, what is called, space debris (hereafter, debris). Situation of space environment is getting worse as the number of debris increases, leading to collisions of debris with an operational spacecraft. This implies that the debris may produce a serious and growing problem and that the recognition of necessity and emergency of debris treatment is increasing in space community. Several countermeasures have been proposed such as the Active Debris Removal (ADR) which is one of the feasible solutions to improve space environment immediately. In order to bring the ADR in action, this paper proposes the international framework for the ADR operations.

The framework was designed based on the systems engineering procedure. The first step was to review the current space environment situation in order to analyze the requirements for keeping the safe and sustainable space activity. Then, the system boundary was specified following the system functions analysis. Finally, the ADR operations architecture was designed with some mechanisms to be built-in to urge many space faring countries and/or parties to support this framework.

Jakhu of McGill University et al. had submitted “Active Debris Removal – An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space”¹ at the 47th session of the Scientific and Technical Subcommittee of the UN/COPUOS and proposed the organizational and operational aspects of the ADR. Their report also proposed the interesting funding scheme to facilitate the ADR. As the goal of their report was to contribute to the discourse regarding the ADR issues, the rationale of the proposal was not clear. In fact, they recognized the need of a Global Economic Fund but the resource of funds was not clear and no analysis was carried out from the point of view of fund investor. Other few works have been done regarding the organization or operations of the ADR.

Our research is unique in that the ADR operations have been studied from the systems engineering point of view, not only technical, but also economic, strategic, legal, or fairness etc. and the systems engineering analysis is convincing the space faring countries and/or parties to support the proposed international framework.

2. Safe & Sustainable Space Activity Requirements

With increasing the number of debris, the safe and sustainable space activities are getting exposed serious negative risks induced by debris.

Therefore, risks managements plans have to be taken into account. According to the 5th edition of the PMBOK (Project Management Body of Knowledge) Guide², which deals with the knowledge area of risk management, there are four possible responses to a risk:

- Avoid, i.e. change the project plan to remove the risk;
- Transfer, i.e. give the risk control liability to the other party;
- Mitigate, i.e. control the risk occurrence possibility or the damage induced by the risk and keeping them under the acceptable value;
- Accept, i.e. accept the damage induced by the risk

In order to keep the safe and sustainable space activities, the space faring countries and/or parties try to deal the debris risk by means of mitigation methods, that is to take the following two actions in order to control the number of debris, to reduce the risk of collisions occurrence and to keep the damage induced by the collisions with debris under an acceptable value:
① Prevention of space debris increase
IADC and several space agencies have already set its own space debris mitigation guidelines and the guidelines require that the spacecraft will be designed not to generate new debris. For example, JAXA defines the risk assessment standard to confirm the tolerance design for collision with small (size of less than 1mm) debris in JERG-2-144 and European Code of Conduct for Space Debris Mitigation requires “the operator of a space system should perform disposal maneuvers at the end of the operational phase to limit the permanent or periodic presence of its space system in the protected regions to a maximum of 25 years”, what is called “post mission disposal” (PMD).

   Based on the monitoring information of debris, the spacecraft operators will take the Debris Avoidance Maneuver (DAM) operations for their active spacecraft, which is only 6% of the catalogued object population on orbit, to avoid the collisions with debris. Then the number of additional debris generated by the collisions with existing debris will be suppressed.

② Removal of existing space debris
As the number of existing debris decrease, the collision possibility with space debris becomes lower.

A projection of the low earth orbit (LEO) environment, obtained with the NASA’s orbital debris evolutionary model: LEGEND, is shown in Fig. 1. Herein, regular number of launches, 90% compliance of PMD and different ADR operations scenarios are assumed. If we keep our space development activities with regular number of launches and 90% PDM, the number of debris keeps increasing (Red Line). In the actual space development activities, we achieve 20-30% PMD, 50% PMD at most, and 90% PMD is a very ideal number. We can conclude that ADR is indispensable besides PMD (Green Line). Therefore, on the basis of the results of simulations shown in Fig. 1, the number of debris can be kept at the current level if both conditions A and B listed below are satisfied (condition C).

A. Complying with the space debris mitigation guidelines including 90% post mission disposal (PMD)
This prevents increase of debris. Especially PMD contributes to remove the spacecraft which ends its lifetime. With 10% failure of PMD, IADC set 90% as a practical target value.

B. 5 ADR executions annually
Many space faring countries and/or parties are developing the ADR technologies and have their own plan that which debris and how many debris they are going to remove. As space development shall be carried out for the benefit and in the interests of all countries, it is necessary to carry out the ADR under international cooperation.

C. Continuous execution of A&B
If each country or party executes the treatment to space environment under its own space policy, it may stop the treatment with its resource condition, for example, its economic condition. The international framework can be helpful to compensate each country and/or party’s resource condition.

The requirement analysis concludes that in order to keep the safe and sustainable space activity, it is necessary to establish some international framework to promote the ADR operations continuously and to compensate each participant’s resource condition. Hereafter that will be called the ADR international framework.

3. Function Analysis and Allocation
3.1. System functional analysis for the ADR operations
In order to specify the boundary of the ADR international framework, the use case diagram shown in Fig. 2 is used and four processes are identified to execute the ADR; ① to decide the ADR target ② to remove debris ③ to monitor the ADR activity ④ to cover the ADR cost

The requirement analysis for each condition is stated below.
A. Complying with the space debris mitigation guidelines including 90% post mission disposal (PMD)
B. 5 ADR executions annually
C. Continuous execution of the above two (A&B) conditions
The functions envisaged in the ADR international framework, together with their relationships, are shown in Fig. 3, and are described, from (a) to (k), as follows.

At first, the ADR target will be selected (a), the debris condition will be grasped (b), the ownership of the debris will be checked (c), and the debris conditions (i.e., shape, orbit information etc.) will be surveyed (d). After the owner is identified, the issues regarding the ownership of the debris should be negotiated (a).

Along with deciding the ADR target, in the process to remove debris, the ADR executor will be decided (e). The ADR executor will procure the ADR satellite (f) whose mission is to remove the target debris and the launch contract (g) of the ADR satellite. The ADR executor also will operate the ADR satellite (h) during the mission.

Every activity should be monitored (i) whether it complies with the ‘ADR rule’, which will be defined (j) like the guidelines to execute ADR.

All the cost of these activities should be covered (k).

Fig. 3. The relationship among the functions of the ADR international framework.

3.2. Function allocation

Through analyzing the functions of the ADR international framework, four subsystems are designed and each function is allocated.

The subsystem design concepts are as follow:
- Avoid complicated interface (I/F)
  Subsystems are designed to have simple I/F among many actors.
- Avoid the concentrated interests to one subsystem
  Each subsystem is designed to be independent from each other to avoid the concentrated interests to one subsystem. Then the whole system could be trusted by the space faring countries and/or parties. We refer to the political system separating legal, administrative, and judicial powers.

The administration subsystem is the main system involved in the execution of the ADR. It decides the target debris and the ADR executor by surveying the debris condition and also deals with all the necessary procedures to execute the ADR. Functions (a), (b), (c), (d) and (e) are allocated to this subsystem.

The executive subsystem is responsible for the actual execution of the ADR and functions (f), (g) and (h) are allocated to it. From the administration subsystem, the executive subsystem receives the notice to execute the ADR and after the ADR is done, the executive subsystem reports the result of the ADR to the administration subsystem.

The legal advisory subsystem works to establish the ADR rule and to monitor the activities of the administration and executive subsystems. Its assigned functions are (i) and (j).

The purpose of the cost subsystem is to cover the ADR cost, function (k).

Fig. 4 shows the functional allocation to each subsystem.

4. Architecture of the ADR International Framework

Using the function allocation results, the architecture of the ADR International Framework is designed in this section, and the architecture is explained including some major study topics.

4.1. The ADR Union and ADR execution scenario

In the framework, it is very important to select the target debris and the technologies regarding the ADR. The target debris information can be sensitive for space faring countries and/or parties because the space technology sometimes takes an important role in the national security. So there might be long and heated discussion to establish new organization operating the ADR.

In order to avoid to spend long time with the fruitlessly discussion, the ADR Union is designed to set under the existing organization represented by the United Nations (UN). In fact, because many countries join the UN, this organization has the ability to negotiate the issues between the participating members.

The UN appoints the ADR Union members and the ADR Union reports its activities to the UN. Within the ADR Union, the legal advisory subsystem and the administration subsystem are allocated as Legal Advisory section and Administration section, respectively. These two sections are independent from each other in order to separate their power and act fairly.

The ADR will be carried out by the ADR executor and the ADR executor includes the executive subsystem and the cost subsystem.
The relationship among the ADR Union, the executor and other outer actors is shown in Fig. 5.

4.2. Relationship between the ADR Union and IADC

Taking insights from the relationship between the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) – which assesses the climate change from an academic point of view and do not allow to deny its advice - , the ADR Union is designed in order to utilize the debris information from the IADC, which assesses the debris issue from the academic point of view. The ADR Union selects the target debris based on the IADC debris list and its information.

4.3. Funding

In order to operate the ADR, funding should be secured. Let discuss the several ways to establish the fund. At first, let investigate the funding by collecting money from private space faring companies.

Case 1 is to establish the ADR fund from the launch or the spacecraft insurance. The idea is that when the launch or the spacecraft operation is being planned, the launch operator or the spacecraft operator should make the insurance contract regarding the debris risk and ADR fund will be established based on this insurance. There are two issues about this idea. The first one is that the debris risk insurance can be used for compensating the loss by the debris and the ADR is the way to prevent the occurrence of the risk. So to establish the ADR fund from the debris risk insurance, it needs to change the risk insurance rule. The second issue is that the current fare of the debris risk insurance is too cheap to establish the ADR fund because the collision occurrence possibility is very low. If the fare is raised up enough to establish the ADR fund, it obstructs the space activities by the private companies.

Case 2 is to establish the ADR fund by collecting money directly from the private space faring companies, for example adding tax to the launch. It means that the current private companies promoting the space activity are obliged to deal with the legacy (the debris) and it is the controversial way, especially in setting the fair cost allocation. It will need long time to reach the agreement.

Through the investigation of two cases, we reached the scheme that the country leads the ADR activity and also generates the ADR market inside the country. When the country is selected as ADR executor, then it can avoid the several ADR issues, technology and/or National Security information transfer because the country can carry out the ADR using domestic industry or company, and the ADR Union can just dedicate to promote the ADR operations.

Then two options of case 2 are analyzed with the condition that the ADR executor is selected from the countries. Option 1 is that the ADR Union collects the fund from the participating countries and pays the ADR cost to the ADR executor. Option 2 is that the ADR Union collects the minimum fund from the participating countries to maintain the ADR Union and the ADR executor (country) covers the ADR cost by itself. Figs. 7 and 8 show the image of each option.
In option 1, same as the discussion in adding extra cost to the launch cost, it will need long time to reach the fund allocation agreement. Each country should burden the ADR Union operation fund and it may pressure the domestic space activity budget and will trigger the domestic protest because the budget for the national policy is allocated to the international organization.

In option 2, the ADR Union collects the minimum fund to maintain the Union which is used in compensation for the damage by the ADR execution and the ADR executor should manage the ADR cost by itself. Same as the option 1, the ADR cost comes from the domestic space activity budget, but the country has several choices to carry out the ADR and can utilize the ADR cost to promote the domestic space industry by procuring the ADR satellite from the domestic company. It will stimulate among the domestic space industry to enhance the ADR cost competitiveness. And the ADR Union is free from the negotiation of the ADR cost allocation. The overall analysis shows the option 2 will work well.

5. Process to Establish the ADR International Framework

Although the debris risk is common among the space faring countries and/or parties, there could be objection to establish the ADR international framework because it is a new organization under the UN and the ADR requires actual cost and work.

The Inter-Governmental Organization (IGO) was founded in 1964, and operated until it was renamed INTELSAT, in 1973. The reason starting as IGO with the tentative agreement was that the starting countries thought that utilizing the space communication technology should come first. So they established the international organization and started to use the space communication technology. Then other countries joined the IGO because they noticed the importance of the space telecommunication technology and the permanent agreement was established leading to the creation of INTELSAT.

Following the process of INTELSAT establishment, the four-step process to establish the ADR international framework is proposed. Figure 9 shows the image of establishing the ADR international framework and the detail explanation of each step follows.

#1 Declare ADR Promotion:
Following the declaration of the ADR promotion, discussions among many countries will lead to the agreement with the ADR spirit. No actual work will be performed and the result will be to collect many different opinions. Along with the discussion, letting the existing space debris mitigation guidelines apply mandatory will work effectively to establish the ADR international framework. This step is like the discussion phase among the counties joining IGO, the former organization of INTELSAT.

#2 ADR Union Establishment:
As the affiliated organization with UN, the ADR Union with the administration section and the legal advisory section will be established. The discussion on the ADR number, the ADR rule and the processes stated in chapter 4 will be done to make them being realized. This step is like the IGO starting phase.

![Fig. 7. ADR cost control: Option 1.](image1)

![Fig. 8. ADR cost control: Option 2.](image2)

![Fig. 9. Timeframe to establish the ADR international framework.](image3)
#3 ADR Spirit Penetrations:
Actual ADR will be carried out by the initial participating countries. They will be the advanced space developing countries, such as the United States, Russia etc. Like INTELSAT process, the actual practice of technology (ADR execution) shows its benefit and the ADR spirit will penetrate among many other countries.

#4 Sustainable ADR Operations:
The ADR operations will be carried out sustainably and the ADR spirit will lead many countries to join the ADR Union. This is like the INTELSAT operation phase.

6. Legal Investigation of the ADR Operations

To carry out the ADR, some legal issues should be considered.

6.1. Ownership & jurisdiction
When the ownership of the debris is clearly identified, no one can remove it from the orbit without the permission of the owner and before the ADR operations, the negotiation of the ownership should be done.

From the liability point of view during the ADR activity, it is desired to transfer the ownership to the ADR executor. But the national security policy will thwart to transfer the ownership to some other country and/or party. Then the ADR Union is required to be fair and neutral so that the debris owner can trust to transfer the ownership.

There is an argument that the ownership of debris is lapsed but still the jurisdiction is effective. So along with transferring the ownership, the country where the owner belongs is required not to exercise the jurisdiction.

Transferring the ownership will make the debris owner and the country where the owner belongs be free from the liability caused by the debris and the several procedures concerning the ADR execution. It could be incentive for the debris owner and the country where the owner belongs.

The ADR rule will be established considering these ownership and jurisdiction issues.

6.2. ADR liability
During the ADR operations, the following risks are identified;
- The ADR satellite launch failure
- The ADR satellite mission failure
The ADR satellite fails to remove the target debris for example; it collides with the target debris during the approach and will turn to be the debris.
- Re-entry failure
In order to burn the debris, re-entry operations will be performed and the residual of the debris may hit the ground and cause the casualty.

Though these risks are common in the space activity and can be covered by the space insurance, for the ADR executor, it will bring the troublesome procedure when the risk occurs actually.

Then the ADR rule will clearly state that the ADR Union has the liability of the ADR execution and the participating countries will be exempted from the liability of the ADR execution. This statement will temp the space faring countries and/or parties to join the ADR Union.

7. Conclusion

The space debris issue is one of the most important and difficult issues because its solutions need interdisciplinary studies. The ADR is just one of the technical solutions of the space debris issue and in order to carry out the ADR functionally, efficiently and cooperatively, it requires some international framework.

The ADR International Framework to promote the ADR sustainably was designed based on the systems engineering method, assessing the issues on the ADR. To execute the ADR effectively, some knowledge was found in the existing law system. Discussions that the ADR is carried out as private business or public business lead the ADR funding scheme.

This paper made an attempt to propose the idea to promote the ADR internationally and the further study will show the validation.

References

3) The risk assessment standard to confirm the tolerance design for collision with small debris, JERG-2-144, 2012 (in Japanese).
4) European Code of Conduct for Space Debris Mitigation, Issue 1.0, 28 June 2004, approved by ASI, CNES, DLR.