Criteria for a Time-effective Selection of Active Debris Removal Targets

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論 文 名　：　Criteria for a Time-effective Selection of Active Debris Removal Targets
（能動的デブリ除去ターゲットの時間効果のある選択のための基準）

区　　分　：　甲

論　文　内　容　の　要　旨

This Doctoral research has been conducted in the aim of improving our understanding of space debris' removal conditions to give better care of the future space environment.

The necessity to proceed to ADR is explained though the support of previous results obtained by the author and researches made by space agencies. In this context, this research proposes to evaluate the impacts of removal processes on the evolution of future population. Two independent studies, with two different goals, have been conducted. Both of them demonstrated the necessity to introduce, in the analysis, time consideration, meaning the period when the removal is considered, since physical phenomena, like drag, may have a different impact on the evolution of the number of debris if the time parameter is changed. To perform the research, the environment model that supports this study is presented, together with the program specially created to enable the identification of all fragments in the future. Then, the two application-studies are presented in separated parts. One is linked to the Earth-Moon-trajectory mission scheduled in year 2045 by the company Astroscale PTE. LTD. The other one is linked to the evaluation of the space environment at three periods of time: short, mid and long terms. In this second study, effort is made on the identification of efficient targets, i.e. targets whose removal is expected to efficiently decrease the fragment population at the different time scales. This last study is closely linked to research work made at JAXA. Finally, comparisons between the results obtained at different time scales are made in terms of nature, number and location of targets.

A complete description is made about the tools that were developed and used to conduct the whole research. One of them is called NEODEEM, the Near-Earth-Orbit debris environment evolutionary model jointly developed by Kyushu University and JAXA. The description includes the forces implemented into the model, the launch traffic model, the main modes chosen to perform the simulations, and the initial object population to set up the space environment. Then, taking consideration of the common agreement on the necessity of ADR to reduce debris population in the future, the description focuses on the way to choose the targets that may increase the efficiency of ADR process. Therefore, the second tool known as the Origin-tracking program was developed in SSDL, Kyushu University, by the author. This tool is one of the originality of this research since it was fully developed for the purpose of this Doctoral program. Details are provided about code and adaptation to the data and files given by NEODEEM. This program is based on a back-in-time process that determines the parent objects expected to generate future debris at a particular period of time. This function includes the knowledge of collision events, explosion events, and launch traffic predicted in the environment model.

The first study developed in the Doctoral thesis deals with securing an Earth-Moon-trajectory manned mission scheduled in 2045 by the company Astroscale PTE. LTD. The results from the simulation of the environment in year 2045 are presented and analyzed. First, the goal fixed by Astroscale is defined, that is securing a manned mission to the Moon, with a launch planned in 2045. Then, the process to secure the mission is detailed. To do so, it is necessary to evaluate all possible sources of threats, mainly collision risks with the spacecraft. Therefore, this study can also be considered as an application of the environment modeling and the origin-track program. Indeed, the objects that may intersect the spacecraft trajectory in 2045 have been determined through the mean of 100 Monte-Carlo simulations, and a back-in-time process has been followed through the use of the tracking program in order to identify the parent objects present in initial year that are responsible for the generation of the collision events. This whole way has led to a list of objects in year 2014 that may be removed in order to avoid future collisions in 2045, and then secure the Earth-Moon mission.

The other study, jointly conducted with JAXA is presented through the results obtained at each step (for each period of investigation) until the final comparison analysis. The aim is here to determine the most adequate criteria for a removal targets' selection to match a given period of observation. The criteria in question are mainly the altitude of objects, the number of removed targets, and the implication in chain-collision phenomena, according to different periods of observation. Indeed, it could be demonstrated that one given future required an adequate and particular criterion to select the best removal scenario in terms of efficiency on its population. As a proof, three sub-studies are detailed through the evaluation of ADR impacts at LONG (over 100 years), SHORT (over 20 years) and MID (over 50 years) time scales. The corresponding Top 100 target-ranking lists are also exposed for comparison. Concretely, the results come from the mean of 100 simulations respectively at long, short and mid terms, i.e. projections at 100, 20 and 50 years in the future. The respective studied periods of evolution for the Near Earth environment are extended from year 2009 to year 2109, 2029 or 2059 using the initial population created at purpose. As a first, the environment in the future targeted year (2109, 2029 or 2059) is evaluated through the use of NEODEEM in future mode. This step leads to the determination of future debris. Then, the tracking program is run in order to go back in time until year 2009 so as to identify the origins of the above debris, that is to say the parent objects. In this way, the focus is made on the objects in the initial population that are expected to generate the most debris or the biggest debris in the future. Therefore, a top-100-target list has been built for each of the three studies in order to classify the most dangerous objects in initial year. Each list can be proposed as a ranking list to select priority targets for an efficient removal at the corresponding term. The appropriateness of the potential candidates has been checked a second time through the run of a new simulation (100 runs) that includes the removal of the candidates along the period of analysis (100, 20 or 50 years).

To finalize the study, the results obtained from the three studies have been gathered in order to establish comparisons between ADR effects at short, mid and long terms. An analysis of the zone of high presence of near-Earth objects shows that this zone is expending as going far in the future. This is explained by the increase of fragments in low region (around 800 km high), due to the effects of drag and chain collision events that have been underlined by the origin-tracking process. Then, the targets classified in the three ranking lists (short, mid and long terms) are different and appear at a different rank according to the future that is considered. This observation is closely linked to the consideration of the objects' altitudes explained just previously, but also to the number of targets considered, as well as the zone of removal. Graphs and lists of targets are also presented to support the analysis and to underline the necessity to differentiate the way of considering ADR according to the period of action each organization has fixed as a goal.

Lastly, all the results are gathered so as to propose new perspectives to go further this study, mainly by underlying the possible adequacy of the "double-check" process (using the tracking program) to other researches dealing with the problem of space debris. May this research be considered as a small stone to the giant edifice of space environment securing.