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Conceptualizing an economically, legally, and politically viable active debris removal option ☆

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ABSTRACT

It has become increasingly clear in recent years that the issue of space debris, particularly in low-Earth orbit, can no longer be ignored or simply mitigated. Orbital debris currently threatens safe space flight for both satellites and humans aboard the International Space Station. Additionally, orbital debris might impact Earth upon re-entry, endangering human lives and damaging the environment with toxic materials. In summary, orbital debris seriously jeopardizes the future not only of human presence in space, but also of human safety on Earth. While international efforts to mitigate the current situation and limit the creation of new debris are useful, recent studies predicting debris evolution have indicated that these will not be enough to ensure humanity's access to and use of the near-Earth environment in the long-term. Rather, active debris removal (ADR) must be pursued if we are to continue benefiting from and conducting space activities. While the concept of ADR is not new, it has not yet been implemented. This is not just because of the technical feasibility of such a scheme, but also because of the host of economic, legal/regulatory, and political issues associated with debris remediation. The costs of ADR are not insignificant and, in today's restrictive fiscal climate, are unlikely/to be covered by any single actor. Similarly, ADR concepts bring up many unresolved questions about liability, the protection of proprietary information, safety, and standards. In addition, because of the dual use nature of ADR technologies, any venture will necessarily require political considerations. Despite the many unanswered questions surrounding ADR, it is an endeavor worth pursuing if we are to continue relying on space activities for a variety of critical daily needs and services. Moreover, we cannot ignore the environmental implications that an unsustainable use of space will imply for life on Earth in the long run. This paper aims to explore some of these challenges and propose an economically, politically, and legally viable ADR option. Much like waste management on Earth, cleaning up space junk will likely lie somewhere between a public good and a private sector service. An international, cooperative, public-private partnership concept can address many of these issues and be economically sustainable, while also driving the creation of a proper set of regulations, standards and best practices.

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1. Introduction

This paper will explore briefly the non-technical challenges associated with fielding an active debris removal (ADR) concept, propose a method of evaluating a concept for feasibility against a few non-technical criteria, and then apply this method to one case study, the Swiss Space Centers CleanSpaceOne project. The paper will begin with some background information on the current debris situation in high-use orbits and several of the currently proposed ADR concepts. It will then give a brief overview of the economic, political, and legal challenges associated with ADR and then propose some criteria for evaluating our case study. The intent behind this paper is to identify what elements would be necessary for an ADR concept to be considered economically, legally, and politically viable; thus addressing those non-technical hurdles satisfactorily. The authors hope to contribute to the ongoing discussion about ADR and help advance the likelihood of debris remediation in the near future.

2. Background

In over half a century of space activities, more than 4800 launches have placed some 6000 satellites into orbit, of which less than a thousand are still operational today. The U.S. Space Surveillance Network regularly tracks and maintains in its catalog an estimated 15,000 items in orbit, but this only includes objects larger than approximately 5–10 cm in low Earth orbit (LEO) and 30 cm to 1 m at geostationary altitudes (GEO). Only 6% of their cataloged orbital population represent operational satellites, while 38% can be attributed to decommissioned satellites, spent upper stages and mission-related objects (launch adaptors, lens covers, etc.). The remaining 56% originates from more than 200 in-orbit fragmentations, which have been recorded since 1961. Except for a few collisions (less than ten accidental and intentional events), the majority of the 200 break-ups were explosions of spacecraft and upper stages typically due to leftover fuel, material fatigue or pressure increase in batteries [1].

Several studies have already assessed the current state and future evolution of orbital regions showing the increase in space debris threats coming from existing debris and future launches. In 2002, the Inter-agency Space Debris Committee (IADC) developed a series of mitigation guidelines that were adapted for the 2007 United Nations (UN) resolution [2]. These guidelines, although important, only address active satellites currently in orbit and future launches. Despite the serious threat posed by existing orbital debris, which regularly endanger active operational satellite [3] and manned operations [4], they were not addressed by these international initiatives. About 89% of the roughly 1000 operational satellites currently in orbit are either in LEO (300–2000 km altitude) or GEO (36,000 km altitude) [5]. In LEO, satellites and orbital debris are quite widely scattered in terms of altitude, inclination and ascending node. This, in combination with the fact that orbital speeds are considerably higher than in the GEO case, makes both the amount of crossings and the relative velocities of the bodies during these crossings very high on average. The wide and random distribution of objects in LEO also implies that a system of graveyard orbits is not possible like it is in GEO. Another critical issue is that International Space Station operations are performed at low LEO altitudes, making it essential that the risk of collision is minimized to the greatest possible extent in this area for safety of human spaceflight. On the other hand, objects in LEO experience a certain amount of atmospheric drag causing them to gradually spiral down towards Earth, a process of which the duration depends on the object's altitude, area-to-mass ratio and solar activity. Unlike the LEO case, the majority of satellites at GEO altitudes are located in a confined ring in which geosynchronous motion is possible. Due to the higher altitude, and thus distance from Earth, detection of objects in GEO is limited to those larger than 1 m. Furthermore, debris in GEO will orbit the Earth for many centuries, as the stabilizing effect of atmospheric drag is absent. However, because the semi-major axis and thus the circumferential area of geosynchronous orbits is so large, spatial densities in the GEO band are still two or three orders of magnitude lower than in the most crowded regions of the LEO region [6]. In addition, because of the uniform motion of all objects and their high altitude, relative velocities are substantially lower than in the LEO region, leading to less severe collisions. Finally, it should be noted that after their mission lifetime, GEO satellites can be injected into a quasi-non-decaying graveyard orbit reducing the hazard for other and future missions.

Therefore, threats from orbital debris are greater in the LEO region due to a combination of high debris concentration, large number of crossings and high relative velocities [7]. The combination of these factors may lead to an exponential growth of debris objects by future cascade of collision [6] as outlined in Fig. 1. The cascade effect, or Kessler syndrome [8] is based on the fact that every intact satellite or other large body, has the potential to fragment into numerous smaller pieces due to a collision with a debris object or other active spacecraft. Many resulting fragments will then, in turn, pose a certain risk for the catastrophic destruction of another large orbital body, and so on. Once a certain debris density has been reached, this effect causes the debris population to continue growing, even without the launch of new objects.

Space debris in LEO can be divided into three categories in terms of size, potential risks and possibility of detection.

An important fact is that although the number of debris objects is many times higher for the small-sized debris, nearly all the mass of the LEO debris is concentrated in the large objects (Table 1). In the long term, the large >10 cm objects pose a greater risk. Their significant mass means that they could create large clouds of new, smaller, high-speed debris should they even be involved in a collision, thus adding substantially to the problem. Moreover, although the number of collisions between an intact object and a fragment has higher probability then impacts between two intact objects, since the latter contains more mass in the process, the result in terms of contribution to the future debris population is almost the same. Therefore, an effective and technologically feasible method for ADR should focus on intact objects that also have the advantage of a known size, mass and shape.

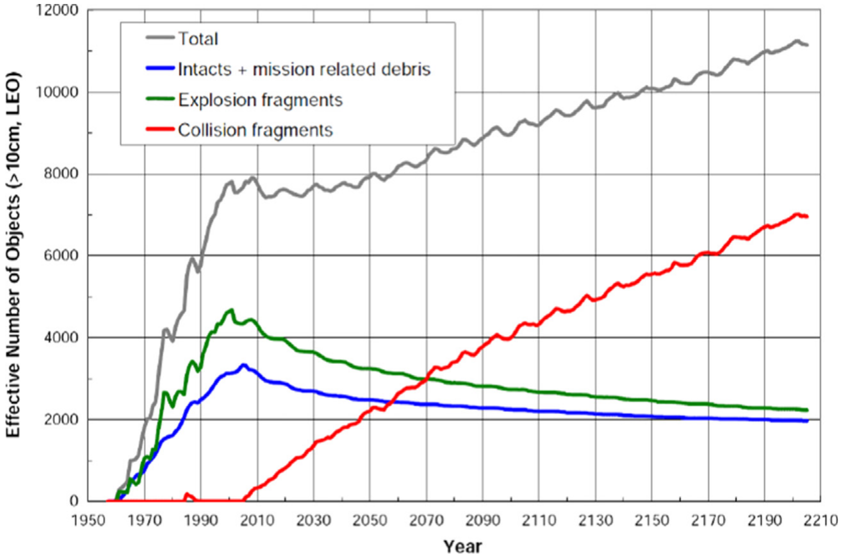

Fig. 1. Future model of amount of large debris objects in the LEO region, based on a "no-launches after 2006" scenario [9].

Table 1
Space debris according to a generally accepted categorization [9].

Size (cm)	Potential risk	Detection	Number	Mass fraction (%)
> 10	Complete destruction	Tracked	21,000	> 95%
1–10	Partial/total destruction	Partially tracked	500,000	< 5%
< 10	Damage, can be shielded	Not tracked, statically assessed	> 100 million	–

A study performed by NASA, using their LEGEND debris evolutionary model, investigated the future of the LEO environment considering compliance with UN guidelines and a repetition of the 1999–2006 launch cycle, which is an underestimation of the future situation according to more recent forecasts [10]. The scenario was completed with the assumption of an ongoing space debris removal program beginning in 2020. According to the cases analyzed, illustrated in Fig. 2, five large objects would need to be removed per year to stabilize the LEO debris environment. The necessity of an efficient ADR program is highlighted by these results.

3. Review of non-technical challenges

3.1. Legal and political challenges

Since the seventies scientist opposed the idea that space could be exploited without limits. Nowadays, space debris seriously threatens sustainable use of space, as it is considered to become a major navigational hazard to functioning (operating) satellites. The cascade effect previously explained has increased the number of warnings and collision avoidance maneuvers. Furthermore, space debris can also endanger life on earth, since pieces of space junk can survive re-entry into the atmosphere and fall on Earth where they could cause injury or death, not to mention damages to property and environment. Although there are different sources of space debris (break up of spacecraft and rocket bodies, mission related debris, and non-functional satellites), there is no internationally recognized definition about what is and what is not space debris.

US, Europe and Russia, are tacking actions to monitor debris, but the only country that has formulated a strategy in this regard is the US [11] so far. However, just monitoring together with mitigation are passive means to face the debris situation. The passive solutions should be combined with an active removal of debris, which is currently not incentivized by the unclear definition of debris and the complicated liability and licensing regulations that expose contingent public and private efforts to high risk.

The international space law framework is not even in a position to effectively deal with issue of space debris creation and mitigation [12]. Moreover, space debris are not even mentioned in the Article IX of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty), entered in force in 1967, which provides for protection of space environment. The lack of definition makes impossible to recognize which objects can be removed. However even if we were able to make such a distinction, removal would have been complicated due to international regulations that apply to space objects. Art III of the Convention on International Liability for Damage Caused by Space Objects (Liability Convention), ratified in 1972, establishes that, in the event of damage being caused elsewhere than on the surface of the earth to a space object of one launching State or to persons or property on board such a space object by a

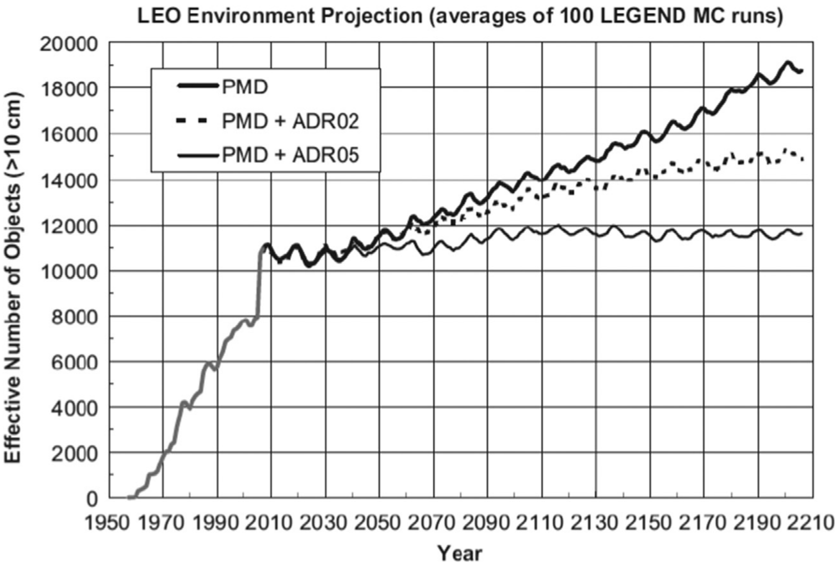

Fig. 2. Comparison of three different scenarios. From top to bottom: post-mission disposal (PMD) according [2] (removal within 25 years), PMD and Autonomous Debris Removal (ADR) of two objects per year, and PMD and ADR of five objects per year.

space object of another launching State, the latter shall be liable only if the damage is due to its fault or the fault of persons for whom it is responsible [13].

Further analysis of the Liability Convention also helps to understand that there is no legal provision, which imposes any clear obligation upon the states to prevent the space debris creation or to undertake the mitigation measures. However the consequences of liability are mitigated since whenever a similar situation occur states generally go into negotiations and compensation payments to avoid fully liability. Article III of Liability Convection together with article VII of Outer Space Treaty declaring that Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies [14], establish a regulatory framework that does not facilitate debris removal, since each debris should be identified and its removal negotiates with the launching state that is the only one that had jurisdiction and control over that object. There is a possibility that the launching state abandon the space object, determining the fact that this latter could be removed without permission, and however the launching state remains liable for the space object and damages caused by it.

Considering the number of debris such practice is not doable, especially in the commercial framework, which is becoming important in space activities. Some object may serve important or secret purposes or might be subject of US International Traffic in Arms Regulations (ITARs) or similar. ITARs in particular establish that spacecraft and related cannot be transferred to any foreign person (company or state) without prior approval of US State Department. It applies if the object is American or carries American technologies. In practice since very few objects do not belong to this category ITARs free objects are a limited number. This is not the only reason why there are no florishing activities of ADR. If during ADR attempt any damage is caused to a third party the launching state of the company carrying out the ADR will be held liable and be required to pay a compensation to claimant state. This reimbursement is a condition of the license issued to private companies. ADR are risky because of the crowded environment and lack of space situational awareness as well as traffic management capabilities, therefore such close on the license is highly discouraging. The present international space law conventions and instruments fail in creating a legal regime for ADR and even the relatively new Space Debris Mitigation Guidelines fails in clearly providing for a legal regime, which would impose responsibility upon the states to undertake responsibility for creation of space debris [15].

According to the above considerations, in order to foster active debris removal the international community would need to take at least a series of actions as follows:

- Agreed on a shared definition of Space debris in order to enable space farers actors to proceed with the development of practices and technology needed to do ADR.
- Definition of a pro-active legal regime to envisage a public private partnership method of responsibility sharing.
- Develop greater technical capability in order to perform ADR.
- Develop more accurate monitoring capabilities in order to classify and share information about space debris develop transparency and confidence building measures in this regard establish an organization to track and store data about orbital debris.

- Develop a more efficient traffic management system that will make the operation of ADR less risky and thus reduce licensing costs.

3.2. Economical challenges

The goal of this section is to identify what commercial and economic considerations there are when analyzing trades for active debris removal options. There are two sides to this type of trade. The first is the cost of an ADR architecture. The second is the value the activity provides that can be recovered in some manner. This second aspect of the problem must, in part, be addressed by policy approaches and there are many different frameworks that this could be accomplished in. Examples of these frameworks include an international tax or license on launch operations. In such example, the proceeds would then be used by the taxing authority to purchase ADR services from a commercial provider. Alternatively, if the owner of certain debris that needed to be removed was identified, the owner would pay a fee to have it removed. Another option could involve those assets in potential hazardous areas that could pay a tax on that "*real estate*" to pay for commercial ADR services or they could pay directly given a particular threat.

After *who should pay the bill* is defined, *how much* must be addressed. Given the particular payer framework, to assess the value it is important to know how much the stakeholders value the activity. Depending on the cost of the activity, which would be traded against several possible 'targets' with several alternatives, the cost and value determination could be made. If the cost of the activity is less than the value proposition and less than the cost of the alternatives (such as collision avoidance maneuvers), the activity should be pursued and the stakeholders would use their payer structure to procure the service. The cost of collision avoidance maneuvers has been already analyzed (but just in term of propellant used) in the work of Jenkin and Peterson [16]. Although the economic considerations have to be derived by the context, it provides some considerations the value of such mitigation measure. The value of removing debris can be established instead by determining the risk that debris would otherwise have to nearby space assets. The manner in which a value proposition can be established depends on several factors including who the stakeholders are, the time horizon used and how one treats risk. This value proposition determination must take into consideration collision risk due to debris and its potential growth (both catastrophic risk and simply mission-limiting risk). In addition it needs to consider the time-discounted value of the space assets at risk (both present and future assets), and finally the cost of reducing that risk at different points (i.e. costs of removing debris early while still potentially intact or after a collision or break-up event when the debris is more dispersed [17]). This risk can then be applied not just to assets that are immediate risk of a collision but also at a less-likely and more time-discounted, but potentially still non-zero risk, of future collision with a secondary effect. One of the principal barriers to ADR is the development of the applicable technology and a consistent ADR technology road-map. To convince stakeholders on the service offered, it should be considered also the possibility of a *build it first* demonstrator. A demonstrator mission, either privately funded or supported by government defense or space agency, would solve some of the technical issues, setting a baseline mission cost and resolving some of the operational issues. Once the demonstrator has proven the concept, not only the future application would become more real disclosing the technology development costs but also appropriate frameworks will be established making commercialization more likely. National space agencies have followed this approach of covering the developmental costs and by doing so establishing many of the procedures and policies that can then be applied by economic forces, in different fields (telecommunications satellites, launchers, space station and in the far future maybe space mining). One of the compelling reasons for having a public element in debris policy could be to establish longer time horizons for debris-related risk discounting as this might see past a potential cascading future and have the time to act appropriately before that risk is realized.

Assuming that there the legal or policy concerns are resolved and will not impede commercial constraints on ADR then the primary commercial objectives of a conceptualized ADR option are

- Clearly identified value proposition for clearly defined stakeholders.
- Modeling of risk to multiple assets over a discounted time horizon.
- Identification of alternatives and trade study of those options.

4. Assessing ADR systems

The above considerations have brought the authors to start developing an objective method to multidisciplinary assess ADR projects, in order to identify potential successful candidate but also to suggest a path to follow.

4.1. Scorecard method

The scorecard method is a strategy performance tool that is used to keep track of criteria considered important of the performance of the system. In this case, the scorecard method defines a methodology to assess ADR projects, according to specific criteria. The method is ultimately about choosing measures and weight. The criteria are summarized as indicators that measure the weight of the criteria itself against the others. All the criteria identified are presented with value. The method takes especially into account the legal and policy framework but also considering the technical and economic criteria to discern among different kind of projects and it must be considered a first proposal to be developed further with addition of new indicators.

4.2. Scorecard method for ADR projects

The scorecard assigns for each framework 9 points which are the measures of the project's effectiveness in the specific field. Therefore, 9 points are given to Legal Framework (*LF*), Policy Framework (*PF*), Technical Framework (*TF*) and Economical Framework (*EF*). In this framework, the single criteria are evaluated and they would have a certain value, obviously less than the total for the framework. The criteria and the framework will be organized in a scheme, representing all the possible solution considered for an ADR mission. The scheme will also offer the "perfect" line, following which, it will be possible to see all the criteria needed to acquire the best score. The score represents an assessment of the feasibility of the projects, considering all together the frameworks involved in a typical ADR mission. The scorecard method does not want to provide a complete and organic description of the ADR project assessed, but it can provide a simple and easy-to-use indicator to determine the overall value of the ADR projects analyzed.

4.3. Policy and legal framework

The *PF* and the *LF* are considered together, giving the close connection between the two frameworks. Five criteria have been chosen, reflecting the influence of current laws, strategy, countries involved, composition of the project and danger represented by a possible military use of the technology used for debris removal.

(a) Nationality
(b) Strategy
(c) Type of cooperation
(d) Legal framework
(e) Possibility of weaponize

4.3.1. Nationality

The nationality of the project is rather important, because it involves many aspects to take into account when dealing with space, in general. The nationality influences not only the technology that can be used and the economic resources available, but also, in the current legal framework of international space law, the objects that can be deorbited (Table 2).

Given their resources and the legal framework, a project solely carried out by initiatives in US or Russia would give a minimum score, due to the reasons abovementioned. International projects would instead have a higher score. The score has been decided in relation at the nationality of the orbiting debris in LEO. The number of Russian-American debris is many times higher than the other countries together; therefore, their score is higher.

4.3.2. Strategy

Higher value is given if a project is within an elaborated strategy to tackle the space debris problem provided by agencies or other kind organizations. The strategy would guarantee appropriate involvement and commitment to face the challenged posed at legal, technical and economic level.

Table 2
Summary of the scorecard value given for the Nationality criteria.

Country	**Project**	
	National	International
US	1	3
Russia	1	3
Europe	0	1
China	0	1
Japan	0	1
Others	0	1

4.3.3. Type of cooperation

The cooperation criteria want to emphasize the importance of cooperation in debris removal projects. Therefore, in the frame of international project, a higher score will be given to multilateral cooperation, while bilateral cooperation will not acquire any score because of the cooperation itself. Having a large number of participants, is not only important to decrease the overall cost of development and operation, but also influences the object that can be deorbited.

4.3.4. Legal framework

The possibility that the method used for ADR could be easily implemented within the existing institutional and legal framework of international space law. Active removal of debris is currently not incentivized by the unclear definition of debris and the complicated liability and licensing regulations that expose contingent public and private efforts to high risk. The realization of the condition of definition, liability and licensing provide the projects with a certain framework within an ADR mission can be, according to the case, more or less effective.

4.3.5. Weaponize

Probability of military or non-peaceful use of outer space due to the method used for ADR leading to violation of Outer Space Treaty and international space law framework (Table 3).

4.4. Technical framework

4.4.1. Technology readiness level

Technology Readiness Level (*TRL*) is a measure used to assess the maturity of evolving technologies (devices, materials, components, software, work processes, etc.). When a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem. Instruments and spacecraft sub-systems are on a scale of 1–9. Levels 1–4 relate to creative and innovative technologies before or during the mission assessment phase. Levels 5–9 relate to existing technologies and to missions in definition phase. When

Table 3
Summary of the scorecard value given for the remaining criteria.

Strategy	Elaborated strategy (1)	No strategy (1)		
Type of cooperation	Bilateral (0)	Multi-cooperation (1)		
Legal framework	Within *LF*		Creation of *LF*	
	Liability (6)	Licensing (5)	Liability (4)	Licensing (3)
	No *LF* (0)			
Weaponize	Yes (−6)	No (0)		

the TRL is too low, then it must be taken into account possible delays or cost over-runs [18].

4.5. *Economic framework*

Although different considerations have been discussed in the previous sections about the economic and commercial challenges, in this first phase of the study, it was decided to focus on just three initial criteria. In the next phase, a broader and detailed analysis of everything involved will consider different aspects of the economic framework.

4.6. *Definition of the business*

Just public or private initiatives, for the above considerations are not enough to completely tackle the issue. Therefore, a public–private partnership is the preferred solution to deal with ADR projects. The scorecard values considered reproduce this consideration: Public (1), Private (1), Public–private partnership (2).

4.7. *Estimated cost per mission*

The estimated cost per mission (*ECM*) is a measure of the total cost of the mission, not including the development phase (Table 4).

Within the definition of “cost per mission” is included manufacturing, launch and operation. Although it may seem too challenging to achieve the maximum score for this specific card, ADR activities should probably be carried out for many years in order to decrease the increasing trend regarding the number of debris in orbit [19], therefore it is mandatory to achieve a low *ECM*. Some of the costs comprised in the *ECM* (i.e. manufacturing) will likely decrease mission after mission, however, the launch will always represent probably the biggest cut of the total cost for traditional mission (ADR-dedicated payload). It would be important then that every ADR initiative would explore ways to decrease this recurring cost, finding innovative solutions to carry out ADR mission (e.g. “piggyback” solutions).

4.7.1. *Estimated cost per kg deorbited*

The estimated cost per kg deorbited (*ECD*) is a measure of the cost in relation to the missions capability. In fact ADR projects are sometimes accused to be not efficient and thus not affordable. *ECD* will define the cost-effectiveness for the analyzed missions.

The value presented in Table 5 is estimated considering the necessity to deorbit especially the bigger debris (e.g. upper stages), which will represent the bigger source of new debris in the case of collisions or explosion. *ECD* is substantially different from *ECM* because it considers the target of the mission in relation with the actual cost of the mission itself. The value does not consider the cost of launch, it is a parameter of the efficiency only of the orbital mission.

Table 4
Scorecard values for the Estimated Cost per Mission criteria.

ECM (**million** $)	**Score**
$ECM > 300$	0
$200 < ECM < 300k$	1
$100 < ECM < 200$	2
$50 < ECM < 100$	3
$ECM < 50$	4

Table 5
Scorecard values for the Estimated Cost per kg deorbited criteria.

ECD (**thousand** $)	**Score**
$ECD > 50$	0
$40 < ECD < 50$	1
$20 < ECD < 40$	2
$ECD < 20$	3

5. Case study

A case study is needed to test the method and verify the criteria proposed.

5.1. *CleanSpace one [20]*

As case study for in this paper, it has been chosen the Swiss Space Centers CleanSpace One project. The project is intended to demonstrate technologies for future debris removal missions of small satellites and it should lead to an ADR satellite in 2015–2016. The first CleanSpace One prototype has been planned to deorbit one of two non-functioning Swiss satellites. Once launched, CleanSpace One will have to match the target satellite's orbital plane of 630–750 km above sea level. In order to do so, it will have to adjust its trajectory, using an ultra-compact electrical motor, still in development. Then, it will have to grasp it with a grabbing mechanism still in development and stabilize it while moving at 28,000 km/h. Once CleanSpace One has captured its target, the two of them will head out

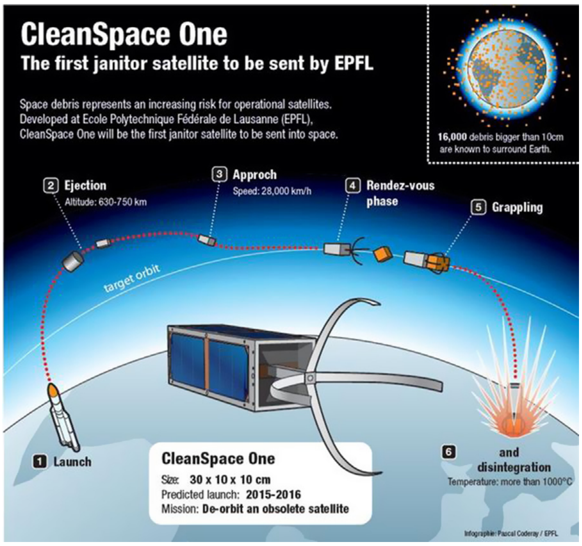

Fig. 3. A CleanSpace One info graphics [20].

of orbit and towards the earth, where they will both burn up in the atmosphere as shown in Fig. 3. A line of CleanSpace-inspired satellites is planned for the future, each one capable of capturing and destroying a different type of satellite.

5.2. *CleanSpace Ones assessment*

Clean space is a project elaborated by the Swiss Space Center. The Swiss Space Center is a unit attached to the Vice-Presidency for Academic Affairs of the cole Polytechnique Fdrale de Lausanne. It has however very close links to the School of Engineering ("Sciences et Techniques de l'Ingnieur") for educational purposes. Its members are industries and academic institutions. This institution is not properly part of the government despite the fact that it is supported by the national ministry of education. However it is not included in the decision making process of the country. The membership is not limited to Swiss industries or universities; nonetheless, participation is mostly from Switzerland based companies. The effort made by the numerous universities and 19 members of the center has produced the results that the center has started a program for the development of technologies for nano-satellites which should remove debris in orbit around the earth. Within this framework the project Clean Space One has find his reason dtre. Clean Space One went public on February 15, 2012, to demonstrate rendezvous and capture technologies and operations. However the paper provided by the EFPL, in June 2013, does not give a clear definition of what kind of debris the project is targeting, outside of the size of it, neither it explain how the project would overcome security issues regarding sensitive technology.

Swiss Foreign-Policy Strategy 2012–2015 is based on the following fundamental principle, i.e., the rule of law, universality, and neutrality. It furthermore adds the notions of solidarity and responsibility. Stability in the rest of the world will constitute a third priority, implemented by way of international cooperation (development cooperation, cooperation with Eastern Europe, and humanitarian aid), along with activities in the domain of peace-promotion, respect for human rights, and fostering the rule of law. For these reasons, although Switzerland is not a space-fairing country, it looks like it could be a suitable country to start active debris removal initiatives, which deal with security and complicated legal issues. However, the scorecard result is poor (7 out of 36 points available), mainly because of the lack of cooperation with countries with a more significant presence in space and the fact that, currently, the project is aimed just to nanosatellite.

6. Conclusion

This paper has explored what an economically, politically, and legally viable active debris removal concept. It has proposed a method of evaluation based on a scorecard with criteria in each of these non-technical areas and applied it to a case study. Future works, carried out within the SGAC Space Safety and Sustainability Project Group, will consider a more detailed analysis of the economic factors to justify ADR missions, in particular, it will be analyzed the cost of ADR versus other practices commonly used to avoid collisions (collision avoidance maneuvers, non-optimal choice of orbit, accurate tracking of debris, heavier structure to resist impacts etc.). In addition, the scorecard method will be expanded and new case studies will be considered (DLR DEOS, ESA, Samara Space Centre) .

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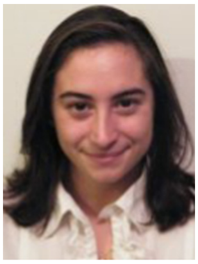

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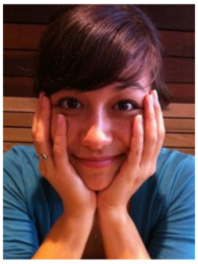

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