Space Debris in the Geosynchronous Earth Orbit: Debris Environmental Asssessment and its Implications on Cost and Benefit Analysis. Mari Takagi[1] and Tetsuo Yasaka[2] [1]Dept. of Earth and Space Sciences. of California at Los Angeles, Los Angeles, CA 90095-1567, U.S.A (mtakagi@ucla.edu), .[2]Dept. of Aeronautics and Astronautics, Kyushu University, 6-10-1 Hakozaki, Fukuoka, 812-8581, Japan (yasaka@aero.kyushu-u.ac.jp)

Introduction: The increase of space junk and threats to commercial space activities in the Geosynchronous Earth Orbit (GEO) predictably caused concerns for the environmental consequences over the long term. A variety of work on space debris research, including on detection, modeling, protection and mitigation measures, has been clearly recognized and conducted over recent decades, however there are no international legislation or administrative regulations in place yet to impose specific debris mitigation requirements. Hence, there has been a gap between egoistical and altruistic utilization of space environment leading to a serious "problems of commons" in the Geosynchronous Earth Orbit. This paper makes an attempt to explore the way to bridge this gap by conducting an environmental Cost-Benefit Analysis (CBA) in the specific context of proposed mitigation measures, including new legal standards such as lower satellite explosion rates, re-orbit maneuvering, and restrictions on the number of launches.

Methodological Framework: From the Environmental Assessment to the Cost-Benefit Analysis: The computer model that forecasts the long-term GEO space debris environment, GEO-EVOL [1][2], was used to run different mitigation scenarios. In the model, satellite objects in the GEO region are placed into several categories based on their orbital properties: geostationary orbit (GST), orbit that intersects with the GEO altitude by shifting their orbital planes with a period of 54 years (GSY), and orbits that are slightly higher or lower than the GEO altitude where they have almost no interactions with operational satellites in geostationary orbit (DRL, DRH). Fragmentation debris that remains in the GEO altitude is also incorporated. Rocket bodies, which usually do not intersect with the GEO altitude, are not assigned in this model. The orbital population growth is estimated in relation to predicted future operations, explosions and collisions based on these categorized objects.

The economical evaluation is done within the framework of CBA to compute the total financial loss due to collisions, explosions, and space debris mitigations. The calculation procedures for the analysis were applied referring to the previous study conducted by Klinkrad et al. [3] as shown below.

Total Financial Loss = (0.5)*Mission Cost *Catastrophically Damaged Operational Spacecrafts + End-of-life Maneuver Cost

End-of-life Maneuver Cost = Fuel Mass*Launch Cost per Unit Mass*Spacecrafts Re-orbited

It is important to note that this does not include partial satellite damage by smaller debris assuming those will not cause any functional damages. It is also assumed that the catastrophically damaged satellites are soon to be replaced with no time intervals, and those damages by collisions and explosions occur after half a satellite lifetime.

The CBA also considers possible spacecraft modifications of the system and discount rate, which could affect the amount of cost necessary for the debris mitigations.

Results: The results show that the number of fragments will increase rapidly with the current explosion rate, and this hastens risks to future satellite operations. Without putting any actions to mitigate the debris in the GEO, the collisions probability will soon reach a critical level for operational satellites to operate, and hence the cost for mitigation is proved to be urgent.

The most cost effective measure to reduce the formation of space debris is to avoid explosive breakups through passivation: venting residual propellant, switching off battery charging lines, or relieving pressure vessels. However, in order to assure the long-term safety in the GEO environment, both the explosion avoidance and re-orbit maneuver are necessary.

Discussions and Conclusions: One of the biggest problems that we encounter at present is that the satellite manufacturers and operators seem to lack a sense of impending crisis on space debris. Increasing awareness of space debris hazards and the recognition of the importance of taking precautionary actions to prevent further degradation in the GEO environment are essential for satellite industries, manufacturers, space agencies, media, and general public as a first step. Along with this, some international regulatory body should be established and enforce rules to prevent the formation of space debris to avoid countries and private companies to have an incentive to lower costs by avoiding technical safeguards. Creating international funds to pay compensation for damages caused by non-identifiable space debris, which should be financed by the polluters [4], might also be effective to encourage nations to adopt national legislation on space debris, and to impose space industries for responsive strategies. Further commitment to have an international consensus on mitigation practices by Inter-Agency Space Debris Coordination Committee (IADC) and endorsement of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) for the action undertaken by IADC on space debris mitigation would certainly be necessary to ensure safety and sustainable development in the GEO.

References: [1] Hanada, T., H. Hirayama, and T. Yasaka. (1999) GEO Debris Environment: A model to forecast the next 100 years. Advances in Space Research, 23, 191-199. [2] Hanada, T. and T.Yasaka. (2002) Orbital Debris Environment Model in the Geosynchronous Region. Journal of Spacecraft and Rockets. Vol. 39, No.1. 92-98. [3] Klinkrad et al. (2001) Update of the ESA space debris mitigation handbook. Proc. Third European Conference on Space Debris, European Space Operations Centre (ESOC), Darmstadt, Germany, 19-21 March 2001 (ESA SP-473) [4] Smith, C. (1995) The need for an international legislation on space debris. SPIE Vol. 2483, 121-131.