Available online at www.sciencedirect.com

SciVerse ScienceDirect

Advances in Space Research 52 (2013) 685–695

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Value analysis for orbital debris removal

Leonard Vance[a,*], Allan Mense[b,1]

[a] Mail Stop TU/M10/9, P.O. Box 11337, Tucson, AZ 85734-1337, USA
[b] Mail Stop TU/840/8, P.O. Box 11337, Tucson, AZ 85734-1337, USA

Received 3 January 2013; received in revised form 22 April 2013; accepted 24 April 2013
Available online 8 May 2013

Abstract

This paper presents methods for deriving first order monetary benefits from removing individual debris objects in high value sun-synchronous orbits. These analyses are intended to serve as an economic metric by which competing debris removal methods can be evaluated.

Orbital debris flux level estimates from NASA's updated ORDEM2000 model are used to establish small debris population estimates. When combined with the replacement cost of satellites in sun-synchronous orbit, the present value of removing individual small (0.5 cm–2.0 cm) objects from orbit is derived.

Large object removal value is more complicated due to the necessity of incorporating effects of impact fragmentation observed with any object about 10 cm or larger. Breakup models published by NASA (Johnson, N.L., Krisko, P.H., Liou, J.C., Anz-Meador, P.D. NASA's new breakup model of evolve 4.0. Adv. Space Res. 28 (9), 1377–1384, 2001.) provide a basis for establishing fragmentation statistics. Assuming the current population of operational sun-synchronous satellites, removal value is then derived via present value analysis.

Keywords: Orbital debris; Economics; Remediation

1. Introduction

Events during the last several years have highlighted the deteriorating situation posed by the proliferation of orbital debris in low earth orbit (LEO). The Chinese ASAT test on Jan. 11, 2007, (Covault, 2007) was followed 25 months later on Feb. 2, 2009, by the inadvertent collision of Iridium 33 and Cosmos 2251 (ODQN, 2009). The combined impact of these two events put orbital debris hazard into the collective consciousness. It also provides the first real opportunity to establish activities for removing existing debris objects before they fragment and eventually produce an untenable LEO environment.

A pictorial of the current LEO objects is shown in Fig. 1. Recent work by ESA and NASA predict that even if no additional objects were launched into LEO starting today, the number of tracked objects in orbit will grow exponentially over time due to satellite collisions producing large numbers of fragments. Eventually, this feeds a chain reaction of collisions, ultimately making low earth orbit unusable. This effect is named the Kessler syndrome (Kessler and Cour-Palais, 1978) after the NASA scientist who first recognized it.

Recognizing this situation, a growing number of researchers began discussing the possibility of actively removing debris from orbit. However, a technique is needed to establish the value of doing so in order to establish credible industry requirements for remediation of the LEO environment.

This paper establishes a technique for deriving the value of removing orbital debris in two steps. First, the value of small debris objects is derived through an analysis of the threat posed by a single debris object upon the

---

* Corresponding author. Address: Raytheon Company, USA. Tel.: +1 520 746 2300, mobile: +1 520 331 8175; fax: +1 520 746 2102.
E-mail addresses: ldvance@raytheon.com (L. Vance), Allan_T_Mense@raytheon.com (A. Mense).
[1] Tel.: +1 520 794 4720, mobile: +1 520 907 7786; fax: +1 520 794 9682.

0273-1177/$36.00 © 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.04.024

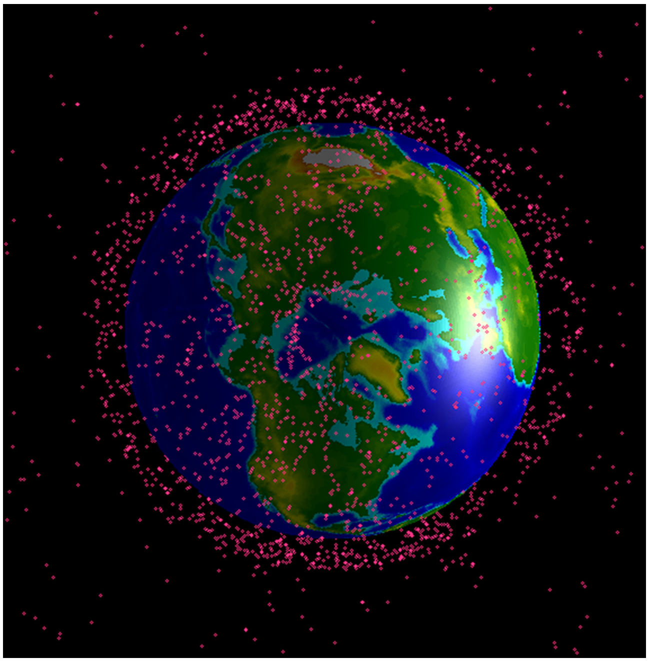

Fig. 1. Cataloged debris passing through 880 km altitude.

calculated total value of all operational satellites in orbit. Second, the large object removal value is calculated by taking into account the number of objects produced in a fragmenting collision, and combined with the small debris object value (from above) and the number of years in the future when impacts occur using present value analysis. Trades are then done to establish an understanding of how removal value varies with variations to chosen key parameters.

2. Materials and methods for establishing removal values

The body of this paper provides a technical description of the methodology used to establish the removal value for debris objects and necessarily jumps back and forth between several sources at different times in the analysis. Fig. 2 provides a template of linear instructions that are necessary to reproduce these results, and provides a methodology for updates. Each of the steps is accompanied by a reference to the section in this paper explaining that particular item. The flow of the resulting diagram establishes small object removal value before proceeding to larger objects.

Specific techniques establishing the values specified in Fig. 2 may vary between users. The authors of this paper chose a set of publically available databases permitting proof of concept for the overall technique while providing a first cut at substantive results.

Establishing the orbital area of interest through analysis of the density of satellites using the Space Track (2010) database, UCS (2009) or other existing catalogs initiates the removal valuation process. Debris flux levels are next established in step 2 for the chosen orbital regime using NASA's ORDEM2000 (ORDEM2000, 2009) software. Step 3 determines the statistics associated with operational assets in this orbital regime using the UCS database to establish the number of operational satellites and their mean mass characteristics. Following this, the curve fit equation derived from the RAE (2001) database establishes a cross-section distribution for satellite busses.

Interest rates are a key part of present value analysis, and this paper takes long-term inflation indexed bond rates from the Federal Reserve (2009) as its basis for the time value of money in step 4. Small object removal value is thereafter a straightforward arithmetic calculation using the process described in Section 4.1.

These initial steps provide the value for small object removal necessary to establish large object value. Step 6 begins this effort by assuming a candidate removal object along with its mass and cross section. Individual satellite mass values can be discerned from the UCS database, and cross sections can be derived from the RAE database or the curve fit estimate derived in Section 3.7.

Once the characteristics of the candidate object are chosen, step 7 establishes the mass and characteristic length of a debris object necessary to cause fragmentation using the breakup criteria described in Section 3.8. The resulting flux of debris objects sufficient to cause a fragmentation event is derived using ORDEM2000 as described in Section 3.1.

The number of fragments resulting from such a collision is derived in step 8 by using NASA's Breakup model as described in Section 3.8. The yearly probability of a fragmenting event for our candidate removal object is calculated in step 9 by multiplying the candidate object cross section by the flux generated in step 7.

Finally, Section 4.2 details how these values are used to derive today's effective removal value through present value analysis.

3. Theory/calculation

3.1. Environmental description

Examining tracked orbital objects by altitude and inclination provides insight into the space environment sectors that need the most protection. The left frame of Fig. 3 shows a distribution of operational satellites as a function of inclination. The largest population of operational satellites has inclinations very close to zero degrees corresponding to their geostationary/geosynchronous status (Space Track, 2010). This group of satellites is a top priority for debris reduction, but analysis is more difficult due to the lack (so far) of an officially sanctioned debris flux predictor for this altitude. By far the second largest group, however, is stationed close to the 99 deg inclination corresponding to sun-sync orbit. The right side of Fig. 3 plots the relative density of LEO satellites as a function of inclination and altitude. The peak at 99 degree inclination and 600–800 km altitude captures the high density of satellites oper-