# The Research on Commercial Opportunity Evaluation Model of Space Debris removal

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**Abstract:** In this paper, to determine whether an economically attractive opportunity exists in space debris removal industry, we establish a *Commercial Opportunity Evaluation Model*. Based on *costs, risks and benefits models*, we formulate an evaluation function: *COM=Benefits (1-Risk)-Cost*. When $COM$ is greater than 0, we think a commercial opportunity exists. It is used to evaluate the best alternative in different orbits. We find it is the most valuable to adopt ground-based laser in LEO( $COM = 4157887.6272$ ). Besides, we obtain the criticality risk (0.697(LEO); 0.713(MEO); 0.789(GEO)) in different orbits.

## Introduction

The definition of commercial opportunity are diverse, it will be influenced by many factors. In the emerging industry of space debris removal, there is no mature commercial system. So we should find an accepted standard to judge whether a viable commercial opportunity exist.

## The Foundation of Model

### Cost, Risk and Benefit models

There are some empirical formulas about the factors to the alternatives evaluation. And the time functions about the factors can be deduced:

$$C(t) = m(i)gAgh + round\left[\frac{V_1}{V_2}\right]gE(i) + DgV\int_0^1 Fdlg_d ground\left[\frac{V_1}{V_2}\right]; \qquad (1)$$

$$R(t) = e^{(j+P(t))} + G(q)gM\ ; \qquad (2)$$

$$B(t) = \sum_{i=1}^{3} E_i\ ; \qquad (3)$$

Where $C(t)$, $R(t)$, $B(t)$ stand for the time functions about *costs*, *risks*, *benefits* respectively. In the equations, $A$, $D$ and $M$, all of them are adjusting coefficients. Other quantities will be introduced in following analysis of specific model. And the following analysis are mainly based on these three functions above.

According to the model, *risks* should meet the equation as follows:

$$R(t) = e^{(j+P(t))} + G(q)gM\ ; \qquad (4)$$

Where $p(t)$ is the probability of a satellite being hit by space debris within a year. $j$ is a collision parameter. So $e^{(j+P(t))}$ is used to measure the risk of debris impact to the alternatives. $G(q)$ is a function of the satellite's fault.

There are three orbits that we should consider. If we regard their heights are 5000km, 6000km and 36000km, then discuss the probability of collision happened in different orbits. From model I, diameters of most of debris are less than 10cm. In the paper we only consider most debris.

*costs* should meet the equation as follows:

 

$$C(t) = m(i) \cdot A \cdot h + round\left[\frac{\upsilon_1}{\upsilon_2}\right] \cdot E(i) + D \cdot V \int_0^1 F dl \cdot t_d \cdot round\left[\frac{\upsilon_1}{\upsilon_2}\right] + k\left[t_d \cdot round\left[\frac{\upsilon_1}{\upsilon_2}\right] \Big/ Y\right] \quad (5)$$

Among them, $m(i)$ represents the quality of the satellite in different alternatives. $A$ is the transmission coefficient, $h$ is the height in different alternatives. So the physical meaning of $m(i) \cdot A \cdot h$ refers to the *costs* that a company launch a satellite to remove the debris.

$\upsilon_1$ is the total area where debris need to be removed, and $\upsilon_2$ is capability of removing the debris(the area where the satellite can remove all debris once). If $E(i)$ is the cost that debris to be removed once, $round\left[\frac{\upsilon_1}{\upsilon_2}\right]$ indicates the number of times to remove. Then $round\left[\frac{\upsilon_1}{\upsilon_2}\right] \cdot E(i)$ is the cost using alternative $i$.

To get $E(i)$, we scan the paper from others**[1]**:

$$E(i) = \frac{V_{cost}}{N_{total}} \quad ; \qquad (6)$$

$$N_{total} = N_{catalog} \cdot \frac{F}{F'} \quad ; \qquad (7)$$

Where $N_{total}$=402000 , $F = 0.0084, 0.0032, 0.0053$ and $F' = 0.0032, 0.0027, 0.0016$ . $F$ and $F'$ are obtained from model I. $V_{cost}$ is the fixed cost of private firm. By calculation, $V_{cost}$ equals to $164.349, $231.923 and $315.779 in different orbits.

$k\left[t_d \cdot round\left[\frac{\upsilon_1}{\upsilon_2}\right] \Big/ Y\right]$ expresses the depreciated cost, $k$ is a depreciated parameter. And Y is lifetime of a satellite.

*benefits* should meet the equation as follows:

$$B(t) = \sum_{i=1}^{2} E_i \quad ; \qquad (8)$$

In this model, benefits are divided into two parts, $E(1)$ and $E(2)$:

$$E(i) = \begin{cases} E(1) = E_m(h) \cdot e^{\alpha F} \\ E(2) = C \cdot round\left[\frac{\upsilon 1}{\upsilon 2}\right] \cdot E(i) \end{cases} \quad ; \qquad (9)$$

Where $E(1)$ represents the space value of different heights. $E(2)$ is the private firm's charges of removing space debris. In $E(1)$, $E_m(h)$ is a function of space value. $C$ is called value coefficient. $e^{\alpha F}$ represents the influence to the space value caused by the flux of space debris. $E(i)$ is the unit price of space removing. $round\left[\frac{\upsilon 1}{\upsilon 2}\right]$ indicates the number of times to remove the debris.

## Commercial Opportunity Evaluation Model

Based on *Costs, Risks and Benefits* calculated values, the model provides a standard for the judgment of removal the space debris. Combined with the evolution of *Costs*, *Risks* and *Benefits*, we define the commercial opportunity as followed:

$$COM = B(t) \cdot (1 - R(t)) - C(t); \qquad (10)$$

The commercial opportunity we calculated with the formula is a net profit. If *COM* is greater than 0, we think that the commercial opportunity exists. Instead, if *COM* is lower than 0, there is no

commercial opportunity. Meanwhile, we can use *COM* to measure the commercial opportunity.

**Sensitivity analysis and conclusions**

The orbit can be classified into 3 kinds: *LEO( Low Earth orbit ), MEO( middle earth orbit )* and *GEO( geosynchronous orbit )*. And we discuss whether the commercial opportunity exists in different orbits:

Table 1:the characters of each orbits

| Orbit | Alternative | Risks(LEO) | Costs(LEO) | Benefits(LEO) | *COM* |
|---|---|---|---|---|---|
| LEO | ground-based laser | 0.0511 | 16010.0000 | 4398700.0000 | 4157887.6272 |
| MEO | space-based laser | 0.2514 | 1047800.0000 | 5604000.0000 | 3147169.5926 |
| GEO | space-based laser | 0.1384 | 1169600.0000 | 5604300.0000 | 3659019.2074 |

As is shown in the table above, the *COM* of the best alternative is greater than 0, it means that there is a commercial opportunity in the orbit. Obviously, the values of *COM* in the table are very high. In other words, there is a great commercial opportunity and the industry has a broad commercial prospect.

To test the sensitivity of the evaluation model, *Risks* is set artificially. We draw the curve of *COM* that changes by increasing *Risks*.

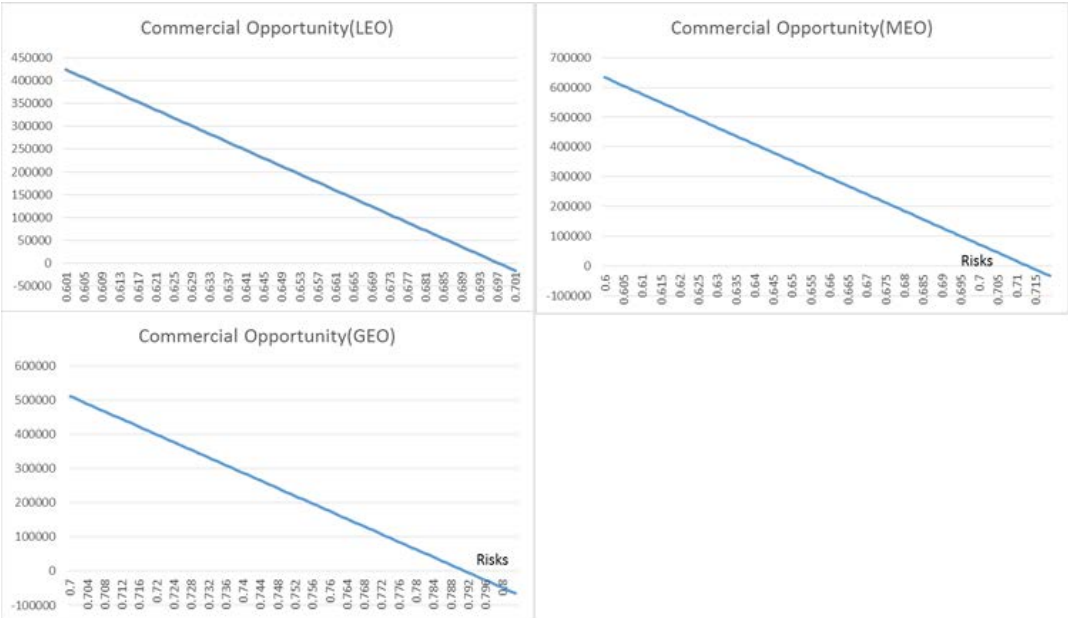


Figure 1 :the relation curve of the *Risks* and *COM* in LEO, MEO and GEO

Table 2: the correspondence between *Risks* and *COM* in different orbits

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LEO | Risks | 0.695 | 0.696 | 0.697 | 0.698 | 0.699 | 0.7 |
| | Commercial Opportunity | 10382.2 | 5983.5 | 1584.8 | -2813.9 | -7212.6 | -11611.3 |
| MEO | Risks | 0.711 | 0.712 | 0.713 | 0.714 | 0.715 | 0.716 |
| | Commercial Opportunity | 11356 | 5752 | 148 | -5456 | -11060 | -16664 |
| GEO | Risks | 0.789 | 0.79 | 0.791 | 0.792 | 0.793 | 0.794 |
| | Commercial Opportunity | 12907.3 | 7303 | 1698.7 | -3905.6 | -9509.9 | -15114.2 |

As is shown in the Table 2 ,

In *LEO*, the biggest criticality *Risks* is 0.697;

In *MEO*, the biggest criticality *Risks* is 0.713;

In *GEO*, the biggest criticality *Risks* is 0.789;

These data indicate even the Risks reach up to a large quantity, the commercial opportunity still exists. The industry of space debris removal shows its potential in the economy. In other words, there is a great commercial opportunity and the industry has a broad commercial prospect.

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