A2_4 Low Earth Orbit - A Tragedy of the Commons?

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Abstract
The increasing number of satellites and orbital debris in low Earth orbit is considered as a form of a 'tragedy of the commons', the overexploitation of a communal resource. This is assessed and analysed using game theory. Some solutions to the problem are suggested.

Introduction

Low Earth orbit (LEO) is becoming increasingly utilised by satellites from all nations for scientific, military and commercial applications. Due to this, there is an ever increasing amount of orbital debris and a rising lack of available space in LEO [1]. Both of these problems can compromise vehicle safety, operation and perhaps endanger astronaut lives. While a number of solutions to this problem have been proposed, at this time none of these solutions are generally available. According to the United Nation's Outer Space Treaty Article II, 'Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means' [2]. This essentially means that low Earth orbit can be described as a commons in the sense that it is open access for all and cannot be owned by any entity.

A commons refers to any resource that is freely consumable by any person or entity. It originally referred to medieval common pasture land, whereby a villager may graze his or her cattle upon the common land. G. Hardin proposed a scenario now known as 'the tragedy of the commons' [3] where it was recognised that it is in each villager's best interest to continue adding cattle to graze, while at the same time if this trend is applied by all the villagers, eventually the common grazing land itself will become overgrazed and unable to be used by any villager. The idea of a 'tragedy of the commons' can be applied to any situation whereby there is a resource to be freely consumed, one such example is the overfishing of cod fish off the coast of Newfoundland [4].

It can be seen that the ever increasing usage of the commons of low Earth orbit, could be seen as an approaching tragedy of the commons whereby sending one satellite is advantageous to all, however a critical point may be reached when there are too many satellites in low Earth orbit for the system to be advantageous to any of them.

Low Earth Orbit

Low Earth orbit is defined as any orbit between 160km and 2000km [5]. The number of satellites in low Earth orbit is currently approximately 3000 [6] and this number has been consistently increasing over time. While it is difficult to know precisely how many satellites could feasibly be placed in LEO without compromising the system, it is foreseeable that this number could be reached soon. Another problem is the widely documented problem of space debris as a result of satellite and spacecraft activity. Due to the high energies involved in these vehicles, the fragments can collide with functioning satellites and cause these satellites to break up themselves. It can therefore be seen that this process is one of positive feedback. One piece of debris can potentially cause many more, which of course themselves can collide with orbiting satellites or other debris further exacerbating the problem. This is known as the 'Kessler syndrome' after D. J. Kessler [1] and the nature of the feedback process could leave space inaccessible due to the ubiquity of space debris and mission-ending collisions. Due to these problems, it seems best to understand how best to avoid such a Kessler syndrome and indeed to prevent the over-utilisation of low Earth orbit.

Game Theory

A tragedy of the commons such as the over-exploitation of low Earth orbit can be described by game theory as a form of the prisoner's dilemma [7]. In the tragedy of the commons rather than having two prisoners with the choice of cooperating or defecting, it is a group of people that are given this choice. In terms of the low Earth orbit problem, these groups of people would be satellite launchers such as governmental agencies, research institutes and commercial operators. This is an interesting extension to the original tragedy of the commons formulation, for it is a collective entity that cooperates or defects rather than an individual. However, this can be modeled in the same sense given that these entities are capable of cooperating and defecting.

The many player prisoner's dilemma exists such that in the idealised game there is a social benefit B that each player can achieve if a cost of C is paid [7]. In such a scheme, launching a satellite (or defecting) would result in a benefit without cost, assuming that n or more choose to cooperate. However, if more than n choose to defect then a tragedy of the commons occurs and no benefit is found. Alternatively, if an entity cooperated by not launching while others launched, the cost would be C with no benefit. If more than n choose to cooperate then a benefit is realised along with a cost. This is shown in the payoff matrix below.

Table 1: Payout matrix depicting the costs and benefits of cooperating and defecting in a 'tragedy of the commons'-type game [7].

Decision	More than n choose to cooperate	n or fewer choose to cooperate
Cooperate	$C + B$	C
Defect	B	*0*

As can be seen, if fewer than n entities choose to cooperate then the payout is *0* for defectors. The only worse scenario than this is a cooperator in a situation where there exists n or fewer cooperators who is subjected to the cost without any benefit. Thus the payoffs are order $B > (B + C) > 0 > C$. There are two stable equilibrium points to this payout matrix. The first where everyone is a defector and receives *0*. Any cooperator in this scenario would simply see the cost of cooperating with no benefit. This could be seen as the situation now, where all entities choose to continue to place satellites in to orbit and space debris continues to grow. The second stable point is where just more than n choose to cooperate. In this scenario, the defectors will gain the benefit, B, and the cooperators will receive $(B + C)$. However, if a defector becomes a cooperator, they move from B to $B + C$ and a cooperator becoming a defector will force the system to fewer than n cooperators and result in a payout of *0*.

Potential Solutions

When expressed in a payout matrix this conclusion seems obvious, however it is unlikely in a real situation that full knowledge of the problem is available and it is impossible to know when the stable n point has been reached. To address this problem, entities launching satellites and those responsible for space debris need to be in open dialogue so that a better understanding of the stable n point can be reached and a potential tragedy of the commons averted. This would be the equivalent of a government legislating to protect a commons, however even in this system there may be law breakers. Other less mathematical solutions to the tragedy of the commons problem in general have been determined. One in particular is the privatisation of the commons in question. This would undoubtedly resolve the problem due to reducing access to the commons (it would cease to be a commons at all), but there are negative side effects, both of a practical nature and an ethical nature. Essentially the problem can be resolved by mutual understanding between all entities as to the effect of their actions. In the space industry, the relatively low number of parties involved could make this process easier, however military space technology satellite launches and locations are often classified and any such definitive discussion could prove difficult.

Conclusion

The proliferation of satellites in low Earth orbit along with an associated increase in space debris can be assessed in the form of a 'tragedy of the commons'-type problem. The problem was assessed with the use of game theory. While not easily resolvable, these type of problems appear frequently in resource allocation and solutions can be employed. It is in no-one's interest to cause a 'Kessler syndrome' event or to overpopulate low Earth orbit, thus these issues must be addressed.

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