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A Statistical LEO Model
to Investigate Adaptable Debris Control Strategies

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Space Debris are an increasing threat to the space environement and infostructure
accounting for more than 90% of the current Low Earth Orbit (LEO) catalogued population [1]

Since the beginning of the space age, the number of orbital debris has steadily increased. Moreover, even without ongoing launch activities, new explosions and collisions are likely to result in a continuing degradation of the environment, posing a growing hazard to future space activities [2]. Preventing some of these collisions, together with the widespread adoption of other mitigation measures, could be the to limit the increase of the number of objects in low Earth orbit (LEO).

The Model

We develop a multi-species deterministic source-sink model for LEO [3]. It uses discrete time-steps and a system of first order linear equations to describe the population evolution of three object species (intact objects, explosion fragments, and collision fragments) in a custom number of spherical concentric altitude shells in LEO, from 200 to 2000 km (Figure 1).

Explosions remove one intact object whereas collisions remove two objects from the relative species involved. The number of fragments generated during both explosions and collisions is computed a priori via the revised NASA break-up model [4, 5]. Drag is the only natural sink mechanism and is computed via a piecewise exponential model of the Earth's density with an average value of the solar activity [6, 7]. The model does not includes solar radiation pressure, solar cycle, Earth's oblateness or other third-body perturbations. If defined, the model can remove intact objects in response to post-mission disposal measures, and ADR with different control laws.

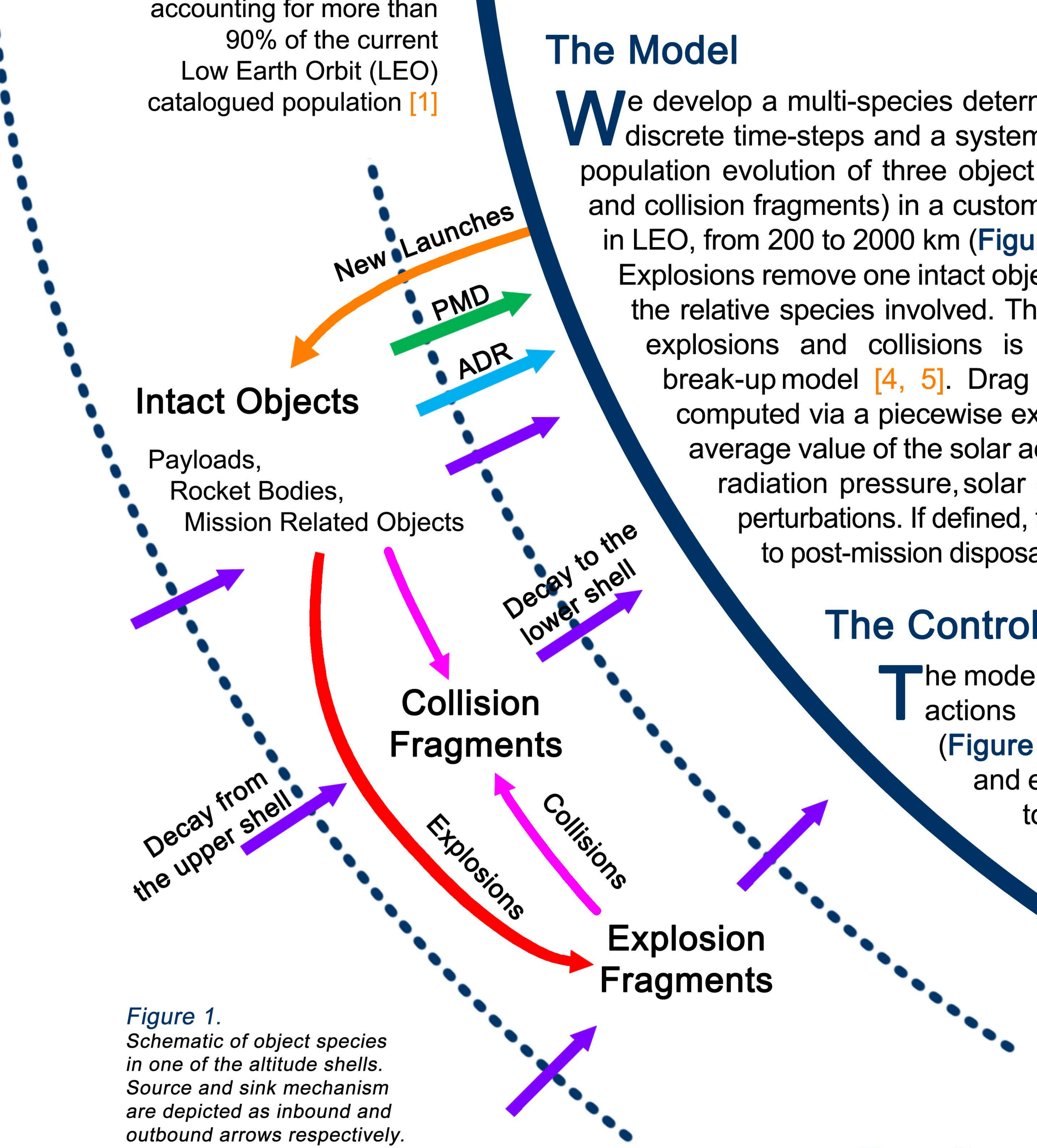

Figure 1.
Schematic of object species in one of the altitude shells. Source and sink mechanism are depicted as inbound and outbound arrows respectively.

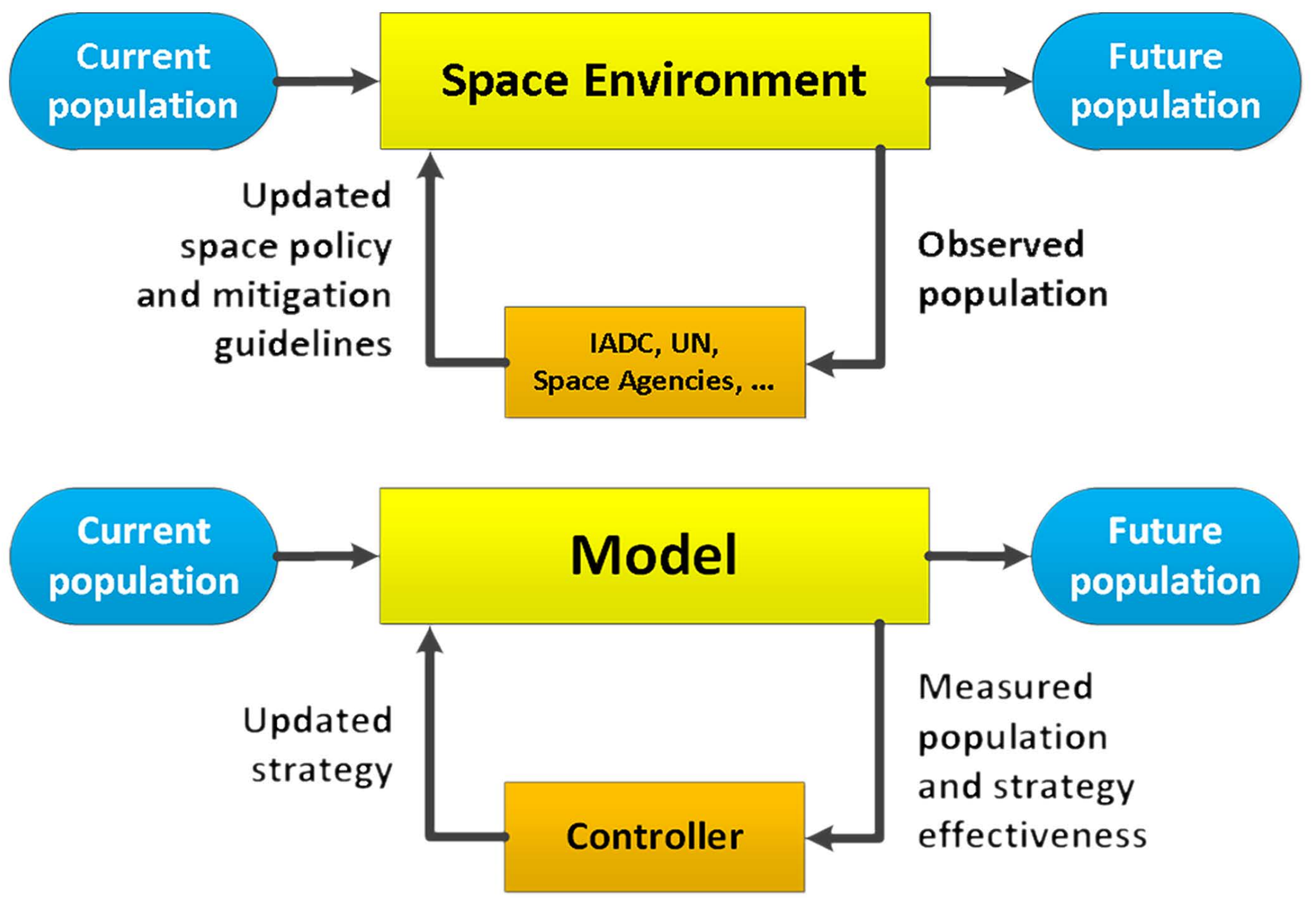

Figure 2.
Schematics of the space environment (upper image) and the model architecture (lower image).

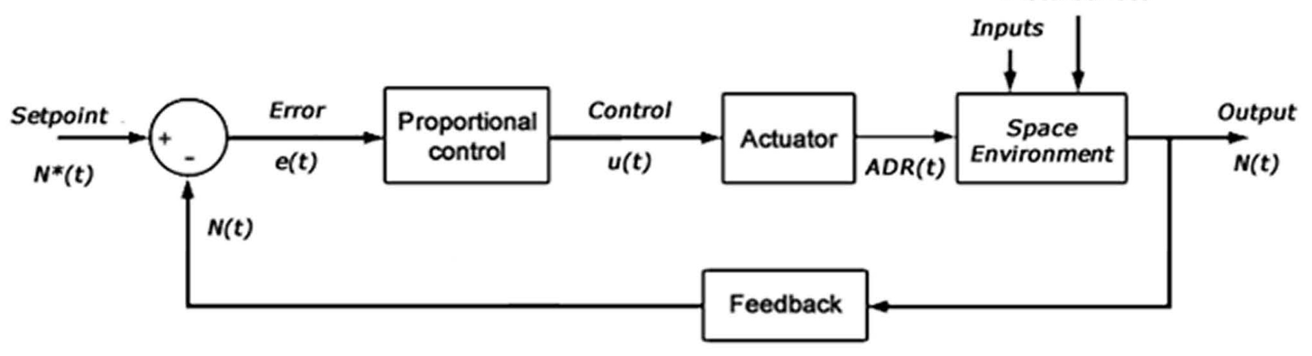

Figure 3.
Schematic of a proportional controller for the space environment.

The Controller

The model uses an innovative controller that mimics the human-driven corrective actions of observing and reacting to the space environment evolution (Figure 2). Similarly to reality, the model simulate the space environment and evaluate (at a fixed time interval) the current population which is passed to the controller that define a debris-management strategy adopted in the following time step.

Two types of control law on ADR can be used: a fixed removal rate or an adaptive proportional controller (Figure 3) [9]. In the latter, a simple proportional law determines a removal rate with a linear law from zero up to the selected maximum value which represents a realistic upper limit for the yearly number of removals (Figure 4).

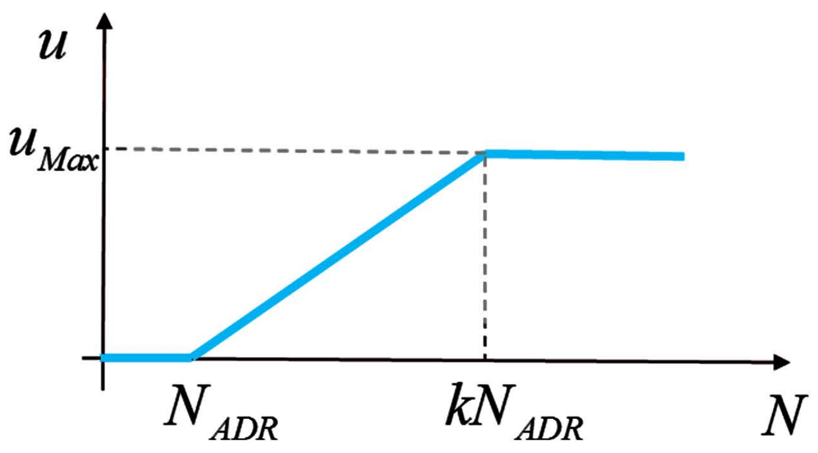

Figure 4.
The proportional control law as function of the total population.

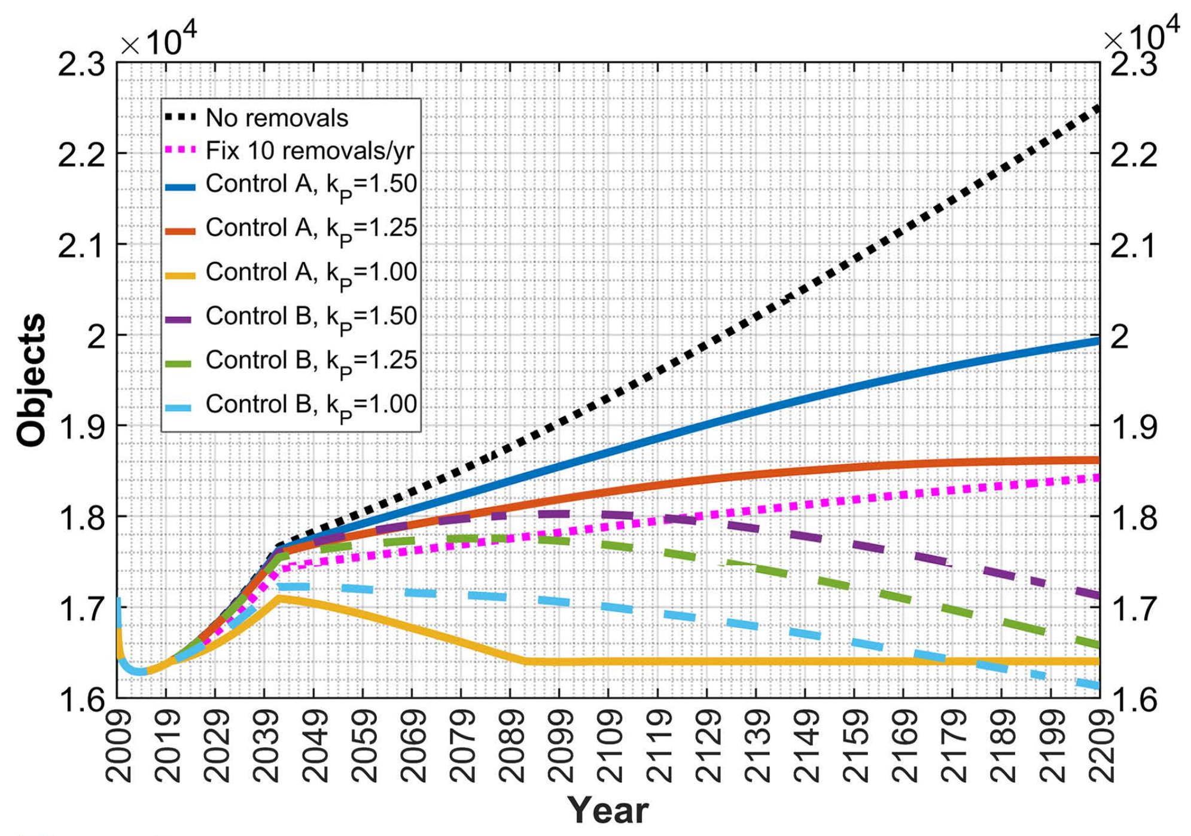

Figure 5.
Comparison of total population for different control strategies.

Results and Discussion

After he validation against the IADC comparison study of 2013 [2], two different adaptive control strategies were tested with three values for the proportional gain Kp: 1.5, 1.25, and 1.0. The first strategy, denoted as A, used a controller proportional to the total number of objects at each time step, then the computed removal rate was split equally among all the shells, while in the second strategy, denoted as B, it was split in all the shells proportionally to the number of object of each of them. Both strategies had lower end population with the reduction of Kp (Figure 5), but in the A strategy the end population is lower than the initial one only with Kp=1. The strategy B had, almost always, better performances than the A-strategy with the same Kp (but also compared to fixed removal strategies) in terms of total removals, maximum yearly removals, total collisions, and end population (respectively up to -48.04%, 45.85%, -13.24%, -14.09%) and its derivatives at the end time.

Conclusions

This new statistical multi-species source-sink LEO model can perform quantitative analysis and obtain results comparable to other literature works. These results demonstrate that proportional adaptive strategies that locally optimise the removal rate perform better compared to both a fixed and to a whole LEO-based proportional removal rate strategies. The proposed controller can improve the effectiveness of ADR, reducing at the same time the end population and the number of removals required. This reflect in higher chanches in meeting external constraints due, for example, to logistic and economic factors (e.g. launch availability, cost, and total number of ADR missions).

Acknowledgements

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Image Credits

Header image retrieved from National Aeronautics and Space Administration, Blue Marble Next Generation Images from Terra / MODIS, Scientific Visualization Studio. (2008). https://svs.gsfc.nasa.gov/3539 (accessed April 5, 2017).

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