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Quantifying the Scientific Value of Mobility in Planetary Exploration

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Abstract

Some considerations are outlined to quantify the science enhancements afforded by planetary surface mobility.

1. Introduction

It is obvious that for many investigations (seismic observations excepted, perhaps) a mobile lander or rover is 'better' than a fixed lander. But how much better? Is it worth the extra cost? To address these questions requires science value metrics, which recent work [1] has suggested may be constructed from prior and posterior certainty (Bayesian probability) on specific questions (e.g. "is there life on Europa?"). The expectation value of such scientific return must be conditioned by the probabilities of successfully obtaining the measurement (notably, the probability P_L of landing safely in the first place), and of acquiring samples (in biosignature detection missions) that have a high probability P_D of having detectable amounts of the sought signature. Some first steps towards quantifying the incremental science value of mobility can be developed by considering these probabilities separately

2. Advantages of Mobility

Surface mobility is a tremendous enhancer of science return, as recognized in Mars rover considerations since the 1970s and affirmed many times since (e.g. [2]). This enhancement, manifested in the Mars rover Curiosity or in relocatable lander concepts, arises in four distinct and quantifiable ways.

First, such an architecture permits the (typically anticorrelated) coupling of P_L and P_D to be broken – one can land at a safe site with high P_L and then transit safely to the science target with high P_D (see figure 1.)

Second, the likelihood of signature detection for the mission becomes not that of a single site, but the aggregate of many sites N. In general, the mission-integrated probability of success becomes $1-(1-P_D)^N$.

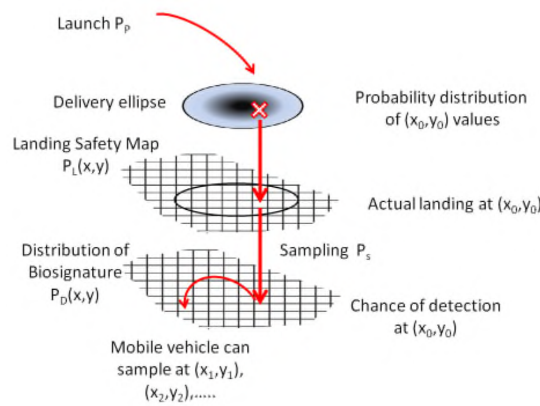

Figure 1. Mobility permits decoupling of the spatial distributions of P_D and P_L.

This enhancement is particularly powerful in the limit that $P_D(x,y)$ is small e.g. some value δ, where the expression simplifies to $\sim N\delta$.

Third, information obtained in-situ permits an ongoing reassessment of $P_D(x,y)$ at a much finer spatial resolution : as is well-recognized in resource prospecting, geological processes often yield heterogeneity at a range of scales, such that the average P_D for a region is actually the result of a small area fraction of high-value materials. The ability to select such areas by 'reconnaissance on the fly' will dramatically enhance the set of P_D sampled. . This nested-search approach (with reconnaissance by sonar and then photography by towed sled) was in fact instrumental [1] in discovering biota at hydrothermal vents on the seafloor, a fact often forgotten in the popular narrative of exploration.

A fourth, important but not widely-acknowledged, aspect is that the ability to investigate areas with values of P_D known to be low provides an important 'blank' measurement : only with samples expected not to contain a biosignature can the probability of false positives be confidently ascertained in-situ (pure 'instrument blanks' may not fully expose the measurement system to environmental factors, or the possibility of contamination of the landing site or sampling system).

All these aspects are evident in the success of the Curiosity Mars Science Laboratory (MSL). and surface mobility has allowed Curiosity to visit many sites of high interest (high P_D). Furthermore, the ability to access sand without expected organic content allowed the background levels of the analytic instrumentation to be determined on Mars (after e.g. in-flight outgassing had occurred) and, indeed, the surfaces of the sampling hardware to be scrubbed by the abrasive action of this 'blank' sample. In contrast to Viking, where debates about the interpretation of its results continue, and indeed the ongoing discussion of methane on Mars and the issue of false positives, the organic detection in sediments by Curiosity seems not to have been disputed.

3. How much mobility is enough ?

Mobility itself need not require a wheeled rover. One can imagine a lander (e.g. on Europa) with restartable rocket propulsion that takes off and lands somewhere else (as in fact did Surveyor 6 on the moon in 1967). On Titan, aerial mobility is much easier to achieve, as in the proposed rotorcraft Dragonfly concept presently under study. In these cases, the new (x,y) position can be selected without considering the trafficability of intermediate positions, as is necessary for conventional rovers.

Historically, rover mobility has been determined more by reasonable capability than by requirements formally traceable to specific aspects of the terrain. A full quantitative elaboration of the value of mobility in terms of distance traveled requires consideration of the (typically fractal) spatial arrangement of the fields P_L and P_D, and how knowledge of P_D may be refined by in-situ observations.

In terms of a biosignature search, one can consider the number of sites to be visited (independently of their separation distance). Consider the scenario where 'pixels' of a P_D grid may be zero or one (i.e. some places have a biosignature in abundance, and some places have none) with half of the sites being favorable, but there is no reconnaissance data to inform which ones. The problem is then essentially one of coin-tossing – a single fixed lander has a 50:50 chance of landing on a favorable spot. A relocatable vehicle can perform successive Bernouilli trials, such that after moving to a second spot, the chance of finding the biosignature is ~75%, 87.5% after the third spot, and so on. For the 95% or 99% success probabilities often demanded of space missions, the number of sites required would be 5 or 7, respectively.

More probably the biosignature is present only in a tiny fraction of the area under consideration. If no knowledge is available, or no control can be exerted on which successive sites are visited, then the exercise is again a Monte Carlo problem, but with a much lower success probability for each trial. If perfect knowledge and perfect control exist, the target can be reached in a single step. More typically, the situation will be between these extremes – it is pertinent to consider the game of golf, where knowledge of the target is essentially complete, but some stochastic element frustrates the ability to relocate exactly and several iterations are required to home in. It is pertinent to note that most golf courses (18 holes, par 72) anticipate approximately 4 steps to reach success for each target. Thus, considering the coin-tossing and golf analogies, it is reasonable to assume ~5 steps to attain a desired target unless additional information is available to refine the spatial distribution of the material and/or the accuracy of the targeting process.

4. Conclusions

These considerations are only the first steps in developing a formal value metric. However, the substantial costs and expectations of exploration demand that such quantification be attempted.

Acknowledgements

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References

[1] Lorenz, R. (2019) Adv. Space Res. (submitted).[2] Space Studies Board (1999) *A scientific rationale for mobility in planetary environments*,