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A DECISION ANALYSIS APPROACH FOR RISK MANAGEMENT OF NEAR EARTH OBJECTS

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ABSTRACT

Risk management of near-Earth objects (NEOs) (e.g., asteroids, comets) that can potentially impact Earth is an issue that has only recently been addressed. Thousands of NEOs large enough to cause substantial damage are known to exist; although only a small fraction of these have the potential to impact Earth in the near future. The probability and location of a NEO impact is subject to complex physics and great uncertainty, and consequences can range from minimal to devastating depending upon the size of the NEO and location of impact. Interventions to divert a potential NEO impactor would be complex and expensive, and inter-agency and international cooperation would be necessary. Such deflection campaigns may be risky in themselves, and and failure may result in unintended consequences.

Considerable work has been applied to identification of NEOs and much thought applied to potential interventions; however, to our knowledge the benefits, risks, and costs of different potential NEO risk management strategies have not been compared in a systematic fashion. We present a decision analysis framework targeted toward this issue. Decision analysis is the art and science of informing difficult decisions. It has a long and varied history, with roots in economics, business, psychology, statistics, engineering, and other fields. It is inherently multi-disciplinary, especially with regard to managing catastrophic risks. Note that risk analysis clarifies the nature and magnitude of risks, whereas decision analysis guides rational risk management. Decision analysis can be used to inform strategic, policy, or resource allocation decisions.

The basic steps in decision analysis are universal to most rational and systematic decision-making processes. Briefly, a problem is defined, including the decision situation and context. Objectives, based upon what the different decision-makers and stakeholders (i.e., participants in the decision) value or deem important, are defined. Quantitative measures or scales (i.e., attributes) for the objectives are determined. Alternative choices or strategies are defined. The problem is then quantitatively modeled, using expected value methods (described below), and the alternatives are ranked in terms of how well they satisfy the objectives. Sensitivity analyses are performed in order to examine the impact of uncertainties, and the need for further analysis, data collection, or refinement is determined.

The first steps of defining the problem and the objectives are critical to constructing an informative decision analysis. Such steps must be undertaken with participation from experts, decision-makers, and stakeholders. The basic problem here can be framed as: “What is the best strategy to manage risk associated with NEOs?” The objectives of the risk management decisions (or sequence of decisions) are less clear, especially when the consequences (e.g., causing misallocation of resources) of an impact or even a near-miss vary so widely; depending upon the size of the object, when and where it impacts, and other factors. For example, the following might be high-level objectives: Minimize mortality; minimize damage to critical infrastructure (e.g., power, communications, food production, etc.); minimize ecosystem damage; minimize property damage; minimize ungrounded speculation; minimize resource utilization; minimize cost; and, maximize inter-agency/government coordination. Note that some of these (e.g., “minimize mortality”) are readily quantified (e.g., deaths averted), while others are less so (e.g., “maximize inter-

agency/government coordination"); however, these can be scaled. There are obvious tradeoffs across these objectives; e.g., a strategy that minimizes mortality to the greatest degree probably would not cost the least amount. The objectives are also unlikely to be weighted equally. Up-front elicitation with experts, decision-makers, and stakeholders is necessary to define the objectives, the degree of weighting, and the nature of tradeoffs.

High level decisions include whether to deflect a NEO, when to deflect, what is the best alternative for deflection/destruction, and disaster management strategies in the event of an impact. Important influences include, for example: NEO characteristics (location, orbital characteristics, size, mass, composition), impact probability and location, time duration from discovery of the impact possibility until the date of impact, time duration from discovery of the impact possibility until the date when the intervention must be accomplished, costs of information collection, costs and technological feasibility of alternatives, risks of interventions, requirements for inter-agency and international cooperation, and the need to inform the public.

The analytical aspects of decision analysis center on estimation of the expected value or utility of different alternatives. The expected value of an alternative is a function of the probability-weighted consequences. This is estimated using Bayesian calculations in a decision tree or influence diagram modeling construct. The result is a set of expected-value estimates for all alternatives evaluated, which allows a ranking; the higher the expected value, the more preferred the alternative. A common way to include resource limitations is by framing the decision analysis in the context of economics (e.g., cost-effectiveness analysis).

An important aspect of decision analysis is the ability, known as sensitivity analysis, to examine the effect of parameter uncertainty upon decisions. The simplest way to evaluate uncertainty associated with the information used in a decision analysis is to adjust the input values one at a time or simultaneously to examine how the results change. A more powerful way to do this is to use methods such as Monte Carlo simulation to adjust the inputs over ranges or distributions of values, and then to use statistical means to determine the most influential variables. A measure known as the expected value of imperfect information can then be estimated. This is highly informative, because it allows the decision-maker under a state of uncertainty to evaluate the impact of using experiments, tests, or data collection (e.g. Earth-based observations, space mission information collection, etc.) to refine judgments; and indeed to estimate how much should be spent to reduce uncertainty. Influence diagrams, which are a more efficient way of performing decision analyses than decision trees, are particularly useful in estimating the expected value of information.

The decision analysis framework will be applied to a hypothetical case study involving the 300-meter NEO 99942 Apophis; which will closely approach Earth in 2029 and possibly in 2036.