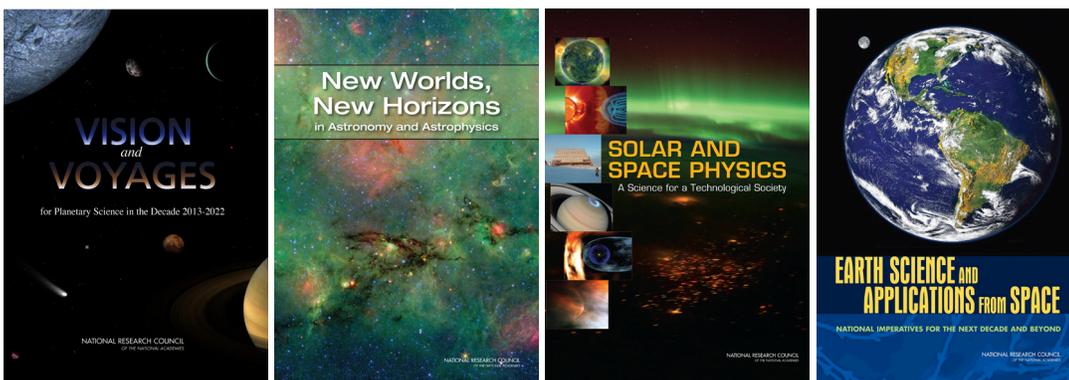


The Space Science Decadal Surveys: Lessons Learned and Best Practices

Decadal surveys are reports that communicate community-consensus science priorities and programmatic recommendations to federal agencies for the coming decade. Since 1964, the National Academies of Sciences, Engineering, and Medicine have completed 11 decadal surveys, first developed for astronomy and astrophysics and later extended to planetary science, solar and space physics, and Earth science. The democratic decadal survey process has smoothly and reliably defined the scientific frontier and the nation's agenda in these disciplines each decade, gaining strong support from scientific communities as credible and unbiased science assessments. *The Space Science Decadal Surveys: Lessons Learned and Best Practices* is a review of the four most recent decadal surveys and aims to serve as a handbook to guide the organizers of future surveys. This report identifies valuable aspects of decadal surveys that could be developed further, as well as some challenges future surveys are likely to face.

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The findings of this report consist of lessons learned from prior surveys and the resulting best practices. In reviewing the entire decadal survey process—from the formulation of science priorities to defining recommended methods of implementation and stewardship—the committee found that the four surveys faced surprisingly few issues given the magnitude of their task. There is little, if any, doubt that decadal surveys have been widely successful across the disciplines. Still, the process could be made more effective with slight modifications.



This report details some of the lessons learned from recent decadal surveys in the fields of planetary science, astronomy and astrophysics, solar and space physics, and Earth science.

BACKGROUND

Decadal surveys are requested by federal agencies that use them as roadmaps for planning their own projects in the coming decade. Conducted by the Academies' Space Studies Board (SSB), alone or in conjunction with other boards, decadal surveys are the result of a rigorous two-year effort by some of the nation's leading scientists and engineers. A primary survey committee along with thematic science panels of community members defines the nation's agenda for a specific discipline by constructing a prioritized program of science goals and defining an executable strategy for achieving them. Decadal surveys work on the principal that consensus is compelling. By demonstrating a discipline's consensus for a specific course of action, a decadal survey helps win approval for the most important programs and shields them against cancellation when difficulties are encountered. A decadal survey is also a prime weapon to wield against groups that lobby for special-interest programs lacking broad community support. Despite the survey's historical success across space science disciplines, few non-space disciplines have chosen a democratic process like the decadal survey to define the discipline's frontier for the next decade.

To systematically explore the benefits of the decadal survey process, the Academies brought together recent survey participants and stakeholders for the "Lessons Learned in Decadal Planning in Space Science" workshop in 2012, which focused on four recent surveys: Earth science and applications from space, astronomy and astrophysics, planetary science, and solar and space physics (also called heliophysics). At the request of NASA Science Mission Directorate (SMD), the SSB convened a committee to expand upon and evaluate the is-

suces that surfaced during the workshop and generate a report containing formal conclusions directed toward improving the survey process.

CONSENSUS IS COMPELLING

Decadal surveys provide a unique model for how an entire community can come to a consensus and work to provide implementation strategies for achieving these consensus goals. In order to accomplish this weighty task, it is essential to collect community input regarding what those goals actually are. The challenge is ensuring that every idea is heard, and that no good idea is simply missed. The committee found that a review of the state of science just before a survey begins could be a best practice for future decadal surveys in order to determine how the science has evolved since the last decadal and to promote community participation in the survey process. In this way, the survey committee could better recognize emerging opportunities and innovative approaches to program implementation that might not be readily apparent. Additionally, this new process would improve communication throughout the science community before and during a decadal survey and has the potential to facilitate interactions with international groups to better coordinate discussions of shared science goals.

PRIORITIZATION OF SCIENCE OBJECTIVES

Once all inputs have been collected it is up to the decadal survey committee to prioritize the science goals as a foundation for the decadal program. By design, decadal surveys rank science objectives over specific mission ideas. The decadal committee must therefore define a prioritization method that

identifies areas of high-impact science while demonstrating that science, rather than pressure from lobbyists, is the prime motivator. However, for some disciplines, science goals cannot always be separated from missions, so these decadal committees must account for this in the prioritization process. Each decadal committee has the freedom to decide its own methodology for science prioritization, provided that the process strives to be fair and progress-driven and is clearly explained in the report.

TECHNOLOGICAL FEASIBILITY AND COST ANALYSIS

Once priority community goals are established, it becomes a matter of logistics to define a recommended program that achieves these science objectives. The committee knows what science the community wants to achieve, but is it feasible to do so within the decade, and if so, how? The decadal committee determines whether the highest priority science goals are achievable with current and projected technology, and defines realistic terms for implementation based on a formal Cost and Technical Evaluation (CATE) carried out by an independent contractor, the Aerospace Corporation. CATE assesses the technical risk and readiness of mission concepts, and then monetizes those risks into potential design growth and associated threats to cost and schedule. CATE provides the most consistent, accurate, and well-informed analyses of mission concepts and is regarded as a best practice for all future decadal programs.

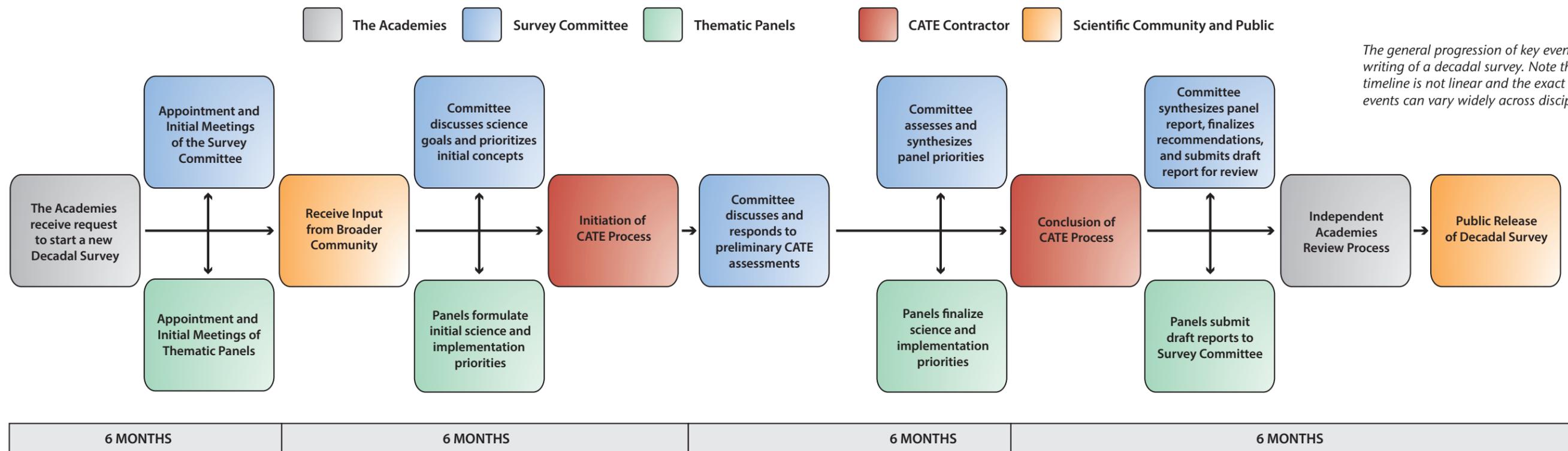
CATE is most useful as a reasonableness check on what is being recommended and can therefore be used for any number of analyses. To provide a sense of scale for initial consideration, CATE could be run as a faster, coarser analysis to evaluate a

larger number of candidate missions before program selection with the full CATE process reserved for selected missions. This two-step CATE would help prevent premature overly-detailed cost estimates from driving the decadal survey process.

It may be desirable for surveys to present selected programs as reference missions rather than exact mission architectures. Reference missions are credible hardware configurations that can achieve the relevant science and are detailed enough for robust cost evaluation. This would help account for changing technology, budget, and science through the decade, and would allow for an evolving understanding of what the mission needs to be successful. Implementing a particular mission architecture is often much more costly than estimated from studying an immature concept. The full cost, especially of ambitious, high-profile missions like the James Webb Space Telescope (JWST) and the Mars Science Laboratory (MSL), may not be known until a substantial part of its budget has been spent. Reference missions are intended to serve as a proof of concept and of financial feasibility for concepts that have not yet been sufficiently developed but achieve high-priority science goals.

BUDGET PREDICTIONS

Budget uncertainty introduces huge challenges to the decadal committee's development of an executable and affordable ten-year program. Decadal surveys have been reluctant to adopt the worst case scenario budget for fear they will be given it, especially in times of tight budgets, so oftentimes the recommended programs are more ambitious than could be accomplished within the decade. It is beneficial for decadal committees to predict budgets based on longer-term trends covering the full decade, rather than the current 5-year model.



Because these uncertainties seem inevitable, it may be beneficial to replace the extrapolations of a current or newly released budget with a baseline that reflects longer-term funding trends for NASA SMD and relevant partner agencies such as NSF and NOAA.

PROGRAMMATIC BALANCE

Armed with CATE and community input, the decadal committee can begin fitting a program to the projected budget that stays true to consensus science goals and strives to promote programmatic balance in mission scale and in the science program across the various disciplines. Elaborate, high-cost, high-profile missions like JWST and MSL present great opportunities for major advances in understanding and technological development but also carry significant risk for maintaining a balanced portfolio of activities should unanticipated costs occur. Multiple smaller, less expensive missions carry much less risk and provide opportunities for many communities to fly a mission, but they cannot individually achieve high-impact science as prioritized by the decadal committee and are easily displaced by uncontrolled high-profile mission spending. International partnerships have the potential to defray the cost of large missions, create a stronger commitment to the mission, and bolster international relations with other space agencies. These partnerships can also, however, introduce programmatic strain and undermine the original intentions of the decadal committee and therefore the science community.

COMMUNICATING THE DECADAL PROGRAM

Clearly communicating the recommended program and directions for execution is the most important factor for the success of a decadal survey. All preferences, decision rules, and contingency plans must be clearly laid out within the survey to ensure

fidelity to the science objectives. The committee would benefit from laying out clear decision rules for high-profile missions including de-scope and cancellation options, a clear delineation between essential and flexible aspects of a mission, and an evaluation of mission concepts based on merit rather than advocacy or inertia. This could provide some level of protection against unconstrained cost growth and possible collateral damage to other programs. In general, to prevent misuse of the decadal survey, it is important for the committee to explicitly state its intentions regarding all major decision points, including the processes for collecting and distilling community input, prioritizing consensus science goals, identifying the roles of CATE, determining a realistic budget, and crafting a balanced decadal program.

STEWARDSHIP

After the decadal survey is published, implementation of the recommended program is overseen by the SSB standing committees, groups composed of experts from each of the major space science disciplines, and through a midterm assessment. Approximately five years into a decadal survey's implementation period, a committee is chartered to prepare and release a midterm assessment that reviews the progress agencies have made in implementing each survey's program.

Decadal surveys set a standard of excellence that could be applied more widely across the nation's science programs. While the review found no flaws, the survey process can, and should, improve and evolve. The remarkable record of decadal surveys in unifying scientific communities and achieving political successes makes the committee optimistic that useful changes can and will continue to be made.

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