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Linking Space Exploration Programs to National Goals

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The end of the Cold War has fueled a national debate over programs and priorities. The state of the economy and a stubborn budget deficit make it clear that the United States cannot do everything and that careful choices must be made. The space program is only one of many important programs that will undergo intense scrutiny in the coming months. Although the long-term interests of the country benefit from a vigorous space program, it will have to have a broad consensus if it is to remain viable. Policymakers can assist in building that consensus by developing an analytic structure that links programs to national goals. As part of an earlier effort evaluating various approaches for the manned exploration of Mars, RAND employed such an analytic structure, which could serve as a model for the broader NASA agenda.

Few would disagree that the United States should remain active in space. More subject to debate are the relative merits of specific programs within the broader space effort. But an active space program, including the continuing exploration of space and the maintenance of a human presence there, serves the nation's long-term interests. This involvement in space has long been an element of U.S. national policy, essentially since the country launched its space program. Although goals have varied over time, the commitment to a U.S. presence in space has never wavered. As part of that commitment, the country has developed a large infrastructure to support space operations, a pool of expertise matched by few nations, a very capable industrial base, and a network of international partnerships. The nation derives substantial benefits from space for defense, communications, science, and a number of other applications. Furthermore, the national and international scientific communities have considerable interest in having the United States maintain an active space program because it is one of the few nations capable of doing so.

Building a National Consensus

Although the details might vary, the broad outlines of the approach necessary to foster such a consensus are relatively clear. A viable space program must have at least three major characteristics. It must:

- *Consider multiple policy perspectives, such as those of economic, commercial, scientific, educational, and defense issues.* The broader the range of policy interests served by a given program, the more support it will engender.
- *Develop broad-based program involvement.* The focus of the program must be deliberately expanded to capture the interest of a number of different groups. The program must involve more than members of the space and defense establishment and a relatively

narrow segment of the scientific community. It should extend to university scientists, educators, commercial enterprises, and, most important, the public at large. It can foster a broad base of interest by informing as wide an audience as possible of the program goals, necessary technologies, and the program progress. It would do well to involve the members of this wider audience in the program as much as possible.

- *Include frequent demonstrations of progress.* It is difficult to justify programs on the basis of benefits realized in distant decades. Fairly frequent demonstrations of progress made and benefits realized will help forge and retain the necessary consensus.

The Analytic Model

RAND has formulated a methodology for achieving such a consensus. RAND developed its approach in the context of a Moon/Mars exploration program, but the general procedure could apply to any major space program.[1] The process requires participants to define the policy framework for the project in terms of high-level goals and identify a range of paths to achieve those goals. A path is an aggregated construct that addresses such considerations as major technical concerns and programmatic issues. It can lead to the development of a number of different architectures but lacks the details of hardware, crew size, number of flights, and so forth. It does include sufficient detail to facilitate analyses of the early phases of a program. Collectively, the paths should constitute a comprehensive view of the policy issues. The paths should then be evaluated in light of their contributions to the policy goals.

Identifying Goals

To identify the policy goals, RAND turned first to those articulated by the National Space Council for the entire space program.[2] Goals at this level are normally broad declarations of intent. They include such statements as:

- Strengthen the security of the United States
- Encourage private-sector investment
- Maintain the freedom of space
- Expand human presence and activity beyond Earth orbit.

RAND also consulted other sources for relevant policy statements, including the Synthesis Group, created by NASA and charged with the overall evaluation of the Project Outreach submissions. The Synthesis Group defined a number of "visions" that were more focused than the national goals. These visions included such aims as developing technologies with terrestrial applications and rejuvenating national interest in science and engineering.[3] Additionally, RAND searched a number of other sources that outlined policy goals in the areas of education, national security, and international relations.[4]

These aggregate goals are important, and identifying them is a necessary first step. Even though they are too general to guide the selection of alternative architecture options, they can serve as a basis from which to derive more focused goals that can suggest paths to accomplish the goals. Searching the range of high-level policy documents allowed RAND to augment the goals of the Space Council and the Synthesis Group. Ultimately RAND distilled eight broad objectives from the collected policy statements. The RAND-derived objectives are:

- Enhance U.S. national security
- Increase scientific knowledge
- Strengthen the U.S. economy
- Enhance U.S. international relations
- Strengthen the U.S. position in space
- Expand human presence and activities in space
- Improve the U.S. quality of life
- Foster public support of space programs.

Constructing Paths

After the goals were identified, the next step involved constructing paths that would lead to the goals. An important aspect of these paths is that they were constructed modularly—from "building blocks." The rationale for this methodology derives from the realization that major space programs take a long time—possibly decades—to complete. It is unlikely that any single path identified early in the program will either

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[1]RAND assisted NASA in Project Outreach, a nationwide solicitation to garner the best ideas for accomplishing a Moon/Mars exploration program. The authors acknowledge the indispensable contribution made to the development of the methodology discussed in the paper and its application in Project Outreach by the members of the Missions and Architecture Panel: Bruno Augenstein, Ike Chang, John Friel, Dana Johnson, Beth Lachman, Patricia Rogers, Jim Rosen, and Carolyn Wong.

[2]*U.S. National Space Policy*, National Space Council, November 1989.

[3]Statement by Lt Gen Thomas P. Stafford, USAF (ret.), Chairman, Space Exploration Initiative Synthesis Group, at the National Press Club, issued as a press release.

[4]Examples include the *National Security Strategy of the United States*, by the White House, 1990; *Leadership and America's Future in Space: A Report to the Administrator*, by Dr. S. K. Ride, 1987; and *Emerging Technologies: A Survey of Technical and Economic Opportunities*, by the Department of Commerce, 1990.

satisfy all goals or successfully anticipate the course of the national debate over the years. Paths constructed from a number of building blocks could be variously combined into composite programs, offering important flexibility.

RAND developed a number of these modular program paths. As a group, they cover the range of concerns expressed in the policy statements. They each contain goals, identify the critical research and development required to achieve the goals, outline implementation activities, and identify broad program requirements. RAND defined eight separate paths:

- Advanced Research, Development, Test, and Evaluation/High Technology
- Maximum Use of Current Technology
- Early to Mars
- Lunar Commercial
- Fast-Paced Mars Habitation
- High Science/Extensive Robotics
- Colony: Proof of Concept
- Colonization: Maximum Presence in Space.

The titles imply general directions and how programs might be combined. Aspects of the Early-to-Mars path, for example, could be joined with Maximum Use of Current Technology to develop a combined path that emphasized an early presence on Mars while relying on readily available technology. No single path fully satisfies all goals, but in the aggregate they address the breadth of policy concerns.

In developing the paths, RAND was conscious of the variation in risk, cost, time schedules, and infrastructure across the range of paths. Although RAND's effort did not include cost estimates, it noted that a broader application of the methodology would require comparative cost estimates as an essential input to the evaluation process. RAND provided comparative assessments of the overall risk, time schedule, and infrastructure requirements for each of the eight paths. Risk assessment must consider not only risk to program or mission success but also risk to life. The *Challenger* accident showed that the nation has a low tolerance for loss of life in the space program. For this and other reasons, variations in the use of manned and unmanned programs were built into the range of program paths RAND considered.

Not surprisingly, the paths share some common features. For example, all of the paths share certain R&D needs. All require research into life support, microgravity effects, radiation protection, and propulsion issues. Before the country commits astronauts to long space flights, solutions need to be identified for calcium loss from long-term exposure to microgravity, approaches must be developed for providing protection from galactic cosmic radiation, and so forth. In addition, R&D for heavy-lift launch vehicles is needed because of the large amount of material that has to be lifted into orbit to accomplish the missions. The long transit time to Mars makes propulsion for the vehicle that carries the astronauts from orbit to Mars a key R&D issue for any program. One benefit to identifying the research requirements common to more than one program path is that research can get under way early. The results will have applications regardless of final program architectures.

The paths have unique characteristics as well. Each has a distinctive goal that shapes its general direction. Goals for the individual paths appear in Table 1.

Table 1

Goals of RAND Program Paths

Program Path	Goal
Advanced RDT&E/High Technology	Develop foundation for possible implementations of manned programs for planetary exploration, commercial development, and colonization.
Maximum Use of Current Technology	Make maximum use of available technology to establish a human-tended Mars outpost.
Early to Mars	Establish human-tended outpost on Mars as early as possible.
Lunar Commercial	Establish economically self-sufficient lunar base to benefit Earth and to support expeditions to Mars. Foster extensive private-sector involvement.
Fast-Paced Mars Habitation	Establish permanent, staffed base on Mars as soon as possible.
High Science/Extensive Robotics	Establish infrastructure for research and exploration of Moon and Mars.
Colony: Proof of Concept	Mount large-scale demonstration of all essential elements required to support colonization of Mars.
Colonization: Maximum Presence in Space	Establish self-sustaining colony on Mars.

Evaluating Paths

Once the paths were defined, it remained to evaluate them from a policy perspective. This evaluation involved RAND's subjective determination of the extent to which each program path satisfied the policy issues expressed in the eight objectives. These subjective comparative evaluations were made by a panel of experts familiar with both the policy goals and the capabilities of each of the program paths by assigning the following values:

HIGH indicates that the potential is large for a program path to contribute to a goal.

MEDIUM indicates a modest potential.

LOW indicates a small potential.

Figure 1 displays the results of the evaluation process that qualitatively assessed each path's degree of support for each of the space policy goals.
The evaluation process was straightforward. Each path was considered in light of a specific policy objective and awarded a rating based on the extent to which it contributed to the objective. The evaluation process did not take into account cost considerations. Not surprisingly, in the absence of budgetary constraints, the more elaborate programs, such as the two colony paths, contributed to more objectives and thus provided the highest "policy value." However, the Lunar Commercial path, which is probably not as costly as the colony paths, ranked highest because of its near-term economic returns as well as its significant contributions to all space policy objectives.

Depending on the path, a given consideration could result in a high or low rating. For example, the Advanced RDT&E/High Technology path scored low for the goal of international cooperation because it was deemed likely that the United States would closely hold the results of advanced R&D. Conversely, Lunar Commercial and three other paths scored high for this goal because they had wide potential for using such foreign space capabilities as Russia's *Mir* space station or France's *Ariane* rocket.

The evaluation reflected in Figure 1 used the eight goals RAND derived from a number of sources. It is also possible to evaluate the program paths against a specific policy grouping. This process gives some indication as to the robustness of the results of the aggregated evaluation. At the same time, it will uncover any bias. Figure 2 reflects an evaluation of the program

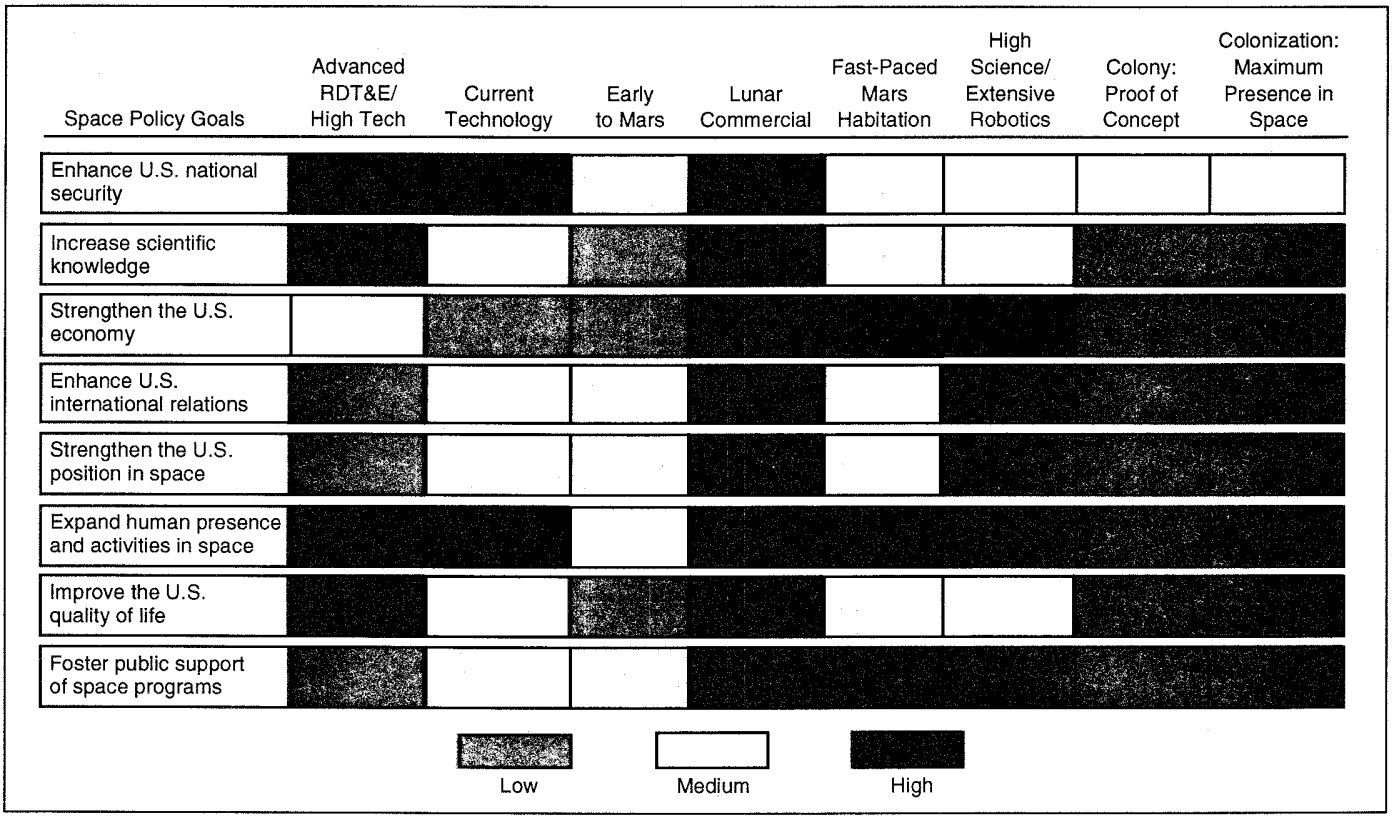

Figure 1—Program Path Evaluations

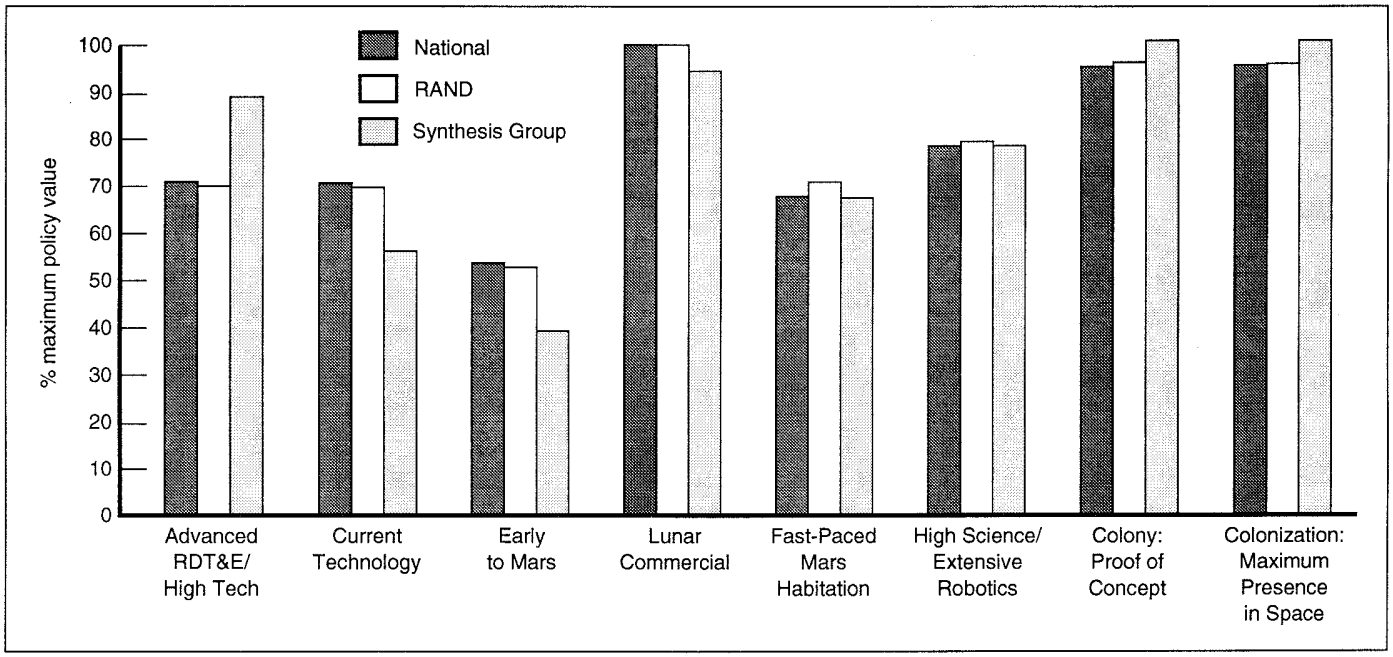

Figure 2—Evaluation of Program Paths Against Separate Policy Groups

paths against three separate policy groupings: the national space goals, RAND-derived objectives, and the visions of the Synthesis Group. Generally, the evaluation reflects similar results for the three groupings. A marked difference of one group against several of the paths would be cause for more searching analysis to determine the reasons for the difference.

The two evaluations depicted here treat all goals as having equal value, but the process does not have to treat them equally. Goals having special import could be weighted. For example, if commercial enterprise were a particularly important policy issue, that goal could be awarded a higher fraction of the total points. Paths that supported that goal well would receive a proportionately higher score in terms of contribution to policy value. The idea is that this methodology offers a good deal of flexibility for a comparative evaluation of various program paths against different sets of goals. As such analyses proceed, the program paths will be altered to better support national goals; in the process, they will become more defined technically and operationally closer to an architecture.

More Detailed Criteria

Although the RAND-derived objectives were suitable for the initial evaluation of the aggregate program paths, more detailed evaluation criteria are needed to guide more specific architecture constructions. The set of more detailed criteria ideally should satisfy two requirements. First, it should span the range of issues implied by any statement of national goals. Second, it should allow comparison among programs to determine how well they meet the national goals. A set of architecture evaluation criteria tied at one end to national policy goals and at the other to a means for making choices among specific architectures, with special emphasis on developing a national consensus, could then serve as a means to assess detailed architectures.

RAND developed a set of these more detailed criteria for consideration by NASA. Although such criteria might vary based on national goals, they reflect the types of issues that would be important in determining architecture choices. The sample criteria for comparing and evaluating programs include:

- General public acceptance incentives (e.g., affordability, economic stimulus)
- Likelihood of program success (e.g., risk, resilience, robustness, program termination criteria)
- Potential endurance of program (e.g., infrastructure development, continuity)
- Visible program incentives (e.g., technology payoffs for the public, quality-of-life improvement, national-security enhancement)
- Public-appeal incentives (e.g., early milestones, public involvement)
- Program longevity (e.g., international/commercial attractiveness, economic benefit)

- Public understanding of space program (e.g., clear goals, clear plan, clear economic leverage, open accomplishments).

Obviously, it is possible to derive other groupings of categories and factors to serve as a checklist or screening mechanism to compare individual programs within an overall space plan. The evaluation criteria above are examples. The underlying idea is to create a methodological basis for comparing individual program paths or architecture options within a national policy framework.

Conclusion

Major space programs make enormous contributions to science. They also involve the prestige of the United States and require considerable financial investment. It is therefore important to develop an analytic process that enhances the possibilities of program success. A policy framework and an evaluation process are essential for any major space venture, both to ensure the broad national consensus and to guide the process of architecture selection. Furthermore, the policy framework and evaluation process must be established at the very outset of the program to provide the basis for making informed decisions. The method RAND used in evaluating a Moon/Mars exploration program can serve as a model for developing such a policy framework and evaluation process.

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