REACHING MARS: MULTI-CRITERIA R&D PORTFOLIO SELECTION FOR MARS EXPLORATION TECHNOLOGY PLANNING

Jeffrey H. Smith, Jet Propulsion Laboratory, 4800 Oak Grove Dr., MS 301-165
Pasadena, CA, 818-354-1236, Jeffrey.h.smith@jpl.nasa.gov
Benjamin P. Dolgin, Jet Propulsion Laboratory, 4800 Oak Grove Dr., MS 82-105
Pasadena, CA, 818-354-5017, Benjamin.P.Dolgin@jpl.nasa.gov
Charles R. Weisbin, Jet Propulsion Laboratory, 4800 Oak Grove Dr., MS 179-224
Pasadena, CA, 818-354-2013, Charles.R.Weisbin@jpl.nasa.gov

ABSTRACT

The exploration of Mars has been the focus of increasing scientific interest about the planet and its relationship to Earth. A multi-criteria decision-making approach was developed to address the question, "Given a Mars program composed of mission concepts dependent on a variety of alternative technology development programs, which combination of technologies would enable missions to maximize science return under a constrained budget?" The scientific value of each portfolio was used to compute each portfolio contribution to a strategic exploration goal. Solutions were found by searching all possible portfolios for the maximum science value within budget constraints.

INTRODUCTION

There has been considerable interest in the scientific community and at NASA in addressing fundamental questions about the planet Mars [1][2]. NASA's program for the exploration of Mars is linked to a need for numerous enabling technologies that must be developed in order to proceed with the variety of missions planned. Eleven Mars missions were considered for implementing the Program's scientific pathways and included 3 lander/rover missions, 2 lander/drilling system missions, 4 orbiter missions, a Mars sample return mission, and 1 low-cost opportunity mission called "Scout" as a placeholder for what was anticipated to evolve into a series of low-cost mission concepts. The technology capabilities were then mapped to the set of missions to define a roadmap of enabling technologies by mission. The eleven missions mapped to a total of 17 unique technology requirements. This was due to sharing of common requirements by some missions and a natural partitioning between rover, lander, and orbiter missions. In each of these eighteen cases, a data set was obtained from technologists, mission designers, or available documentation.

APPROACH

A combined approach was developed for analyzing portfolios of technology investments using multi-criteria decision analysis, Monte Carlo simulation, and mathematical programming techniques [3][4]. The approach enumerated every possible technology portfolio combination in order to identify sets of highest science-value missions and technologies that could be funded within a specified budget. This was done in a stepwise fashion by simulating the uncertainties in every technology required by every mission. After each simulation was completed, the technology costs for each year in the planning horizon were subtracted from an externally specified budget constraint value to determine whether the portfolio as specified was economically feasible. Three budget profiles were examined: 25, 50, and 75 million dollars per year (real-year dollars). A first-order feasibility criterion was used to determine cost feasibility--if the total technology costs exceeded the budget for any year, the portfolio was declared infeasible and discarded. It should be noted that no attempt was made to shift budget funds and technology costs to resolve feasibility problems.

RESULTS

Although a number of cases and sensitivity studies were examined, this paper reports on the primary results obtained for technology budget profiles of $25M/yr, $50M/yr, and $75M/yr per year. The results provided insights into which technologies were important for strategic funding and also identified missions enabled by those technologies. Table 1 summarizes the baseline results for each of the three budget assumptions.

Table 1. Mars Technology Portfolio Results for Three Investment Levels Showing Feasible Technologies and Missions Enabled

Technology Investment	Technology Portfolio (at minimum total technology cost)	Minimum and Maximum Number of Missions Enabled
$25M Per Year	❑ On-orbit science ❑ Telcom network & navigation ❑ Multi-mission survivability, orbiters	❑ Magnetometer orbiter ❑ Synthetic Aperture Radar orbiter ❑ Imaging/Atmospheric Sounding orbiter ❑ Surface Science orbiter
$50M Per Year	❑ Precision landing ❑ Impact attenuation ❑ Hazard avoidance ❑ On-orbit science ❑ Forward planetary protection ❑ Sample characterization, surface ❑ Sub-surface access ❑ Mobility ❑ Sample handling, contamination ❑ Back planetary protection ❑ Telecom network, navigation ❑ Mars Orbit Rendezvous ❑ Multimission survivability ❑ Scout technology	Minimum number of missions: ❑ Mars Smart Lander ❑ Mars Sample Return ❑ Scout mission Maximum number of missions[a]: ❑ Volcanology Rover ❑ Mars Smart Lander ❑ Magnetometer orbiter ❑ Polar Layer Deposit Lander/Rover ❑ Wildcat Lander ❑ Sabertooth Lander ❑ Scout mission [a]Excludes On-orbit science, back planetary protection, Mars orbit rendezvous, and multimission survivability
$75M Per Year	❑ Precision landing ❑ Impact attenuation ❑ Hazard avoidance ❑ On-orbit science ❑ Forward planetary protection ❑ Sample characterization, surface ❑ Sub-surface access ❑ Mobility ❑ Sample handling, contamination ❑ Back planetary protection ❑ Telecom network, navigation ❑ Mars Orbit Rendezvous ❑ Multimission survivability ❑ Scouts	❑ Volcanology Rover ❑ Mars Smart Lander ❑ Magnetometer orbiter ❑ Synthetic Aperture Radar orbiter ❑ Imaging/Atmospheric Sounding orbiter ❑ Surface Science orbiter ❑ Polar Layer Deposit Lander/Rover ❑ Mars Sample Return ❑ Wildcat Lander ❑ Sabertooth Lander ❑ Scout mission

DISCUSSION AND CONCLUSIONS

The results were presented to the Mars Systems Engineering Team and endorsed by that group as providing valuable insights and benefits for Mars Program planning. During the course of this study the following conclusions were drawn.

- At the lowest technology funding levels, the in-situ science strategy was not feasible. Low technology funding implied an orbiter-based program.
- The highest level of technology funding proved to enable all missions and technologies in the portfolio under the current assumptions. As science goals evolve and mission concepts are added, modified, and deleted, different technology portfolios would be derived.
- The inclusion of technology cost profiles and budget constraints immediately focused attention on feasible options. For example, at the $50M/yr level, 89% of the portfolios were eliminated; at the $25M/yr level, 94% of the portfolios were eliminated.
- The methodology provided a systematic rationale that linked enabling technologies to missions and identified high-science value technology portfolios that minimized technology costs.
- The R&D portfolio approach helped clarify understanding between mission planners and technology developers.

The application of the systematic tools and techniques described in this paper to Mars technology and mission planning provided a quantifiable and traceable approach to Mars Program personnel about science, technology, and mission interdependencies. The identification of high-value portfolios was seen as a first step toward making appropriate technology investments for defining the pathway to Mars.

ACKNOWLEDGEMENTS

The authors would like to thank Charles Whetsel of the Mars Exploration Program for his support of this work. This work was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

[1] Greeley, R., Mars Exploration Program/Payload Analysis Group, Part II, Scientific goals, objectives, investigations, and priorities, from Science Planning for Exploring Mars, JPL Publication 01-7, Jet Propulsion Laboratory, Pasadena, California, July 2001.

[2] Mars Exploration and Payload Analysis Group Pathways Science Steering Group Report, "Investigation-Driven Science Pathways for Mars Exploration," Executive Summary, Jet Propulsion Laboratory, Pasadena, CA, June 5, 2002.

[3] McGeary, Michael, and Philip M. Smith, "The R&D Portfolio: A Concept for Allocating Science and Technology Funds", *Science*, Vol. 274, 29 November 1996, pp 1484-1485.

[4] Feinberg, A., and J.H. Smith, "Selection and Scaling of Attributes in Multi-Criteria Decision Making for Ranking Advanced Technology Options," presented at the 1994 Joint National Meeting of TIMS/ORSA: OR/MS Without Boundaries, Boston Marriott Copley Place, Boston, Massachusetts, April 24-27, 1994.