A Modeling Approach to Untangling the Complexity of Space R&D Portfolio Management Decisions

Alexander Burg
Doctoral Research Assistant, The George Washington University, aburg@gwu.edu

Zoe Szajnfarber, Ph.D.
Assistant Professor of Engineering Management and Systems Engineering, the George Washington University, zszajnfa@gwu.edu

R&D Investment Problems

NASA's Mission to "**pioneer the future in** space exploration, **scientific discovery** and aeronautics research" requires technological innovation; yet current performance is inadequate (Fig. 1). Although multiple innovation system have been tried (Fig. 2), there remains a fundamental lack of understanding of how innovation actually happens in institutions like NASA.
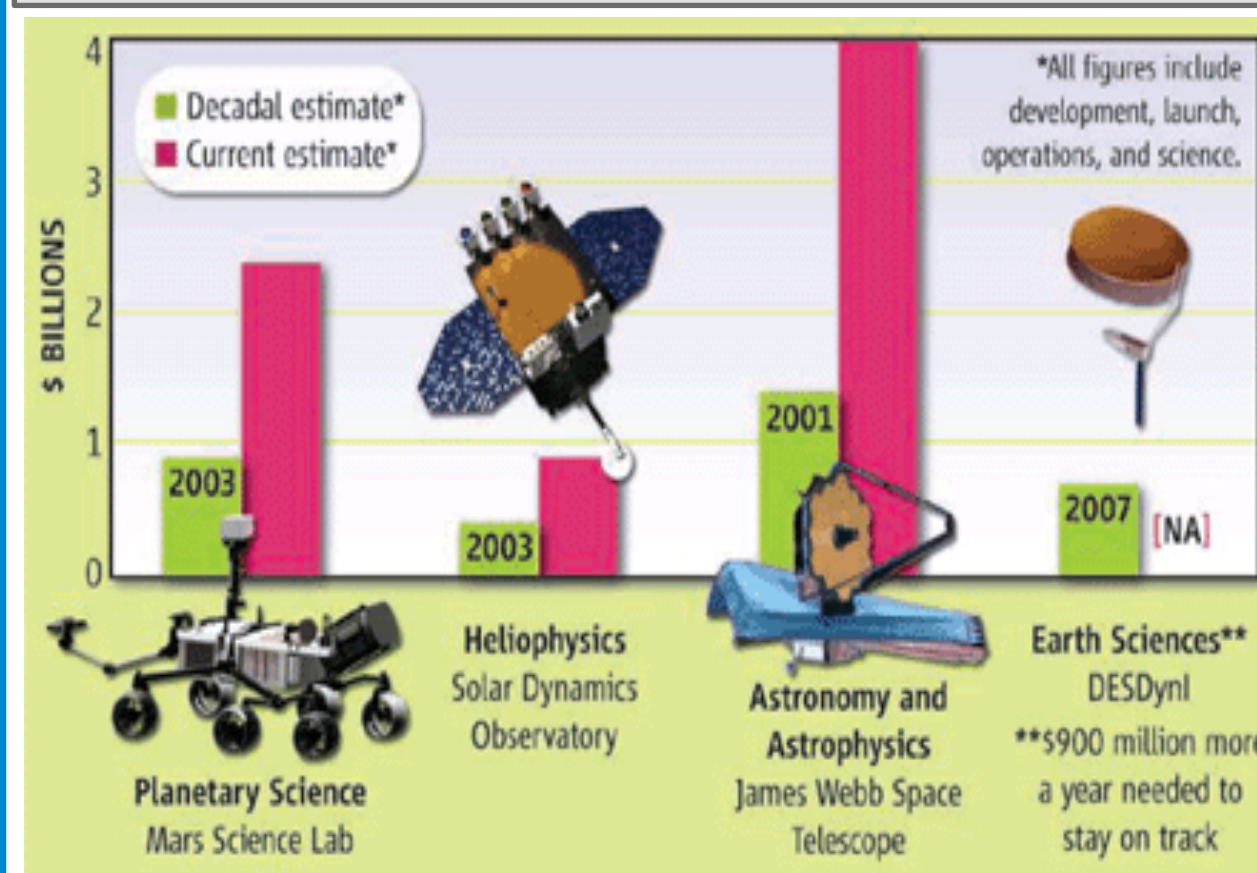

Figure 1: Current Performance
Lawler, A. (2009). Trouble on the Final Frontier: NASA's scientific missions have enjoyed spectacular success. But significant cost overruns and launch delays jeopardize future missions. Science, 324.

Figure 2: Examples of Attempted Innovation Systems
Szajnfarber, Z. (2014) "Space Science Innovation: how mission sequencing interacts with technology policy" Space Policy http://dx.doi.org/10.1016/j.spacepol.2014.03.005

Table 1: Portfolio Method Summary

Method Category	Included Methods	Representative	Data-Feasible	Acceptable	Scalable
Qualitative Portfolio Methods	Roadmapping	Moderate	Good	Good	Moderate
	Strategic Bucketing	Poor	Moderate	Moderate	Good
	Heuristics	Poor	Good	Poor	Good
	Overall	**Poor**	**Good**	**Moderate**	**Moderate**
Quantitative Portfolio Methods	Decision Tree Analysis	Poor	Moderate	Moderate	Moderate
	Real Options Analysis	Moderate	Poor	Moderate	Moderate
	Game Theory	Moderate	Poor	Moderate	Poor
	Overall	**Moderate**	**Poor**	**Moderate**	**Moderate**
Optimization Portfolio Methods	Linear / Non-linear	Moderate	Moderate	Moderate	Good
	Integer	Moderate	Moderate	Moderate	Good
	Dynamic	Moderate	Poor	Poor	Good
	Goal	Moderate	Poor	Poor	Good
	Stochastic	Moderate	Poor	Poor	Good
	Fuzzy	Moderate	Poor	Poor	Good
	Overall	**Moderate**	**Poor**	**Poor**	**Good**

Wicht, A.C., and Szajnfarber, Z., (2014) "Portfolios of promise: a review of R&D investment techniques and how they apply to technology development in space agencies" Space Policy http://dx.doi.org/10.1016/j.spacepol.2014.03.003

Traditional portfolio methods cannot solve this problem. Therefore, we need a modeling framework that captures the relevant dynamics:
- *Mismatched technical project time cycles*
- *Returns have long timeframe with uncertain value*
- *Human matching with R&D and projects*

Figure 3: NASA Innovation Landscape
Szajnfarber, Z. and Weigel, A.L. (2013) "A process model of technology innovation in governmental agencies: insights from NASA's science directorate" Acta Astronautica 84(3-4), 56-58

Objective

Develop a model that is grounded in our empirical observations that actually matches how the system works so that we can answer questions about technology funding, mission planning, and workforce allocation.

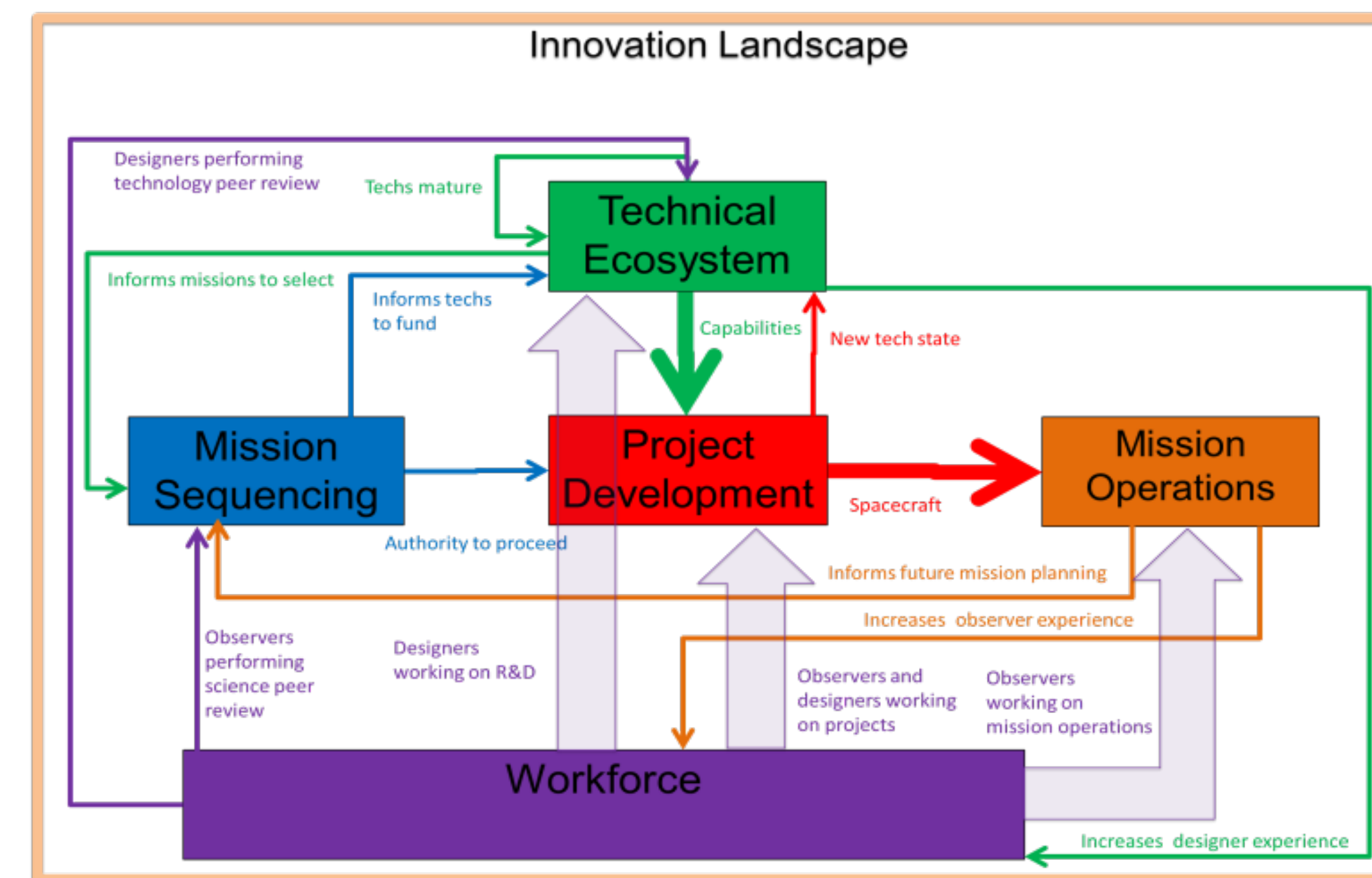Figure 4: Model Overview

Innovation Landscape

Figure 5: In-Depth Model

- Combines workforce, technologies, and missions together in a single framework
- Multiple different types of interactions, occurring at different time scales
- Each module affects the evolution of the other modules

Workforce

- Each member of the workforce has 2 types of parameters:
  - Time Allocation & Knowledge Distribution
- For know we consider 2 types of members of workforce:
  - Observers
    - Scientists who research & analyze data
    - Understand mission priorities, some awareness of developmental technologies
    - Generally work as project scientists and on flight projects
    - Some Observers sit on Decadal Survey Review Panels
  - Designers
    - Build new instruments through R&D and project work
    - Expertise with particular types of technologies
    - Some awareness of new mission concepts
    - Understand technology needs stemming from project work
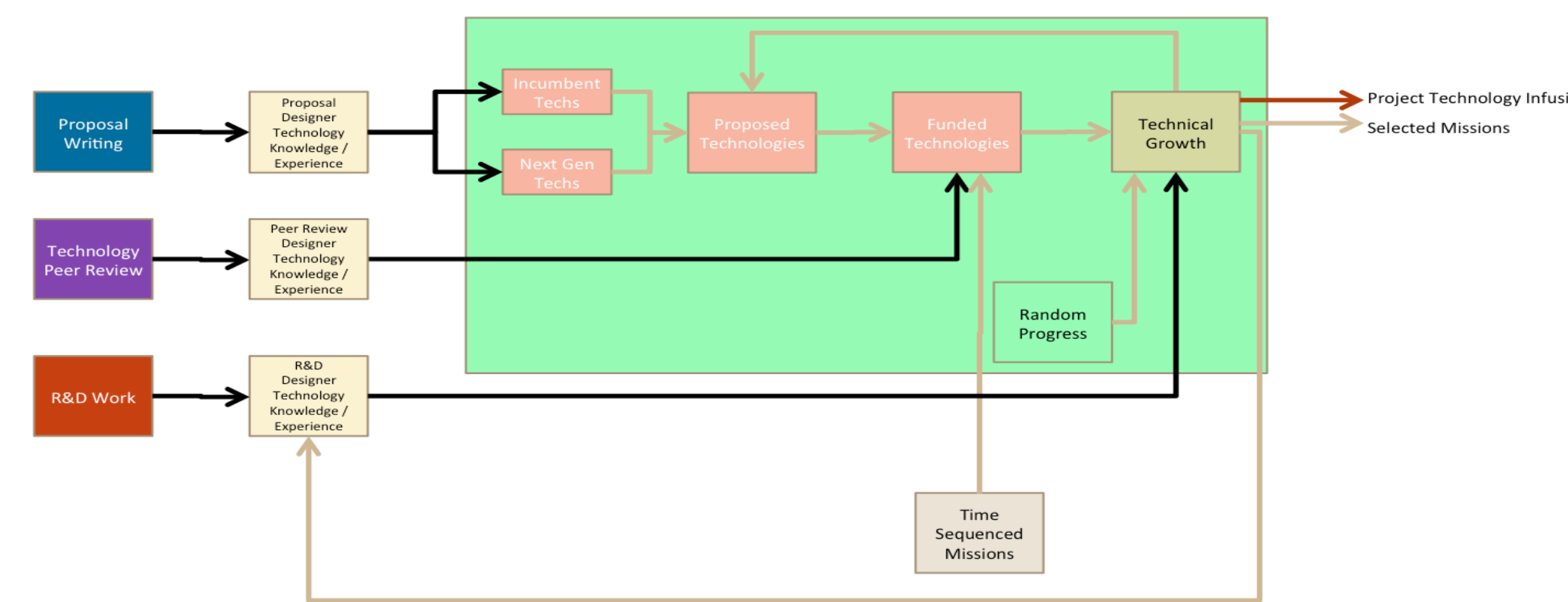   - Some Designers sit on Technology Peer Review Panels

Figure 6: Workforce

Mission Sequencing

- Abstraction of decadal survey process, whereby new missions are selected once per decade
- Input: missions that the "community" wishes to fly.
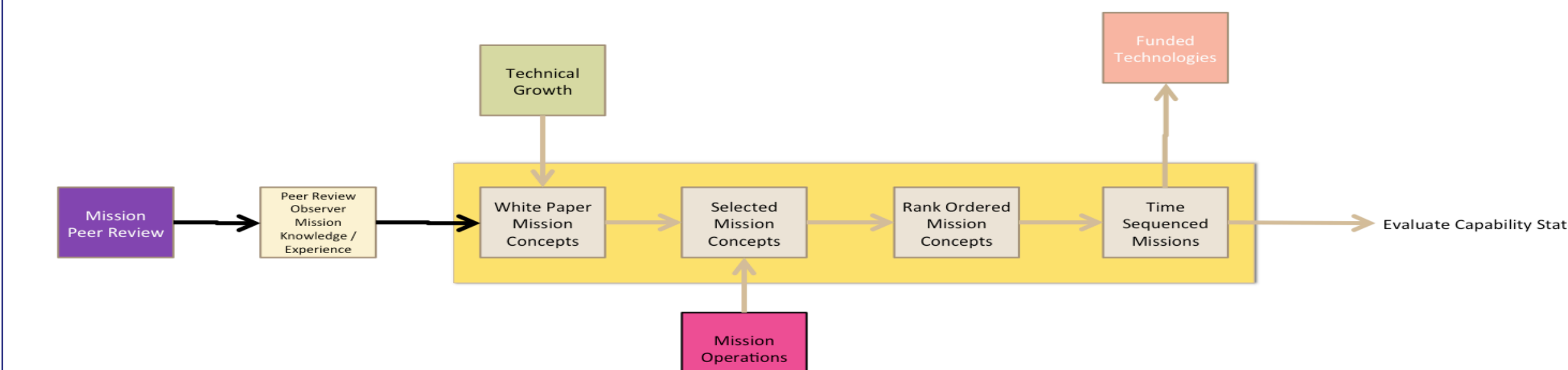 - Prioritizes a subset of them, and slots them into future mission opportunities.

Figure 7: Mission Sequencing

Project Development

- We define projects as being the associations of specific sets of technologies with specific missions
- For each technical capability associated with a particular mission, evaluate whether you think the new version of the incumbent technology or the next generation technology will be at a greater capability level
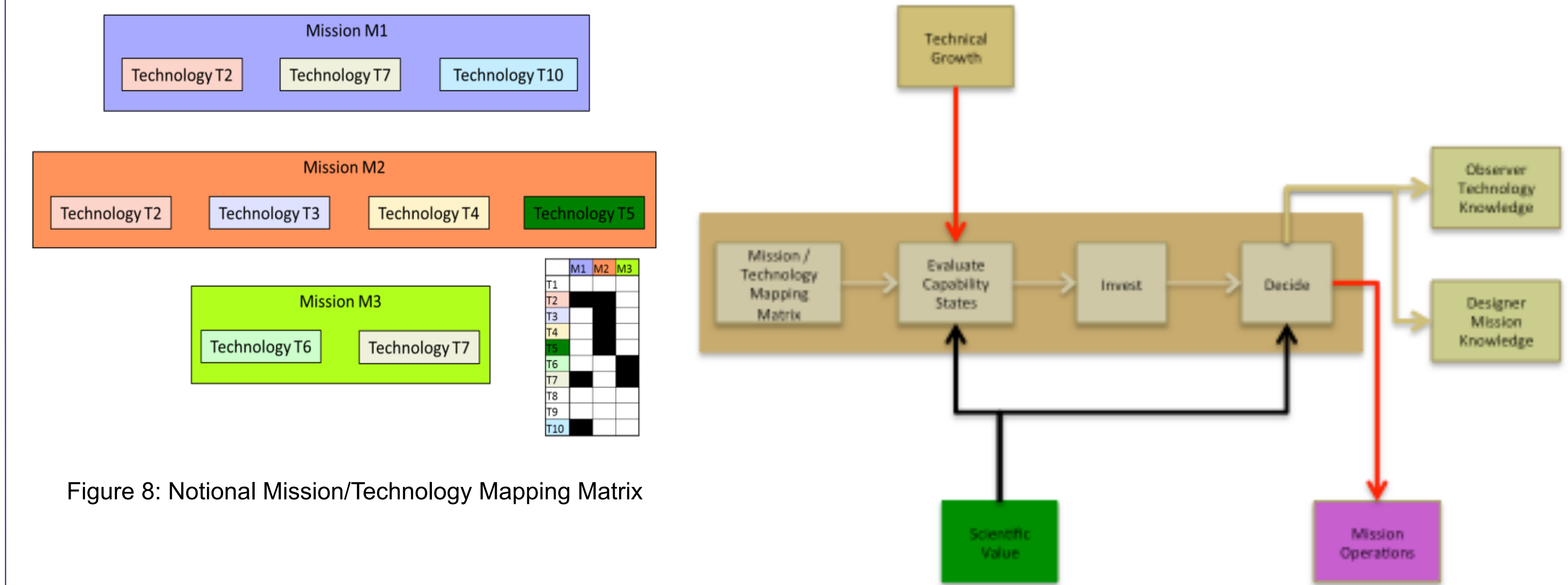

Figure 8: Notional Mission/Technology Mapping Matrix

Figure 8: Project Development

Mission Operations

- Missions launch into space, with the output being science value. Spacecraft are built and operationalized so that they can collect data, which is analyzed by scientists and hopefully leads to discovery.
- Difficult to quantify, but we can make certain assumptions to get to proxy measures for generated scientific value over time.
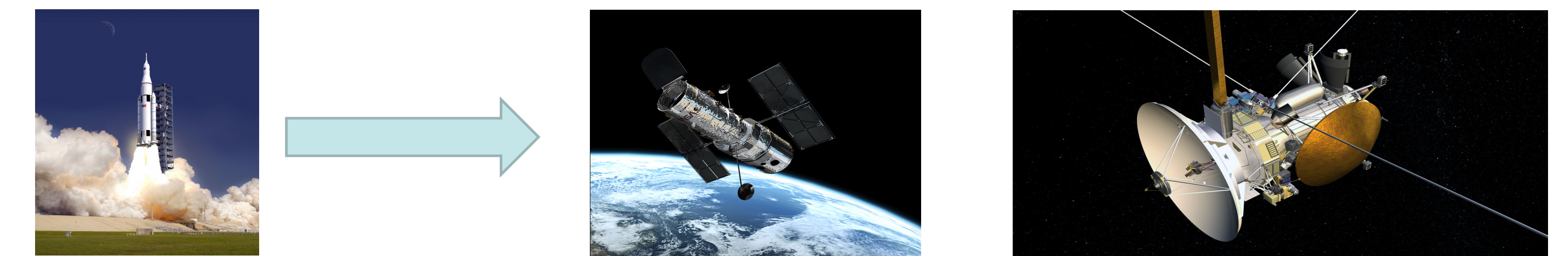

Figure 9: Mission Operations

Initial Results

Average Number of Operationalized Technologies over 20 Years as Average Time Between Missions Varies
&
Average Percent of Technologies Chosen that are Next Generation vs. Average Time Between Missions
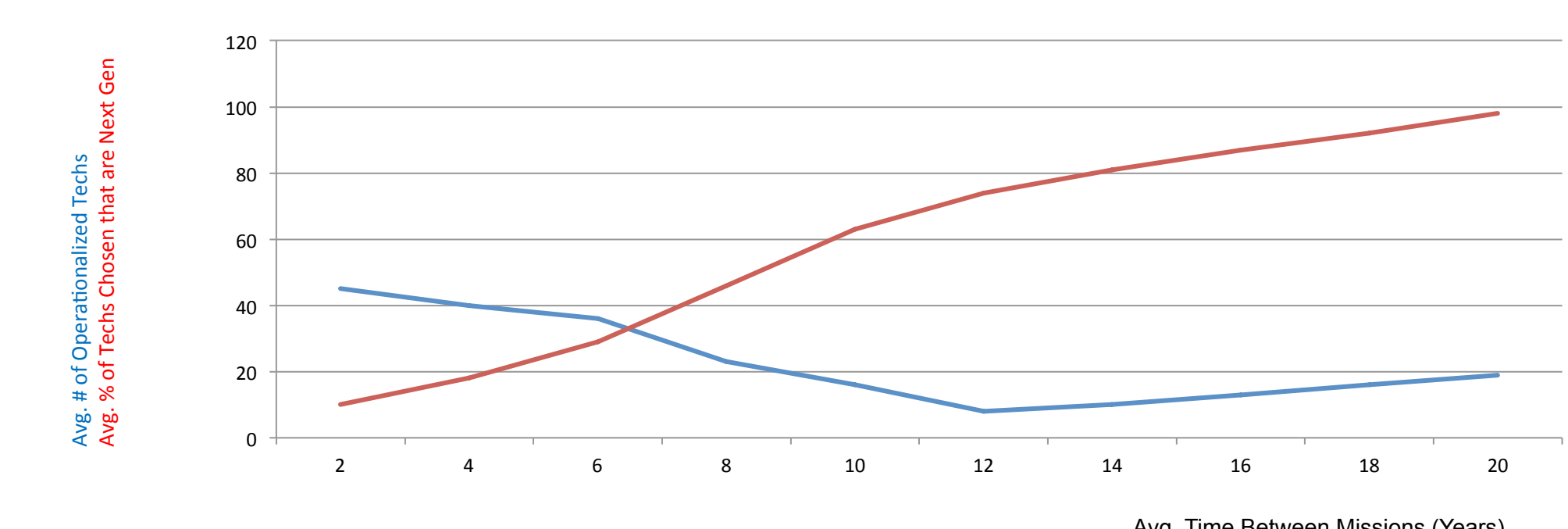
Figure 10: Tradeoffs between Mission Frequency and Technological Progress

- There is a trade-off between mission frequency and technology advancement
  - As mission rate increases, more technologies become utilized in space, but there are smaller technological leaps due to less effort towards R&D
  - As mission rate decreases, fewer technologies become utilized in space, but there are larger technological leaps due to greater effort towards R&D
- Long term health of organization suggests emphasis should be placed towards technological growth

Future Work

- Test narrowing vs. spreading of investments
- Understanding implications of changing workforce policies
- Assessing the overall impacts of changing the set of technologies flown on a particular mission