Systems Engineering Advancement Research Initiative

Massachusetts Institute of Technology

Center for Aerospace Systems, Policy and Architecture Research

Innovation Pathways in Technology Intensive Government Organizations: Insights from NASA

Zoe Szajnfarber, Ph.D. in Engineering Systems (expected in 2011)

Committee: Prof. Annalisa L. Weigel, (chair); Prof. Edward F. Crawley;
Prof. Daniel E. Hastings; Prof. James M. Utterback

Biography

Zoe Szajnfarber is currently working towards her Ph.D in ESD at MIT Zoe has worked as a systems engineer at MDRobotics and Dynacon Inc; and at the European Space Agency as a researcher studying technology development in space science missions. Zoe received a B.A.Sc. in Engineering Science from the University of Toronto (2006) and M.S. degrees in Aero/Astro and TPP from MIT (2009).

zszajnfa@mit.edu

Related Publications

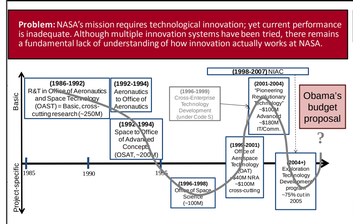
Szajnfarber, Z., and A. L. Weigel (2010) "Towards an Empirical Measure of Spacecraft Innovation: The Case of Communication Satellites" *Acta Astronautica*, 66(7-8), 1266-1279

Szajnfarber, Z., Stringfellow, M. V. and Weigel A. L.. (2010) "The Impact of customer-contractor interactions on communication satellite innovation: insights from communication satellite history" *Acta Astronautica 67(9-10), 1306-1317.*

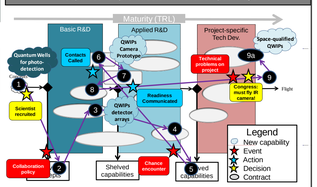
Szajnfarber, Z., Richards, M. G. and Weigel, A. L., "Implications of DoD Acquisition Policy for Innovation: The Case of Operationally Responsive Space," AIAA Space 2008, AIAA, San Diego California, Sept. 9th-11th 2008. (R&R in IJDAM)

Problem Framing

Problem: NASA's mission requires technological innovation; yet current performance is inadequate. Although multiple innovation systems have been tried, there remains a fundamental lack of understanding of how innovation actually works at NASA.



Current stage-gate conceptualization fails to explain observed "loopiness" of pre-infusion innovation pathways

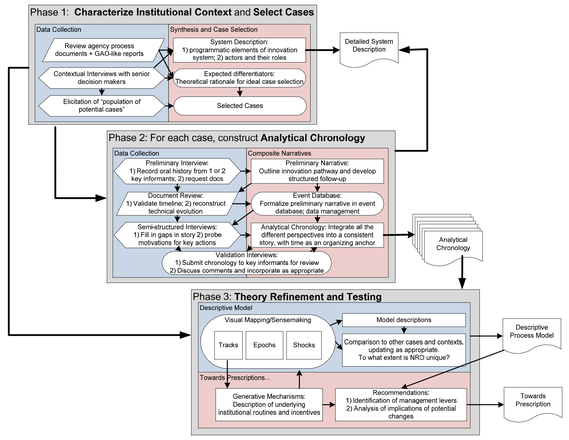


Definition: An **Innovation Pathway** describes the set of events, decisions and actions that mature a new technology or concept from initial conception to implementation on a flight project

Research Questions:

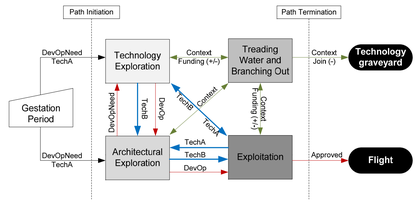
1. What is the structure of NASA's *innovation system*?
2. How do new capabilities traverse the innovation system as they are matured, and infused into flight projects?
3. Are there patterns of *innovation mechanisms*, important across multiple *innovation pathways*?

Research Approach



Model Overview

- Core concepts:
  - System exhibits a punctuated equilibrium (i.e., epochs of persistent stable behavior, punctuated by transition inducing shocks)



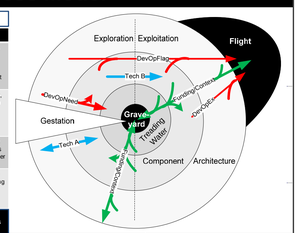
  - Epochs and shocks common across pathways, orders of progression not.
    - 4 distinct and identifiable epochs between path initiation and termination
    - 3 classes of shocks (problems, solutions, context changes)

Descriptive Process Model

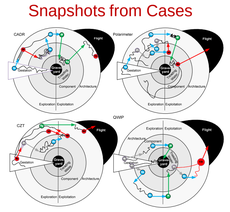
Gestation: Pre-path initiation; sets initial conditions for path (incl. relationships, technical & application knowledge, access to resources). Typically, Multiple disjointed small groups are separately engaged in other, tangentially related projects

Epoch	Description	People	Technology	Funding
Tech Exploration	Simultaneous pursuit of multiple new technological approaches. Goal: fund the effort long enough to find some strategy that works and proves the concept	Small core team of internal experts, augmented by ad hoc external collaborators.	Proliferation of ideas, parallel experimentation, inexpensive mock-ups	Stuck resources at branch-level; different institutional sources applied for indiscriminately, without differentiating among target maturity levels
Arch Exploration	Focused form of exploration, guided by articulated performance-oriented goal. Goal: demonstrating flight feasibility (breadboarding/ detailed simulations)	Similar to Tech Ex, with addition of end-user (i.e., scientists)	Reconfiguration of existing components to solve a new problem	Similar strategy as Tech Ex, with higher funding burden (i.e., more NRA vs. IRAD)
Exploitation	Structured actions taken to mature the selected systems architecture towards flight readiness.	Major expansion of team size; bring on engineers and PMs (internal additions).	Focus on testing and implementation issues.	Typically project-specific or large NRA (cost of activities is proportionally much higher than other epochs)
Treading Water & Branching out	This is survival mode: keep key team members funded, so they won't be permanently reassigned to other unrelated projects	Reduction to original core; external collaborators motivated by branching-out	Proliferation of applications, leveraging same core innovation	Drought. Applying to every possible source and creating new ones.

Termination 1: innovation infused into approved flight project (phase B).
Termination 2: Drought persists to point where key team members are forced to join other funded projects. While constituent ideas may resurface in later projects, this will only occur based on significant efforts from an individual champion.



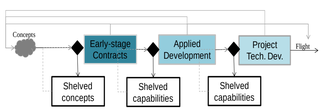
Snapshots from Cases



Shock	Description	Direction of Impact
Solutions	A. 'Tech A:' Laboratory demonstration that a new concept can yield the desired effect (often with poorer performance than incumbent). B. Tech B: Demonstration of practical utility. **Timing:** unpredictable/unpredictable	A. Can open up new search space; shift in current trajectory. Raises or lowers level of exploration (from tech to arch or visa versa) B. Weaker than Tech A (legitimate rather than initiate); Necessary precursor to exploitation, but rarely forces transition.
Problems	C. DevOpFlag: Revolutionary, focused aspirations prompts search for radically new approach in target areas. D. DevOpEx: Explicitly non-specific, relatively small opportunity. Still serve as important focus. E. DevOpNeed: Identification of key technical roadblock in the context of existing architectural concept. **Timing:** cyclical/semi-cyclical/unpredictable	C. Typically initiates architectural exploration (explicitly corresponds to resource availability) D. Enables transition from exploration to exploitation (assuming recent Tech B). E. Can initiate new innovation pathway (per Tech A) or lower the level of exploration from arch to tech.
Context	F. Drought: Sudden and/or sustained inability to secure resources (including yearly center- and directorate-level). Often related to change in administration. G. Context: captures key events and activities exogenous to innovation pathway, not covered by other label (e.g., failures of Astro E/E/II change risk assessment on H). **Timing:** semi-cyclical/unpredictable	F. Initiates transition to treading water & branching out epoch, regardless of current epoch. G. Impact is highly dependent on nature of context change (e.g., in Astro case, it precipitated DevOpEx).
Collaboration	H. Join: In the context of a small team, each member brings unique and important skills/equipment, that often shaped the pathway. **Timing:** semi-cyclical (external)	H. Join (+), particularly when the addition was external, precipitated several Tech As and Bs, but didn't tend to induce transitions. Internal additions tended to correspond to/follow otherwise induced transitions.

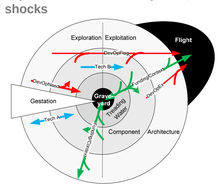
Where does this get us?

Solve relative resource allocation problem; improved gate criteria



vs.

Recognize implication of different epochs; harness directional shocks



Assumptions of stage-gate view	Observations captured in process model
1. New technologies mature from left to right	1. New technologies embody multiple levels of maturity simultaneously, challenging the concept of monotonically increasing "maturity."
2. Process is controllable through funding allocation and gate decisions	2. Experts apply to multiple levels of funding indiscriminately, confounding basic and applied resources, and limiting that avenue for management control.
3. Adding more stages will ease transition (mitigate valley of death)	3. The valley of death is more than just a funding gap; there are explorers and exploiters, but few individuals who excel at both modes of R&D.
4. Rejection at a decision point leads to a shelved capability that can be re-infused as long as it's not obsolete.	4. "Shelf life" is as much a matter of keeping the team intact as a question of obsolescence.

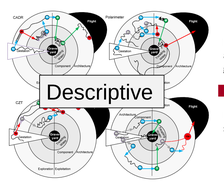
Future Directions

Currently have:
1. Detailed innovation pathways
2. Descriptive, empirically grounded process model

FY2010

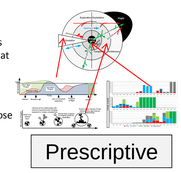
Future Work:
3. Prescriptive framework linking tracks and routines to model.
4. Observed systems principles

FY2011



Map linkages between observed behaviors and the routines & individual incentives that generate them.

Identify key management levers and propose strategies for interventions.



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