Managing Innovation in Technology-Intensive Organizations: The need to move beyond Stages and Gates

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History of Shifts in R&D Strategy

(1986-1992) R&T in Office of Aeronautics and Space Technology (OAST) = Basic, cross-cutting research (~250M)


(1999-2001) Office of Aerospace Technology (OAT)
~$40M NRA
~$100M Advanced
~$180M IT/Comm.

(2001-2004) “Pioneering Revolutionary Technology”
~$100M Advanced
~$180M IT/Comm.

~75% cut in 2005

(1998-2007) NIAC

NEED: Improved understanding as a precursor to change

(Based on data collected for NASA R&T Study and NRC study of NIAC)
Overview

Research Questions:
1. How do new capabilities traverse the innovation system as they are matured and infused into flight projects?
2. To what extent can the observed innovation pathways be improved through feasible management interventions?

Stage-Gate conceptualization is not just coarse; it’s wrong.

Introduce empirically grounded model; explains conflicting observations

Implications for technology management for the long run
Problem Formulation
Current Conceptualization: Stage-Gates

**Innovation as an Optimization Problem**
- Relative resource allocation problem (how much money in each bucket?)
- Resources spacing problem (how many buckets?)
- Gate criteria definition problem (how many should be advanced, and by what criteria?)

*Synthesized from NASA strategic planning documents 1990-2006*
Takeaways

1. An **Innovation Pathway** describes the sequence of events, actions and decisions that lead to the **first use**.

2. Informal mechanisms are important.

3. Observed **switchbacks** in pathway cannot be explained by extant theory.
Limitations of the Stage-Gate View:
Is the model coarse or meaningfully inaccurate?
Stage-Gate Assumptions

Innovation as an Optimization Problem
- Relative resource allocation problem (how much money in each bucket?)
- Resources spacing problem (how many buckets?)
- Gate criteria definition problem (how many should be advanced, and by what criteria?)

Underlying assumptions:
1. Technologies **mature** from **left to right** over time;
2. **Stages** are **mutually exclusive** (at a given time);
3. **Shelving** is an **active process**, controlled by decision-makers;
4. **Shelf life** is **passive** and a function of technical obsolescence.
Observed Switchbacks in Maturity

- Project-specific Tech Dev.
- Applied R&D
- Basic R&D

Expectation vs. Observation

Time


Observed Switchbacks in Maturity
Assumptions #1 and 2, not respected
Passive Gates, Active Shelves

- **Expectation:**
  - Rejection at Gate => Shelving
  - Similar shelf lives for similar technologies

- **Observation:**

<table>
<thead>
<tr>
<th>Case</th>
<th>Rejected + Shelf</th>
<th>Rejected + !Shelf</th>
<th>!Rejected + Shelf</th>
<th>Duration on Shelf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech A</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>8 /1 yrs</td>
</tr>
<tr>
<td>Tech B</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>5 yrs</td>
</tr>
<tr>
<td>Tech C</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Tech D</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2 yrs</td>
</tr>
<tr>
<td>Tech E</td>
<td>1</td>
<td>Multiple</td>
<td>1</td>
<td>2 / 5 yrs</td>
</tr>
<tr>
<td>Tech F</td>
<td>0</td>
<td>multiple</td>
<td>0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Need:** More nuanced understanding of underlying processes
Empirically Grounded Process Model
New technical insights at the component, architectural and ConOps levels

Team composition, tracking role on project and duration of participation

Funding sources, categorized by institutional level (e.g., center vs. HQ vs. program)
Epoch-Shock Model: Track View

- System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**
• System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**

  – **Epochs** are illustrated as boxes, and roughly map to stages
  – **Shocks** induce transitions following arrows from one box to another
Epoch-Shock Model: Track View

- System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**

### Basic R&D STAGE
- Low TRL
- <$100K
- Center-level

### Technology Exploration EPOCH
- Patchwork of funding sources
- Small core **team**; *ad hoc* collaborations
- Multiple parallel technology paths

<table>
<thead>
<tr>
<th>Case</th>
<th>Funding</th>
<th>Personnel</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>CADR#1</td>
<td>4xCenter</td>
<td>team + Inst - Tech</td>
<td>parallel component paths</td>
</tr>
<tr>
<td>CZT#2</td>
<td>3xCenter + 3xNASA + Balloon</td>
<td>team + 4xTech + Inst</td>
<td>multiple technique strategies</td>
</tr>
<tr>
<td>Pol#3</td>
<td>Brainstorm + 2xCenter + 3xNASA</td>
<td>team + Tech</td>
<td>multiple readout strategies</td>
</tr>
<tr>
<td>Si#4</td>
<td>NASA + Project</td>
<td>team + 3xInst + Tech - 3xObs</td>
<td>multiple materials and techniques tried</td>
</tr>
<tr>
<td>Si#5</td>
<td>2xCenter + 2xNASA + Sounding Rocket + Project</td>
<td>team + Tech</td>
<td>multiple materials and techniques tried</td>
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<tr>
<td>Si#6</td>
<td>2xCenter + NASA + SR + 2xProject</td>
<td>no change</td>
<td>multiple readout strategies and techniques tried</td>
</tr>
<tr>
<td>TES#7</td>
<td>Branch +3xCenter + 2xNASA + SR + Project</td>
<td>team + Tech</td>
<td>Exploration of new materials and techniques</td>
</tr>
</tbody>
</table>
System exhibits **epochs** of persistent stable (and identifiable) behaviors punctuated by transition inducing **shocks**

- **Epochs** are illustrated as boxes, and roughly map to stages
- **Shocks** induce transitions following arrows from one box to another
- **Innovation pathways** start in gestation and move through the system.
• Overlay of ALL the transitions from the pathways studied

– Bi-directional and heavy flow between Technology and Architectural exploration.
– Flow through Exploitation forks between Treading Water and Flight
Epoch-Shock Model: Paths Traveled

- Overlay of ALL the transitions from the pathways studied

- Colors differentiate different types of shocks, some of which are more controllable by management interventions
- Combined shocks are possible (e.g., red + blue = purple)
Using the detailed understanding captured in the model to explain the observed behaviors
Explaining the Observed Behaviors

- Recall Conflicting Observations:
  - Innovation doesn’t progress monotonically from left to right.
    - Resources are being drawn simultaneously from different stages
    - AND switchbacks to earlier stages were observed.
  - Shelving isn’t an active administrative decision.
    - Some pathways persist despite being rejected at nominal gates,
    - while others wane due to external context changes

- Explanation in two parts:
  - Architectural complexity creates “option” for switchbacks.
  - This “option” can be strategically exercised to **survive** droughts.
Explanation 1: Architectural Complexity

- **Explanation 1:**

  In a complex integrated product, innovation can happen at different rates, in different sequences at different levels of the architecture. Thus, switchbacks are a natural corollary to complexity.

- **CADR Example:**

  ![CADR Diagram](Diagram.png)
Explanation 2: Survival Strategy

- **Explanation 2:** Technologists can *exploit* the switchback "option" to *survive* funding droughts.

  ... were never concerned that the technical capability would become obsolete... worried about losing one key technician... who was the kind of guy who would rather retire and work on his motorcycle than transition to another project while waiting for funding to be restored. And rebuilding that kind of expertise would have taken a very long time...

**Component Architecture Research**

**Exploit the option by:**

1. Focusing on maturing a key component.
2. Finding a new system application to research.

**The “Option”**

- C/multi-ADR applications
- Alternative components
Explanation

(1) Switchbacks are a natural byproduct of complexity AND
(2) Architectural complexity creates an “option” that can be exploited to tread water
Implications for Technology Management
**Stage-Gates vs. Epoch-Shocks**

**Current control mechanisms**

1. Proportionally more funding for basic R&D to increase pool of early-stage concepts.
2. Used gate decisions to control % progression to next stage.
3. Adding more stages to facilitate transitions

**Assessment based on Epoch-Shock model**

1. Resources can’t be earmarked for “early stage/basic.” In practice that funding stream is split between basic concepts and others that are treading water and branching out.
2. Actively controllable gates don’t exist. As long as teams can draw resources from multiple levels simultaneously, no gate can control the flow.
3. The lack of linear progression invalidates the concept of bridging transitions. There is an important human component of the transition dynamics.

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New control mechanisms are needed
Natural Extensions

Explains why the NASA science innovation system works the way that it does and shows that administrative-level interventions cannot work as intended.

Identify feasible interventions at lower institutional levels

Replicate study in comparable context

>> Do the observed dynamics hold?

Extend the insights beyond one-off missions to technology transition in path-dependent infrastructures.

>> Can changes in org structure and/or funding strategies serve as levers

>> How can mismatches in technology cycles and context shocks be mitigated by architecture
Questions, Comments?

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