# Applying Systems Architecture to Technology Policy Research:
## Models of Space Activity in Developing Countries

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# Research Overview



INCOSE
International Symposium
Philadelphia, PA
June 24-27, 2013

Goals and Outcomes

Analysis & Modeling

Societal Progress and Well-being

Systems Architecture and Systems Engineering

Technology Management and Policy

Implementation Approaches
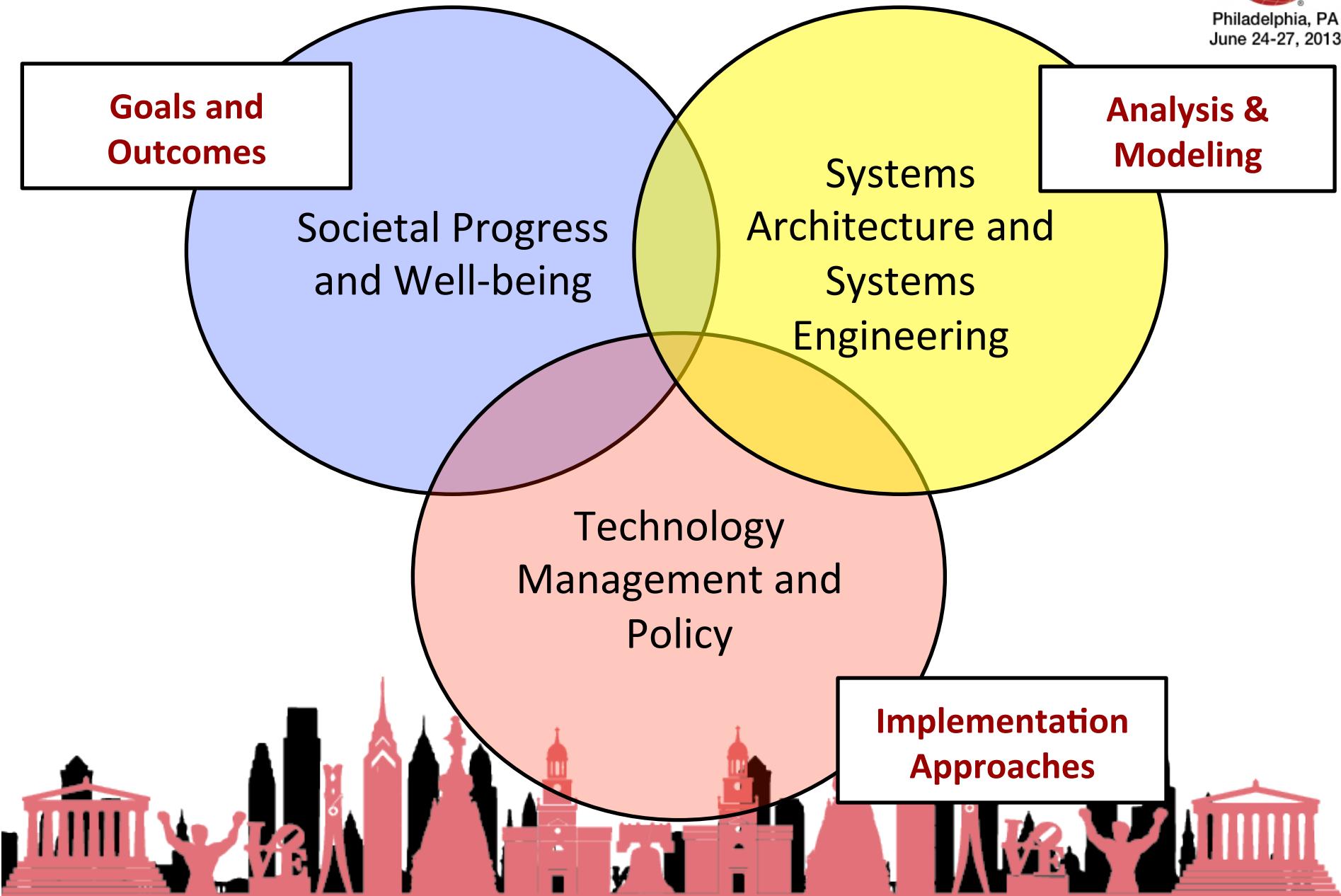
# Architectural Framework for Technology Policy Research

## Stakeholders

**Def**: Individuals, organizations or groups that affect or are affected by the system

## Context

**Def**: Constraints or Opportunities that hinder or facilitate meeting the objectives and requirements

**Influences**

**Hinders or Facilitates**

**Express**

## Objectives

**Def**: High level goals of the stakeholders that define what the system should achieve

**Meet**

## Functions

**Def**: (Verbs) Activities that transform objects of form to meet objectives`

**May include**

## Forms

**Def**: (Nouns) organizations, people, physical or virtual objects or procedures that execute functions

**Transform**

**Execute**

**Allocated to**

# Context of the Research

## Satellite Programs in Developing Countries

# Stakeholder Objectives emphasize National Development
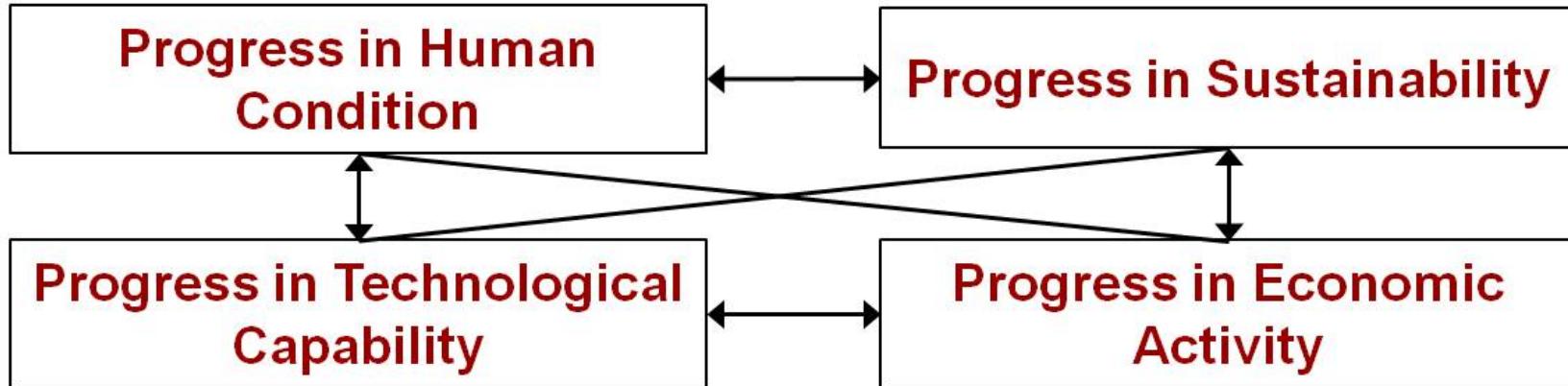
| Progress in Human Condition | | Progress in Sustainability |
|---|---|---|
| Progress in Technological Capability | | Progress in Economic Activity |

| Type of Progress | Example Metric | Source of Metric | US Rank & Score |
|---|---|---|---|
| **Human Condition** | Human Development Index | United Nations | Rank 4/187; Score .91/1 |
| **Sustainability** | Environmental Performance Index | Yale and Columbia University | Score 63.5/100 |
| **Technology** | Information and Communication Technology Development Index | International Telecommunications Union | Rank 17/152; Score 7/10 |
| **Economic Activity** | Global Competitiveness Index | World Economic Forum | Rank 4/139; Score 5.43/7 |

# Space-related activity is relevant to many aspects of national development

| Five Types of Space Activity that Benefit National Development |
| :---: |
| Applying Satellite Services |
| Building Technological Capability |
| Enabling Economic Activity |
| Inspiring Technology Applications |
| Building Scientific Knowledge |
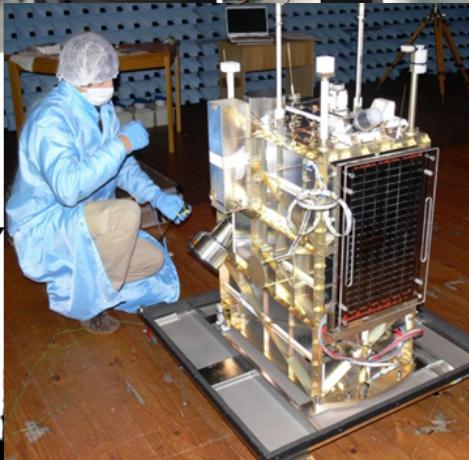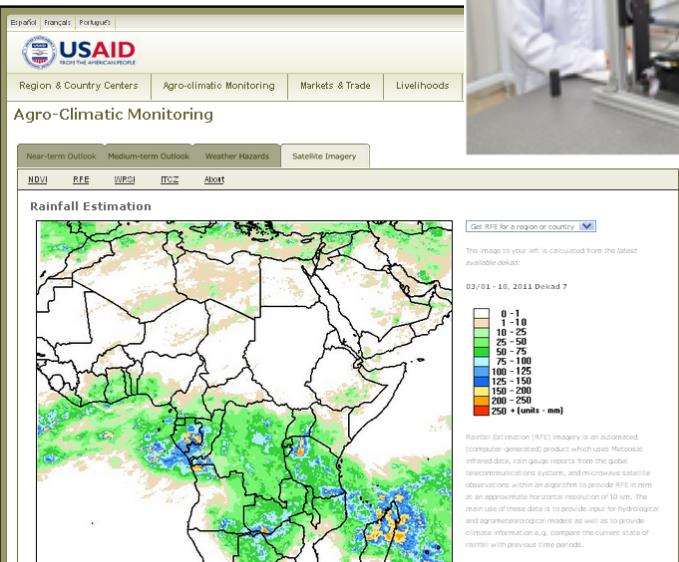
# New countries are investing in satellite hardware, expertise and infrastructure

AlgeriaSat-1



EgyptSat-1



NigeriaSat-X



SumbandilaSat

| Country | National Space Agency Established | First Domestic Satellite Launched |
|---|---|---|
| Algeria | 2002 | 2002 |
| Egypt | 1994 | 1998 |
| Nigeria | 1999 | 2003 |
| South Africa | 2010 | 1999 |

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# New countries are investing in satellite hardware, expertise and infrastructure

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| Region | Country | National Space Agency Or Office (Year Est.) | Buy LEO Sat. (Launch Year) | Buy GEO Sat. (Launch Year) | Build LEO Sat. Locally (Launch Year) | Build GEO Sat Locally (Launch Year) |
|---|---|---|---|---|---|---|
| Asia | Indonesia | LAPAN (1963) | 2007 | 1997 | In process | |
| | Malaysia | ANGKASA (2002) | 2000 | 1996 | In process | |
| | Pakistan | SUPARCO (1981) | | In process | 1990 | |
| | South Korea | KARI (1989) | 1992 | 2009 | 1993 | |
| | Thailand | GISTDA (2000) | 1998 | 1993 | | |
| | Turkey | TUBITAK (1985) | 2003 | 1994 | 2011 | |
| | United Arab Emirates | EIAST (2006) | 2009 | | | |

# New countries are investing in satellite hardware, expertise and infrastructure

| Region | Country | National Space Agency Or Office (Year Est.) | Buy LEO Sat. (Launch Year) | Buy GEO Sat. (Launch Year) | Build LEO Sat. Locally (Launch Year) | Build GEO Sat Locally (Launch Year) |
|---|---|---|---|---|---|---|
| Latin America | Argentina | CONAE (1991) | | | 1996 | In process |
| | Chile | ACE (2001) | 1998 | | | |
| | Mexico | AEM (~2010) | | 1985 | 1996 | |
| | Venezuela | ABAE (~2008) | | 2008 | | |

# Small Satellite Technology

*Smaller, less complex and less expensive satellites are becoming more mature, allowing new countries to execute satellite projects*
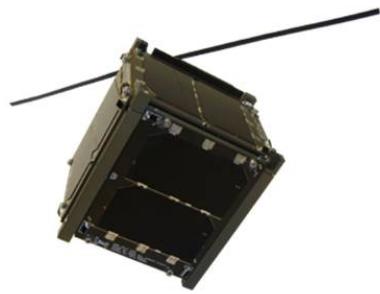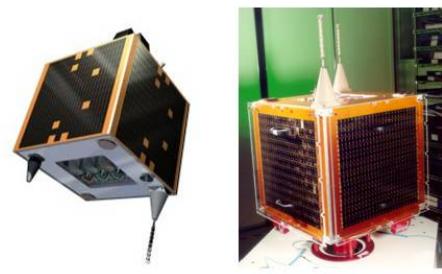
| CubeSat | |
|---|---|
| **Weight** | < 1 kilogram |
| **Capability** | Technology demonstration and Education |
| **Lifetime** | < 1 year |
| **Cost with launch** (USD) | $50,000 – $200,000 |

| Small Satellite | |
|---|---|
| **Weight** | 100 to 1000 kilograms |
| **Capability** | Earth Remote Sensing and Space Science |
| **Lifetime** | ~ 5 years |
| **Cost** (USD) | $10 - $100 Million |

| Commercial Satellite | |
|---|---|
| **Weight** | > 1000 kilograms |
| **Capability** | High Quality Earth Remote Sensing and Space Science |
| **Lifetime** | 7 to 10 years |
| **Cost** (USD) | $100 - $500 Million |

# Benefits of Applying Architectural Framework (AF)

- **Integrating Concepts from Literature**
  - The AF shows links between ideas from diverse literature communities

- **Enabling Multi-Level Analysis**
  - The AF is used to model national technology policy decisions at three levels
    - Technology Management for Development
    - Technology Project Design
    - Implementing a Collaborative Satellite Development Project

- **Enabling Synthesis and Explanation**
  - The AF lays a foundation for building theoretical explanations that combine evidence from multiple case studies

# Integrating Concepts from Literature

| Literature Area | Major Concept | Key Authors |
|---|---|---|
| **Technology and Development** | Technological progress contributes to development along with sustainability, economics and the human condition | Smith 1776; Schumpeter 1936, 1939; Mokyr 2002; Grieve 2004 |
| **Technological Learning** | Latecomers can master, adapt and diffuse existing technology from foreign sources | Amsden 2001, 2007; Lall 1992; Kim 1999; Dosi 1996; Dahlman 1987; Westphal 1981 |
| **Technology Transfer** | Technology transfer through intentional partnerships is one way to access foreign technology | Contractor and Sagafi-Najed 1981; Reddy and Zhao 1990; Gross 1996; Kedia and Bhagat 1988 |

# Integrating Concepts from Literature

| Literature Area | Major Concept | Key Authors |
|---|---|---|
| Complex Product Systems | Capital goods that are engineering and software intensive have specific challenges | Hobday & Rush 1999 |
| Project Delivery | Consider customer's knowledge, risk aversion and regulation to design partnership approach | Gordon 1994; Miller 1997 |

• This set of literature is relevant to analyzing the policy challenges facing developing countries that invest in new technology areas
• Each area of literature has a different purpose and emphasis
• The Architectural Framework provides a unifying structure to link the literature concepts

# Integrating Concepts from Literature

| Literature Areas | Major Stakeholders | Contextual Opportunities & Constraints | Stakeholder Objectives | Functions | Forms |
|---|---|---|---|---|---|
| **Technology and National Development** | Governments, citizens, firms, research organizations, not-for-profit organizations in a country | Market Failures, Institutional Failures, Disease Burden, Globalization, Natural Resources, Infrastructure, etc. | Progress in Human Condition, Sustainability, Technological Capability and Economic Activity | Building Communication Infrastructure, Reducing Corruption, Fighting Disease, Managing Water Resources | Infrastructure Investment, Transparency Initiatives, Vaccination Programs, Monitoring Systems |
| **Technological Learning and Technology Transfer** | Learning Organization, Expert Organization, Oversight Organization | Policy infrastructure, Facilitating event, national level technology vision, leadership approach | Adopt and apply domestically a technology that was previously available from foreign sources | Accessing Technology, Mastering Technology, Adapting Technology, Diffusing Technology | Training Approaches: Theoretical Training, Practical Training, On-the-Job Training |

# Integrating Concepts from Literature

| Literature Areas | *Major Stakeholders* | *Contextual Opportunities & Constraints* | *Stakeholder Objectives* | *Functions* | *Forms* |
|---|---|---|---|---|---|
| **Complex Product Systems** | Customer, Supplier, Subcontractors, Regulators | Geographical distribution of team, Funding, Collaboration Tools, Level of integration of system, System operational environment | Execute design and implementation of a Complex Product System to meet needs of customer and bring financial benefit to suppliers | Designing, Procuring, Manufacturing, Integrating, Testing, Deploying, Maintaining, Supporting | Laboratories, Software Modeling Tools, Test Facilities, Specialized Equipment |
| **Project Delivery** | Project Manager, Customer, Supplier, Financier | Schedule, Funding, Risk, Labor and capital resource requirements | Procure infrastructure that addresses need for public service | Selecting Supplier, Contracting, Financing, Designing, Implementing | Project Delivery Methods: Prime Contractor, Multiple Primes, Turnkey, Build-Operate-Transfer, Design-Build |
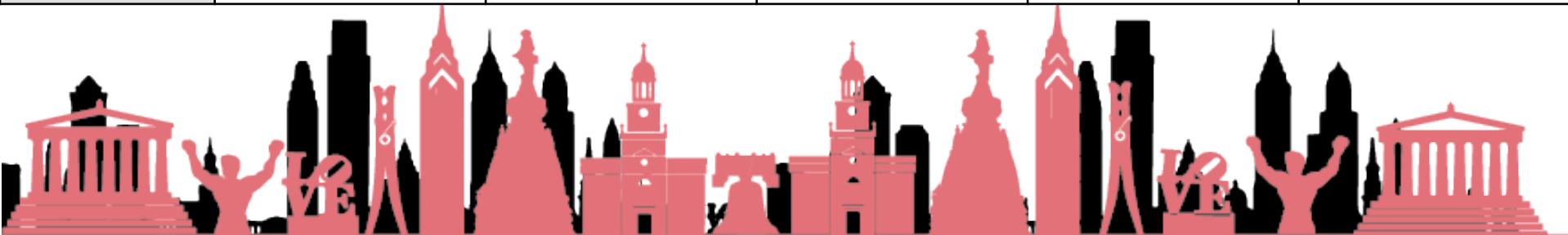
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# Technology Management for Development



| Functions | Forms |
|---|---|
| Identify Technology | Technology Identification |
| Access Technology | Local Technology Adoption · Foreign Technology Access |
| Learn Technology | Collaborative Learning · Independent Learning |
| Transfer Technology | Partnership with foreign firm · Partnership with foreign government |
| Apply Technology | Technology Application |
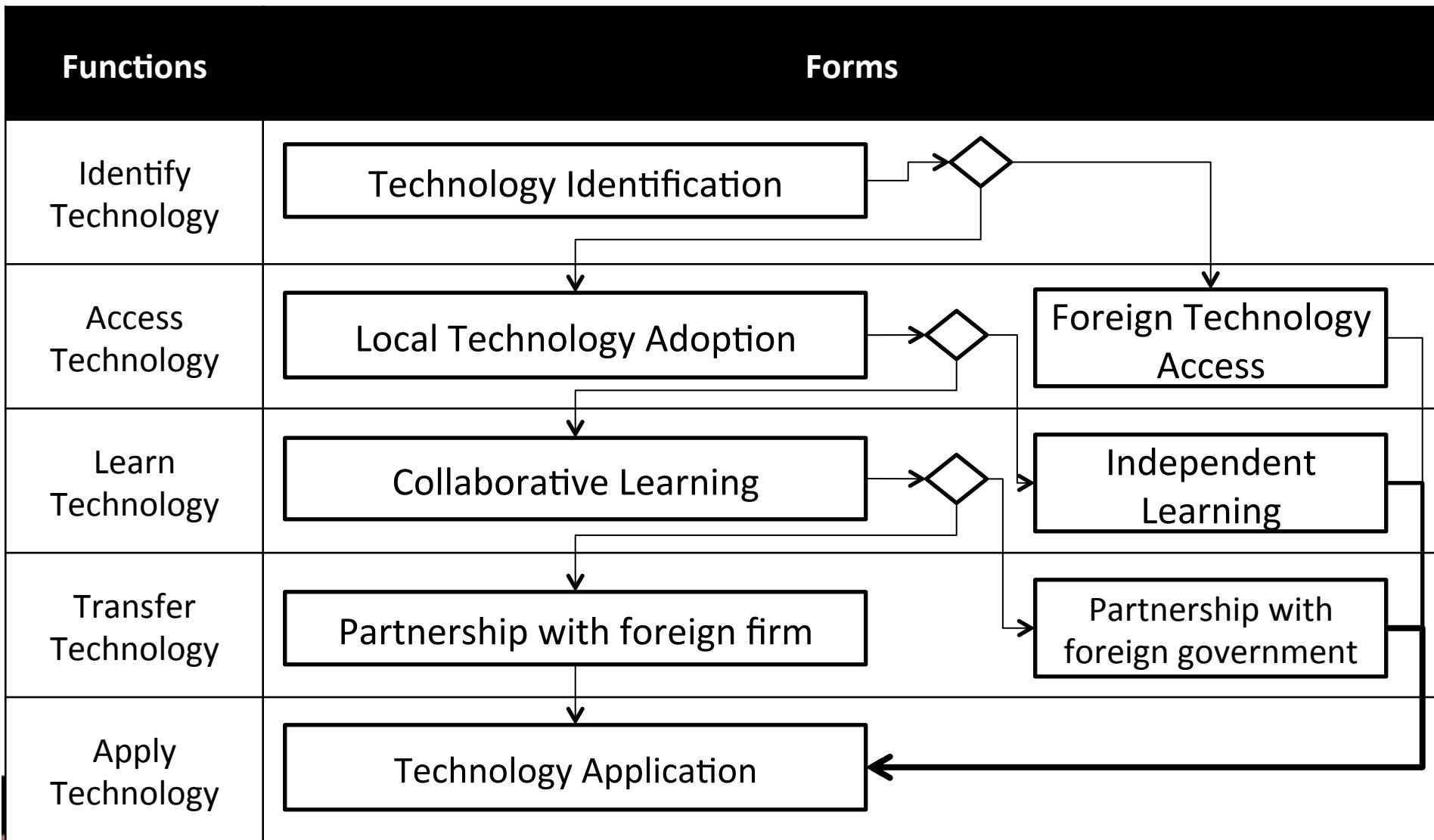
# Technology Project Design

## Turnkey Project

| Train engineers | Design/Build Satellite |
|---|---|
| Local univ | Foreign firm |

| Launch Satellite | Operate Satellite |
|---|---|
| For'n Space Org | Local Space Org. |
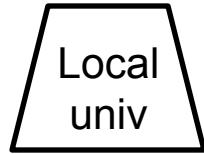
## Local University Project

| Train engineers | Design/Build Satellite |
|---|---|
| Local univ | Local univ |

| Launch Satellite | Operate Satellite |
|---|---|
| For'n Space Org | Local univ |
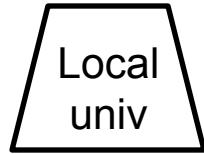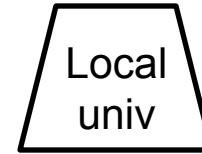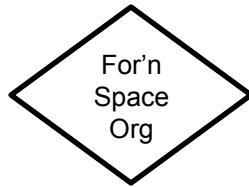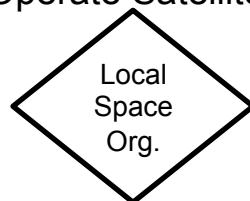
## Education Abroad with Local Development

| Train engineers | Design/Build Satellite |
|---|---|
| Foreign Univ. | Local Space Org. / Local univ |

| Launch Satellite | Operate Satellite |
|---|---|
| For'n Space Org | Local Space Org. |
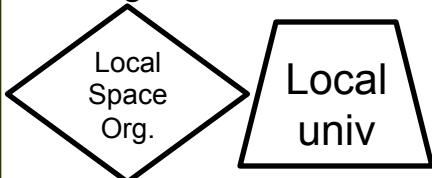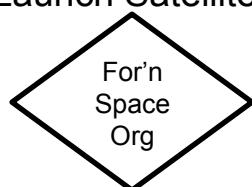
## Collaborative Satellite Development

| Train engineers | Design/Build Satellite |
|---|---|
| Foreign firm | Local Space Org. / Foreign firm |

| Launch Satellite | Operate Satellite |
|---|---|
| For'n Space Org | Local Space Org. |
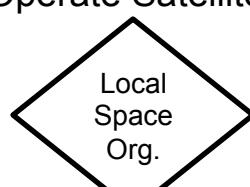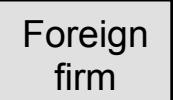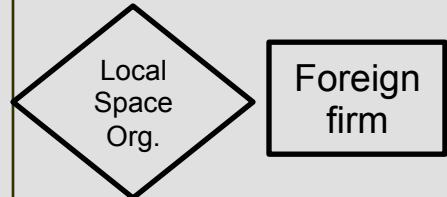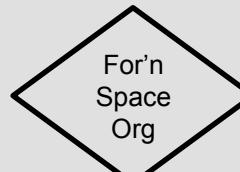
# Implementing a Collaborative Satellite Development Project

- Steps to apply architecture framework to detailed model of a Collaborative Satellite Development Project
  - Step 1: Identify Stakeholders and Analyze value flow.
  - Step 2: Examine Context for Constraints, Opportunities, and Objectives
  - Step 3: Define Functions, Generic Forms, Alternative Forms, Dimensions and Views

# Step 1: Identify Stakeholders and Analyze value flow
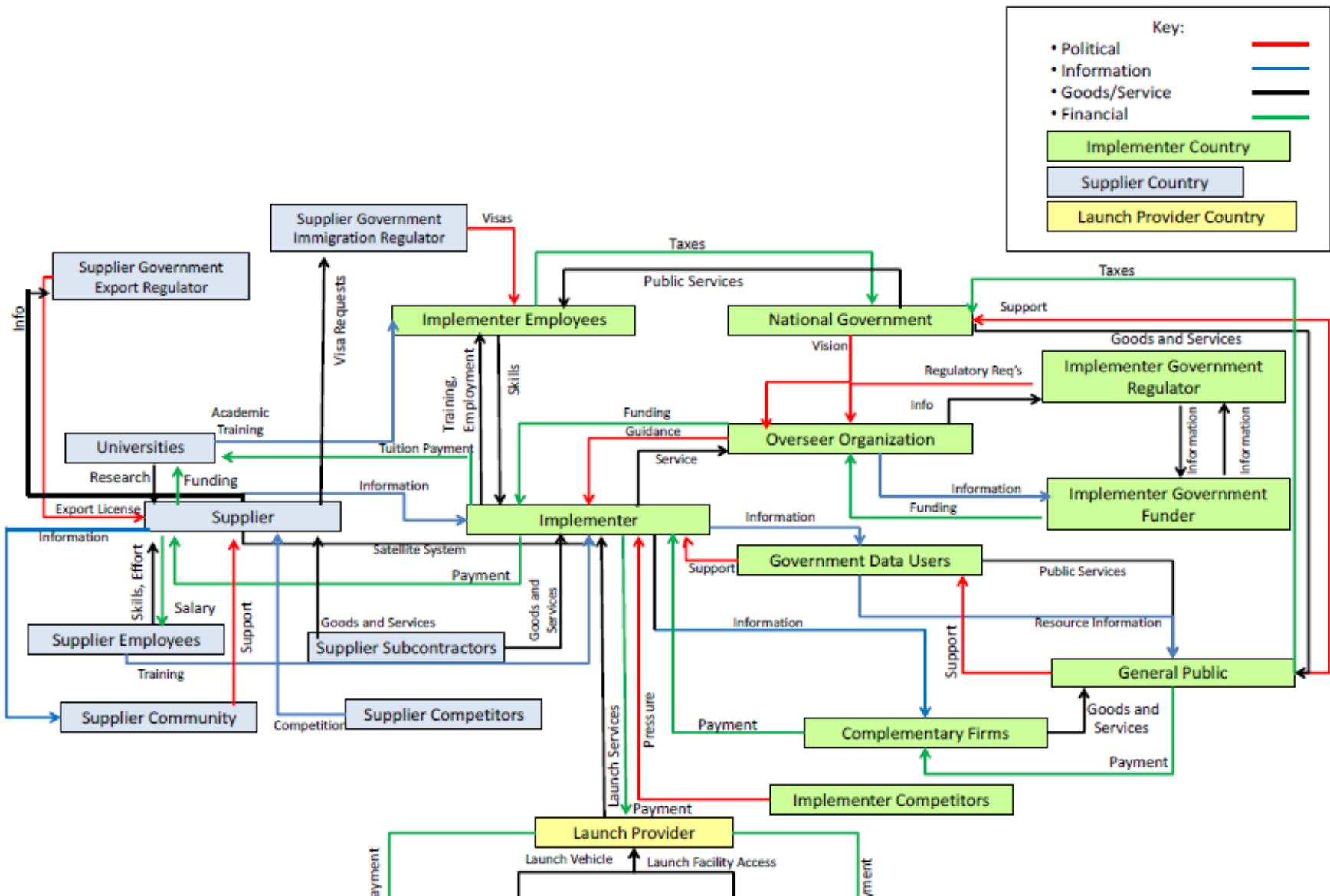
# Step 2: Examine Context for Constraints, Opportunities, and Objectives

| Examples of Contextual Constraints and Opportunities Identified in Collaborative Satellite Development Projects | | | |
|---|---|---|---|
| Prior use of remote sensing services on national level | never | sometimes | often |
| Prior use of communication satellite service by national organizations | never | sometimes | often |
| National Space Office (during time of project) | no | partial | yes |
| Past domestic satellite projects | none | few | many |
| Major space event: Partnership opportunity | no | partial | yes |
| Major space event: Policy or facility established | no | partial | yes |
| Key Leader: Overseer Organization | no | partial | yes |
| Key Leader: Implementing Organization | no | partial | yes |
| National Vision: Space as part of development process | no | partial | yes |
| National Vision: Accomplishment in space tech | no | partial | yes |
| Level of Political Support | low | medium | high |
| National Space Policy Infrastructure | weak | growing | strong |

# Step 2: Examine Context for Constraints, Opportunities, and Objectives

| Examples of High Level Technical Objectives Identified in Collaborative Satellite Development Projects | | | |
|---|---|---|---|
| Maintain data continuity with existing system | no | low priority | high priority |
| Provide medium resolution optical imagery | no | low priority | high priority |
| Provide high resolution optical imagery | no | low priority | high priority |
| Provide operational imagery | no | low priority | high priority |
| Provide commercially viable imagery | no | low priority | high priority |

# Step 2: Examine Context for Constraints, Opportunities, and Objectives

| Examples of Capability Building Objectives Identified in Collaborative Satellite Development Projects | | | |
|---|---|---|---|
| **Key long term objectives:** | **Priority Level** | | |
| Establish national capability to design and manufacture satellites independently | low | medium | high |
| Create local high technology employment opportunities for the country | low | medium | high |
| **Key short term objectives:** | | | |
| Learn to procure satellite system | low | medium | high |
| Local engineers participate in building, testing operating mission | low | medium | high |
| Local engineers experience lifecycle from design to operations | low | medium | high |
| Train engineers enough so they can build satellites with support in future | low | medium | high |
| Train engineers to effectively operate satellite | low | medium | high |
| **Training Focus Area:** | | | |
| Satellite Engineering focused | low | medium | high |
| Operations focused | low | medium | high |
| Payload Engineering focused | low | medium | high |

# Step 3: Define Functions, Generic Forms, Alternative Forms, Dimensions and Views

| Generic Forms | Function | Examples of Forms from Existing Projects | | | |
|---|---|---|---|---|---|
| **Facility View** | | | | | |
| **Supplier Facility Status** | *Defining Supplier Facility State* | Temporary | Transitional | Purpose-Built | |
| **Implementer Facility Status** | *Defining Implementer Facility State* | Temporary | Transitional | Purpose-Built | |
| **Implementer Facility Type** | *Enabling Implementer Activity* | Data Reception | Satellite Operations | Satellite Integration and Test | Optical Laboratory |
| **Satellite Control System Operator** | *Controlling Satellite* | Implementing Organization | Overseer Organization | Satellite Supplier | |
| **Satellite Reception System Operator** | *Receiving Satellite Data* | Implementing Organization | National Remote Sensing Center (non-implementer) | Satellite Supplier | Commercial Antenna Farm |
| **Satellite Environmental Test Facilities** | *Hosting Satellite Environmental Tests* | Satellite Supplier | Government Research Organization | Commercial Firm | |

# Step 3: Define Functions, Generic Forms, Alternative Forms, Dimensions and Views

| Generic Forms | Function | Examples of Forms from Existing Projects | | | | |
|---|---|---|---|---|---|---|
| | | **Personnel Management View** | | | | |
| **Engineer Selection Organization** | *Selecting Engineers for Training* | Implementing Organization | Implementer and Supplier | | | |
| **Engineer Recruitment Source** | *Defining Selection Pool* | Experienced Academics | Military Representatives | Experienced Industry Professionals | Recent Graduates & Young Professionals | National Citizens |
| **Engineer Recruitment Process** | *Announcing Training Opportunity* | Network with universities | Coordinate with Military | Advertise with media | Use personal networks | Recruit among expatriate community |
| **Engineer Evaluation Process** | *Evaluating Engineers for Training* | Application | Interviews | Tests | | |
| **Hiring Time Horizon** | *Defining Hiring Time Horizon* | Duration of Project | Project and Long Term | Long Term Employment | | |
| **Post-Training Assignment** | *Assigning Engineers after Training* | Pre-project organization | Implementer Organization | University in Supplier Country | New Project at Supplier Organization | New position outside Implementer Organization |

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# Enabling Synthesis and Explanation

## Approach for Exploratory Research

- Define a research question

- Collect evidence

- Organize evidence using Architectural Framework

- Develop findings inductively

- Consider how findings relate to existing literature

- Propose theoretical propositions that can be tested with new evidence

# Research Question: Link Architecture to Stakeholder Objectives

- **Model Project Architecture**: *What are the Architectures of Collaborative Satellite Projects?*

- **Model Capability Building:** *What Capability Building Opportunities do Individuals and Organizations have?*

- **Linking Architecture and Capability Building**: *How does Project Architecture influence Capability Building?*

## Summary of Case Studies

| Satellite Projects | AlphaSat-R1 | AlphaSat-R2 | BetaSat-R1 | BetaSat-R2/ BetaSat-R3 | GammaSat-R1 | DeltaSat-R2 |
|---|---|---|---|---|---|---|
| **Customer Nation** | Nation Alpha | | Nation Beta | | Nation Gamma | Nation Delta |
| **Supplier** | Supplier Omega1 | Supplier Tau1 | Supplier Omega1 | | Supplier Tau1 | Supplier Sigma1 |
| **Satellite Technical Performance** | Medium Resolution | High Resolution | Medium Resolution | High and Medium Resolution | High Resolution | High Resolution |
| **Technical Approach** | New Satellite System Engineering Philosophy | | | | | Traditional Technical Approach |

# Supplier Selection Architectural Decision

| Supplier Selection View | Nation Alpha | | Nation Beta | | Nation Gamma | Nation Delta |
|---|---|---|---|---|---|---|
| | AlphaSat-R1 | AlphaSat-R2 | BetaSat-R1 | BetaSat-R2/ BetaSat-R3 | GammaSat-R1 | DeltaSat-R2 |
| **Informal** | No | Yes | Yes | No | No | No |
| **Formal** | Yes | No | No | Yes | Yes | Yes |

- **The Collaborative Satellite Development Projects varied regarding how a Supplier Firm was selected**
- **Some projects used informal approaches to select a supplier, such as working with known contacts or following the recommendations of colleagues**
- **Some projects used formal approaches that emphasized bureaucratic transparency**

## Satellite Technical Characteristics
**Satellite Design Life (Years) versus Spatial Resolution of Satellite Imager (Meters)**
**Size of Sphere is Proportional to Mass (Kilograms)**

More Complex Satellites: AlphaSat-R2, BetaSat-R2, GammaSat-R1, DeltaSat-R2

Less Complex Satellites: AlphaSat-R1, BetaSat-R1, BetaSat-R3

300 kg

750 kg    200 kg

90 kg    100 kg    50 kg

185 kg

Design Life (Years)

Spatial Resolution of Satellite Imager (meters)

**The seven remote sensing satellites procured in these six projects can be divided into two distinct groups based on technical complexity**

# Training Architectural View

| *Training approaches* | AlphaSat-R1 | AlphaSat-R2 | BetaSat-R1 | BetaSat-R2 | BetaSat-R3 | GammaSat-R1 | DeltaSat-R2 |
|---|---|---|---|---|---|---|---|
| Emphasizes **Practical** Skills and **Informal** mentoring | Yes | No | Yes | No | No | Yes | No |
| Emphasizes **Theory** and **Formal** mentoring | No | No | No | Yes | No | No | Yes |
| Emphasizes **On the Job** training and Mentoring **as needed** | No | Yes | No | No | Yes | No | No |

# Defining Capability Building (Stakeholder Objective)

Capability Building can happen when an individual or organization experiences a new topic, a new level of autonomy or a new level of complexity.

**Autonomy**

More Independent

More Managerial

Less Complex

More Complex

**Complexity**

More Technical

**Topic**

Less Independent
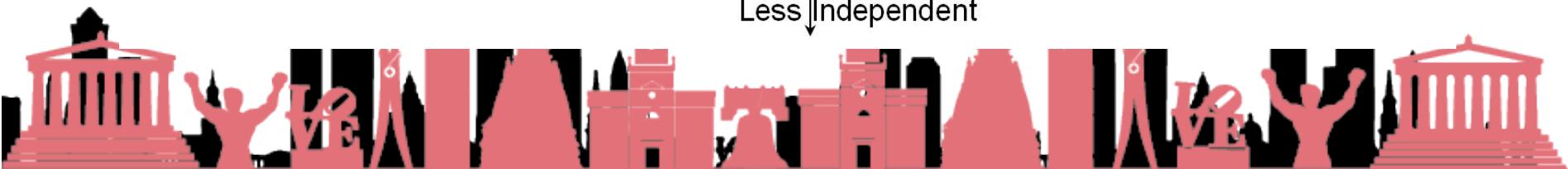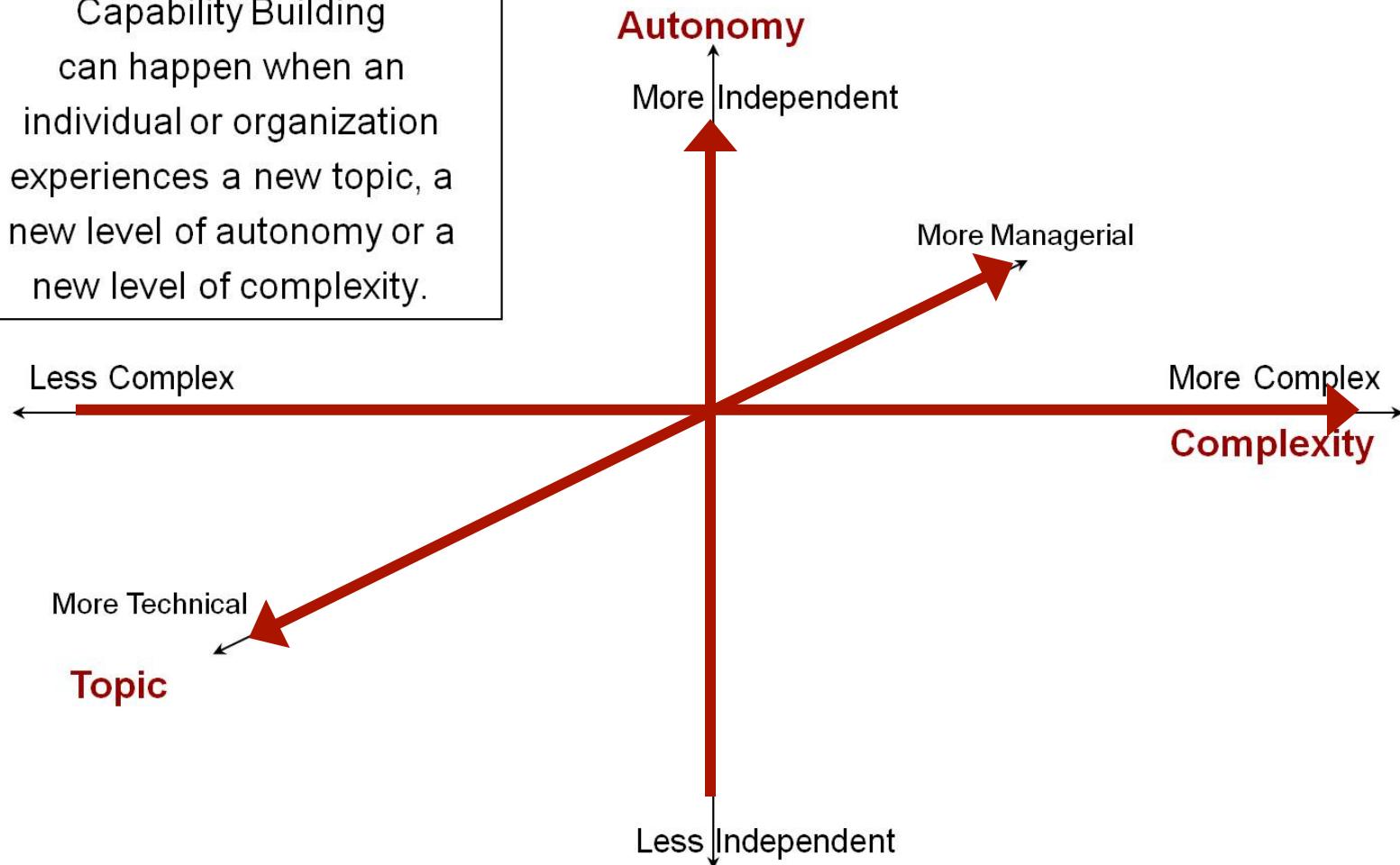
# Modeling Capability Building for Individuals
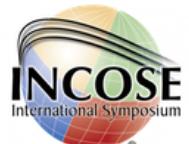
**Color Key**
**Red = Before Training**
**Yellow = During Training**
**Green = After Training**

Early Project Activities ←——————————————→ Later Project Activities

| Increasing Autonomy and Application | Project Definition | Req's | Soft-ware | Design | Procurement, Assembly, Integration | Testing, Verification and Validation | Manage-ment | Launch | Ops |
|---|---|---|---|---|---|---|---|---|---|
| Independent Implementation | 🟩 | | | | | 🟩 | 🟩 | 🟩 | |
| Supervised On the Job Experience | | | 🟨 | 🟨 / 🟥 | 🟩 / 🟨 | 🟩 / 🟨 | 🟩 / 🟨 / 🟥 | | |
| Practical Training | 🟥 | | 🟨 | 🟨 | 🟨 | 🟨 / 🟥 | | | 🟥 |
| Related Practical Experience | | | | | | | | | |
| Theoretical Training | 🟥 | | | 🟨 | | | | | |
| Related Theoretical Training | | | | 🟩 / 🟥 | | | | | |

# Modeling Capability Building for Organizations
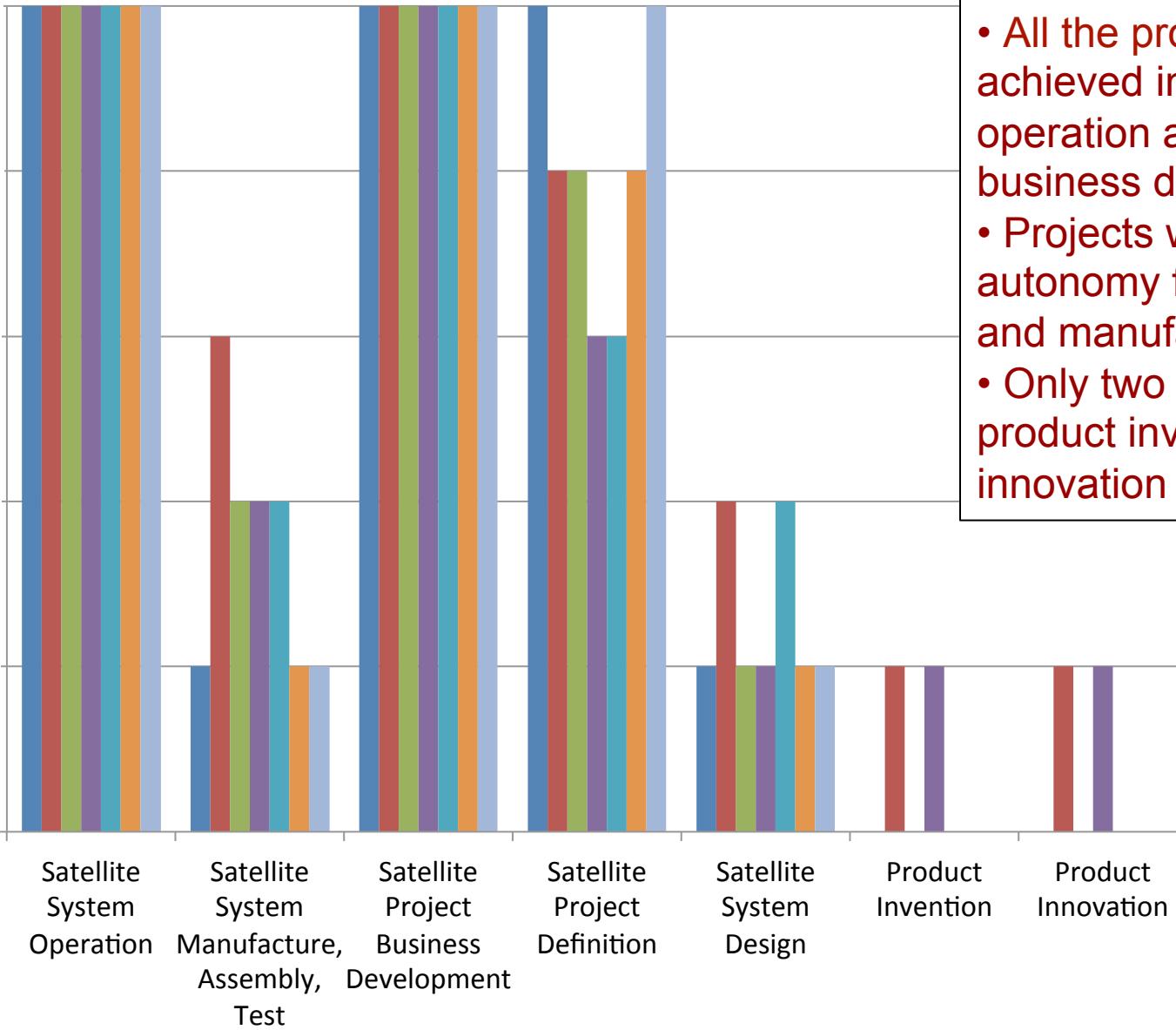
# Linking Context, Project Architecture and Capability Building Outcomes

## *"Politically Pushed" Project*
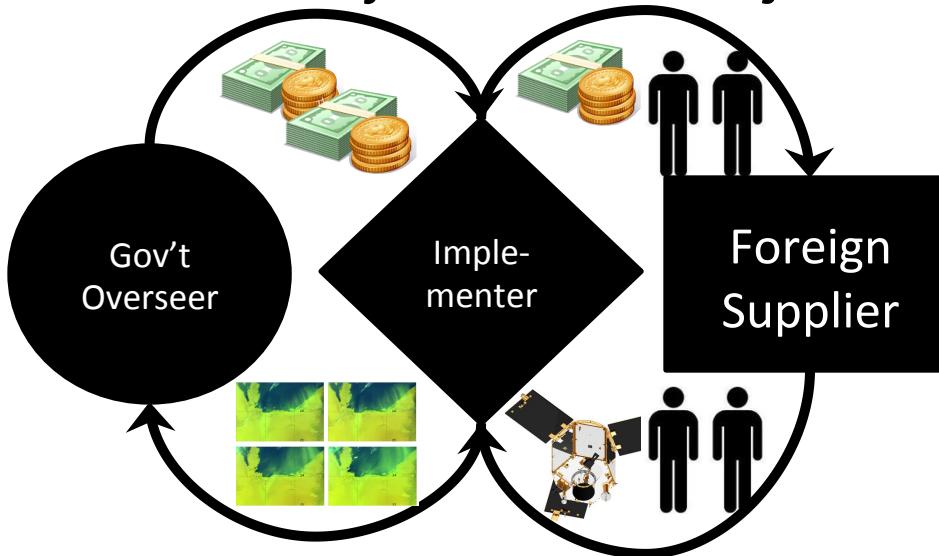


| Project Aspect | Approach in Politically Pushed Project |
|---|---|
| **Fundraising** Process | **Low effort** and informal due to high political support |
| Selection of **Supplier** | Selected based on common **vision** for the project |
| Technical Characteristics of **Satellite** | Low **complexity**, minimal **performance** |
| Types Of **Training** For Engineers | Emphasizes practical technical **skills** and **informal mentoring** |
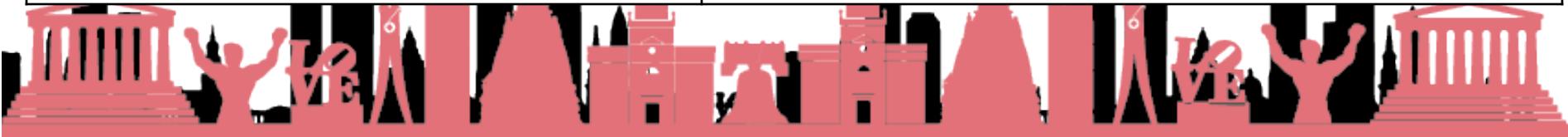
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*"Structured" Project*
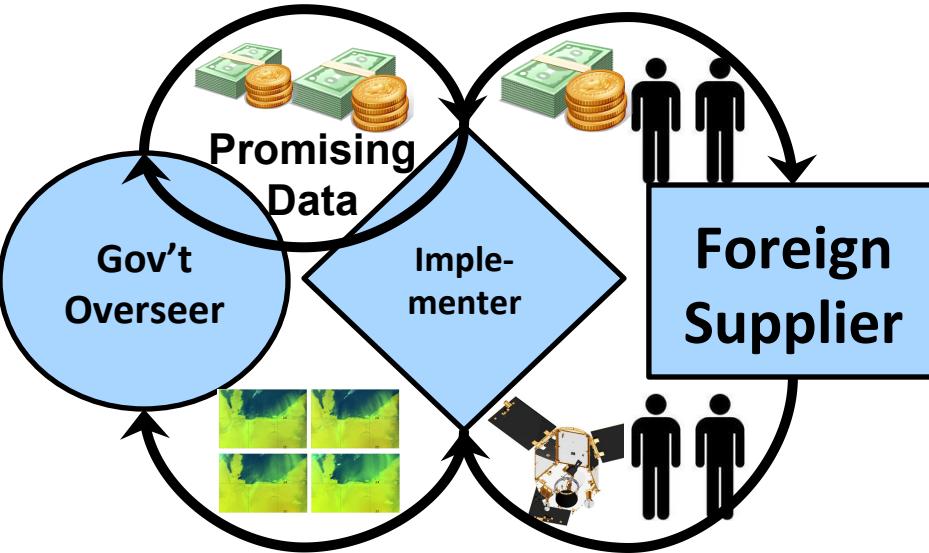
*"Risk Taking" Project*
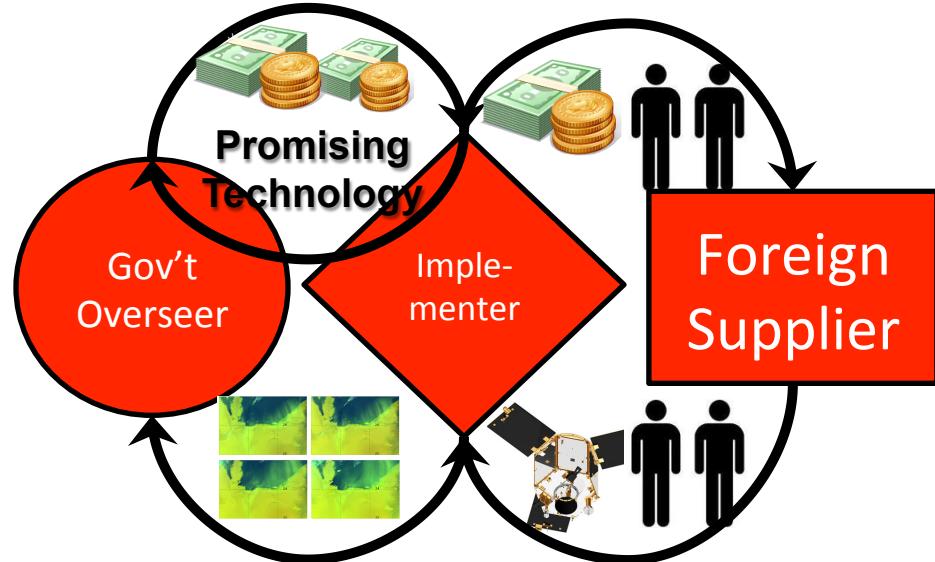


| | Structured Project Attributes | Risk Taking Project Attributes |
|---|---|---|
| **Fundraising** | **High effort;** seek political support formally through data | **High effort;** seek political support formally through technology |
| **Supplier** | Selected based on formal **process** | Selected based on **trust** |
| **Satellite** | **High** complexity and performance | **New** feature or performance |
| **Training** | Emphasizes **theory** and **formal mentoring** | Emphasizes **on the job** responsibility and **mentoring as needed** for the project goals |

# Summary and Conclusion

- The Architectural Framework is a flexible construct that can be applied to multiple topics and levels of analysis

- The AF facilitates modeling of complex empirical data; the architectural models can be used to define inductive explanations for case study outcomes and theoretical propositions

- At this state, the work is focused on **modeling** and **explaining** Collaborative Satellite Development Projects

- Future work will explore how the Architectural Framework is useful for **predicting** and **prescribing** approaches to Collaborative Satellite Development Projects

# Survey

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