Program Engineering
(Systems Engineering at the Program Level)

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Part 1
Program Engineering Concepts

Bob Easter
Background - What is Program Engineering?

- Application of Systems Engineering disciplines in support of Program Management.

- PROGRAM = Series or set of projects or missions aimed at an overall goal or set of goals, often involving development and utilization of new technology.

- New discipline emerging at JPL because of program management assignments from NASA.

- JPL Program System Engineering experience to date suggests need for systems engineering tool set for programs similar to but different from those needed for other levels.
Each level of system engineering may contain some elements of the next lower-level type. That is, the various system engineering levels are considered to be "fractal" or "nested."
Program Engineering
Simplified Functional Chart

Program Engineering

- Program Architecture
  - Support Development of Program Architecture
  - Program Architecture What-ifs, e.g., Risk Rebalancing
  - Flowdown of Requirements During Formulation of Additional Program Elements

- Program Integration
  - Support Development of Program Plans and Processes
  - Program Configuration Management, incl...
    - Performance Measures, Reserves and Margins
    - Plans and Requirements
    - Budgets and Schedules
    - Risk

Formulation Phase
Implementation Phase
Program Engineering Activities-to-Date (Oct '02)

- Mars Exploration Program – Program Plans (including Program-Level Requirements Appendices), Outpost Programs Formulation including Availability Analysis, Risk Tree Program Architecture, Technology Investment Analysis, Engineering Environment Development

- Navigator Program – Program Risk-based Architecture Formulation, Program Plans and PLRAs, Program Risk Management and Review Plans

- Focused Physical Oceanography and Solid Earth Program – Program Phase II Formulation Planning

- Sun Earth Connection Theme (NASA HQ) – Proposal preparation for Program Engineering of SEC Theme, emphasizing Availability and Coverage

- NMP – Flight Options Analysis, Program Engineering Workbench, Mission Data Information System, Investment Analysis

- IR&D - Funded preliminary development of “Workbench” website, processes, and tools
Program Engineering Status

Program Architecture Formulation and Update Processes
Program Formulation and Implementation

Program Engineering

Program Formulation
- Program Architecture
  - Develop

Program Planning, Integration, and Control
- Establish Processes and Plans
  - Implement Processes and Plans

Project Formulation / Implementation

Pre-Formulation

Formulation

Implementation
Program Architecture
Development Process (General)

**External Inputs:**
- Customer requirements
- Programmatic requirements and constraints
- Formulation Authorization

**Define Program objectives and requirements**

**Define, analyze mission concepts**

**Synthesize technology requirements**

**Define mission set options:**
- Apply Science requirements
- Apply programmatic requirements and constraints

**Analyze mission set options:**
- Budget profiles
- Schedules
- Risk
- Performance
- Dependencies

**Identify / Develop:**
- Partnering opportunities
- Technology and Commercialization opportunity options
- Operations and business opportunities options
- Infrastructure needs and upgrade options

**Iterate:**
- Advanced study requirements
- Technology and commercialization approach
- Operations and business opportunities approach
- EO approach

**"Adjust / optimize":**
- Budget profiles
- Schedules
- Risk
- Performance
- Dependencies

**Program Architecture**
- Mission Set
- Advanced Studies Plan
- Technology Development Plan
- Commercialization Plan
- EO Plan

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# Program Architecture Formulation & Update Processes:
## Four Cases

<table>
<thead>
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<th>Top-Down</th>
<th>Bottom-Up</th>
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<tr>
<td><strong>New Architecture Formulation</strong></td>
<td><strong>Starts with high-level, overarching program goal(s)</strong>&lt;br&gt;<strong>Definition of program goals and objectives precedes identification of candidate mission sets</strong>&lt;br&gt;<strong>Program defined as a set of candidate missions that lead to achievement of long-term program goal</strong>&lt;br&gt;<strong>Program formulation in part precedes project formulation</strong>&lt;br&gt;<strong>Process outcome: architecture for new program</strong></td>
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<td><strong>Architecture Update / Revision</strong></td>
<td><strong>Starts with, e.g., changing program reqmts or constraints, directed addition of new activity, etc.</strong>&lt;br&gt;<strong>Assessment of impact focused on individual projects</strong>&lt;br&gt;<strong>Project interdependencies secondary</strong>&lt;br&gt;<strong>Process outcome: revised architecture for existing program</strong></td>
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Pre-Formulation

Program Architecture Formulation Process*
*Code S process, derived from Space Science Enterprise Management Handbook

External Inputs:
- Publications, Presentations
- NRAs
- NASA direction to center

Define Program candidate advanced mission concepts

Define and assess mission set options:
- Aggregate budget profiles
- Schedules
- Risk
- Aggregate performance
- Interdependencies

Define candidate Program
- Mission set
- Science goals
- Budget profile
- Schedule

Program funding decision; Formulation authorization

Establish Program formulation goals and objectives

Formulate Program and projects:
- Partnering opportunities
- Technol/Commerce opportunities options
- Operations and business opportunities options
- Infrastructure needs and upgrade options

Adjust / optimize:
- Budget profiles
- Schedules
- Risk
- Performance
- Dependencies

Iterate:
- Advanced study reqmts
- Technol/Comm approach
- Operations and business opportunities approach
- E/O approach

Program Architecture
- Mission Set
- Advanced Studies Plan
- Technology Development Plan
- Commercialization Plan
- EO Plan

Formulation
Initiating event(s)
e.g.:
- Revised customer reqmts
- Revised Program reqmts
  or constraints; e.g.:
  - Budget
  - Schedule
  - Risk
  - Etc.
- Science/technology feed-
  forward
- Directed addition of new
  mission(s)

Update Program
objectives and reqmts,
as required

Assess impact and/or
opportunities re
current architecture

No impact
of immediate new
opportunities

Identify new technology
requirements

Define new architecture
options(s)
- Previous architecture plus
  new mission concept(s)
- Apply updated objectives,
  requirements, directives, etc.

Define, analyze new
mission concept(s)

Analyze new
architecture options:
- Budget profiles
- Schedules
- Risk
- Performance
- Dependencies

Identify needed updates:
- Partnering opportunities
- Technology and
  Commercialization
  opportunity options
- Operations and business
  opportunities options
- Infrastructure needs and
  upgrade options

Iterate:
- Advanced study
  requirements
- Technology and
  commercialization approach
- Operations and business
  opportunities approach
- EO approach

"Adjust / optimize":
- Budget profiles
- Schedules
- Risk
- Performance
- Dependencies

Updated
Program Architecture
- Mission Set
- Advanced Studies Plan
- Technology Development
  Plan
- Commercialization Plan
- EO Plan
Proposed Commitment Process: JPL Program-Directed Projects
(for New Programs)

Pre-Formulation
(from Space Science Enterprise Management Handbook)

Formulation
(ne Phase A)

Based on Project Phase A-to-B Transition Requirements, D-19301

- Report to include:
  - Science Objectives
  - Operations Concepts
  - Mission Design Architectures
  - Spacecraft Concepts
  - Cost, Schedule, and Risk
  - New Technology Requirements
Principal Program Elements and Dependencies
Program Engineering – Some Elements of the Credo

- Understand and illuminate interrelationships among projects within a program, especially cost and risk interactions

- Emphasize what the program needs from the projects, rather than how the projects should do things

- Establish program engineering processes that make life easier for the projects, if possible

- Meet the program’s needs via existing institutional project processes and moderate revisions thereto, rather than via imposition of new processes
Acknowledgements

Lynn Baroff, Warren Nogaki, and Dr. Kent Volkmer have made major contributions to our growing understanding of Program Engineering.
Tools to Support Program Engineering

Program Architecture Tools
- Operational Availability Analysis, Coverage Analysis *
- Interdependency Analysis
- Risk / Probability of Success Analysis *
- Technology Investment Analysis / Methodology
- Trade-off / Option Analysis of Candidate Architectures
- Parametric Costing / Resource Estimation & Analysis
- High Level Program Milestone & Cost Manipulation and Analysis

Program Integration Tools
- Information Management System
- Requirements Trace and Management
- Budget and Schedule Reporting Standards and Rollups
- Performance Metrics and Reporting
- Program Plans, Policies, Processes
- Integration Teams
What Is Availability (GAP) Analysis?

- Tool belonging to Aerospace Corp.
- Several Monte Carlo computer programs for computing replenishment and procurement uncertainties from satellite and launch reliability inputs
- Simulates mission lifetime of satellite system many times (3000) resulting in statistics to estimate procurement risk and system effectiveness
  - Probability of system outage or loss of data collection
  - Procurement need time distributions
  - Launch time distributions
  - Other outputs
What Is Availability (GAP) Analysis?
(cont.)

Replenishment Sensitivity Analysis

Satellite Constellation

**INPUTS**
- RELIABILITY
  - SPACECRAFT
  - BOOSTER
- LAUNCH STRATEGY
  - FIXED
  - RANDOM
- AVAILABILITY REQMTS
- INITIAL NUMBER OF BUYS
- INITIAL PRODUCTION SCHEDULE

**OUTPUTS**
- AVAILABILITY
  - PROFILE
  - AVERAGE
  - MINIMUM
- OUTAGES
- PROBABILITY OF LAUNCH

Generalized Availability Program

UPDATE PRODUCTION SCHEDULE,
CHANGE SUCCESS CRITERIA,
CHANGE SATELLITE RELIABILITY, ...
Previous Users for GAP

◆ All military navigation, communication, and weather satellite constellations including:
  - Global Positioning System (GPS)
  - Defense Satellite Communications System (DSCS)
  - Defense Meteorological Satellite System (DMSP)
  - Defense Support Program (DSP)

◆ Many civil and commercial communications and weather satellite constellations including:
  - Geosynchronous Operational Environmental Satellite (NASA-GOES) System
  - Iridium
  - Teledesic

◆ JPL Mars Outpost Study (surface architecture)
Constellation Coverage Analysis

Constellation Design Capabilities

- Fast Station View Period Computation WITHOUT ORBIT PROGAPATION! (Using Ergodic Theory)

- Coverage Analysis of Complex Networks Using the "Visual Calculus"
  - Example: SAR GPS (Bistatic SAR)
    - Double Constellation
    - Complex Instrument Performance
    - Ability to Query Complex Statistical Questions

- Formation Flight in Conic and Libration Orbits
Constellation Coverage Analysis

Combined Performance Pass / Fail Map
Constellation Coverage Analysis

TPF in Formation Flight Near L₂
BCR approaches can provide a simple but powerful tool for comparing Program Alternatives.

A benefit/cost/risk ratio for mission implementation approach may be expressed:

- $bcr = \frac{B \times P}{C}$

- $bcr$ is defined such that values of $bcr$ less 1 are unattractive, and the larger the value, the more attractive. $B$ is the basic benefit or payoff of accomplishing the mission's objectives; $P$ is the probability of success; and $C$ is the required investment or cost. In a Program Engineering context, differing implementations of given missions might be roughly compared by seeing which yields the higher $bcr$. 
Use of Simple BCR Analysis

When, Where & Why Humans – An Example

Assume the objective is to refurbish a spacecraft in LEO. It is estimated that the servicing can be accomplished with a probability of success of .85 by a shuttle mission costing $450M.

If this is deemed acceptable, then

\[ B \geq 1 \times \frac{$450M}{.85} = $529M \]

if the spacecraft can be replaced for an expected cost (cost/probability of success) of less than this — if, for instance, the spacecraft would cost $500M to replace — the shuttle servicing mission is not feasible, i.e. (bcr<1). If the replacement cost is $600M then the shuttle servicing mission is feasible, i.e.

If \( B=$600M \), then \( bcr_{human} = 1.13 \)

The bcr for an automated robotic servicing mission is

\[ bcr_{robot} = \frac{$600M \times P_{robot}}{C_{robot}} \]

So, for instance, if \( P_{robot} = .5 \), \( C_{robot} \) must be less than $265M if \( bcr_{robot} \) is to be greater than \( bcr_{human} \).