



Program Engineering – Developing the Discipline

Lynn Baroff, Bob Easter, Warren Nogaki, Richard Pomphrey,
Jeff L. Smith, Kent Volkmer, Chuck Weisbin, Randii Wessen
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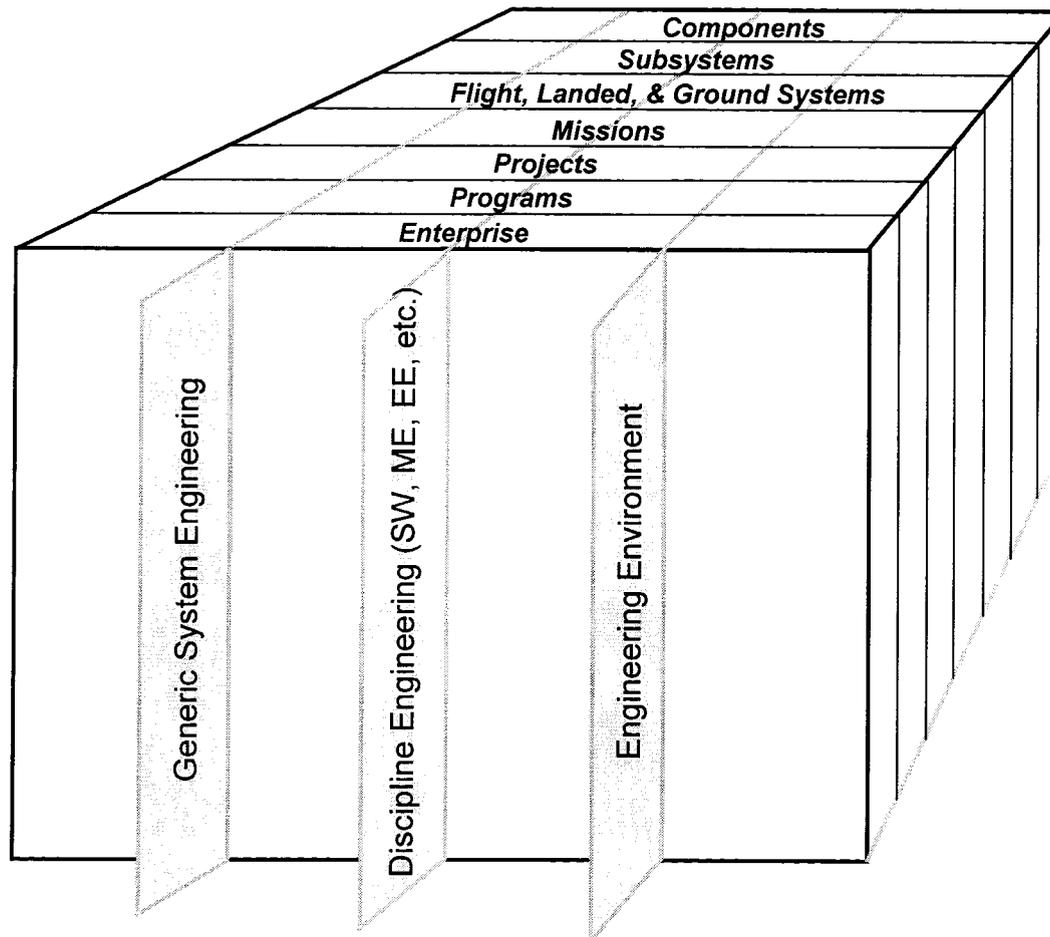


What is Program Engineering?

- Application of Systems Engineering discipline (practices and processes) in support of Program Management.
- PROGRAM =
 - ↗ A system of projects or services intended to meet a public need (*American Heritage*);
 - ↗ A related series of undertakings which continue for a period of time (normally years), and which are designed to accomplish broad scientific, technical, or operational objectives (*JPL Rules!*).
- PROGRAM EXAMPLES = DMSP, Mars Exploration Program
PROJECT EXAMPLES = Coriolis, Mars Exploration Rover
- JPL experience suggests a need for system engineering capabilities similar to (but different from) those needed for other levels.



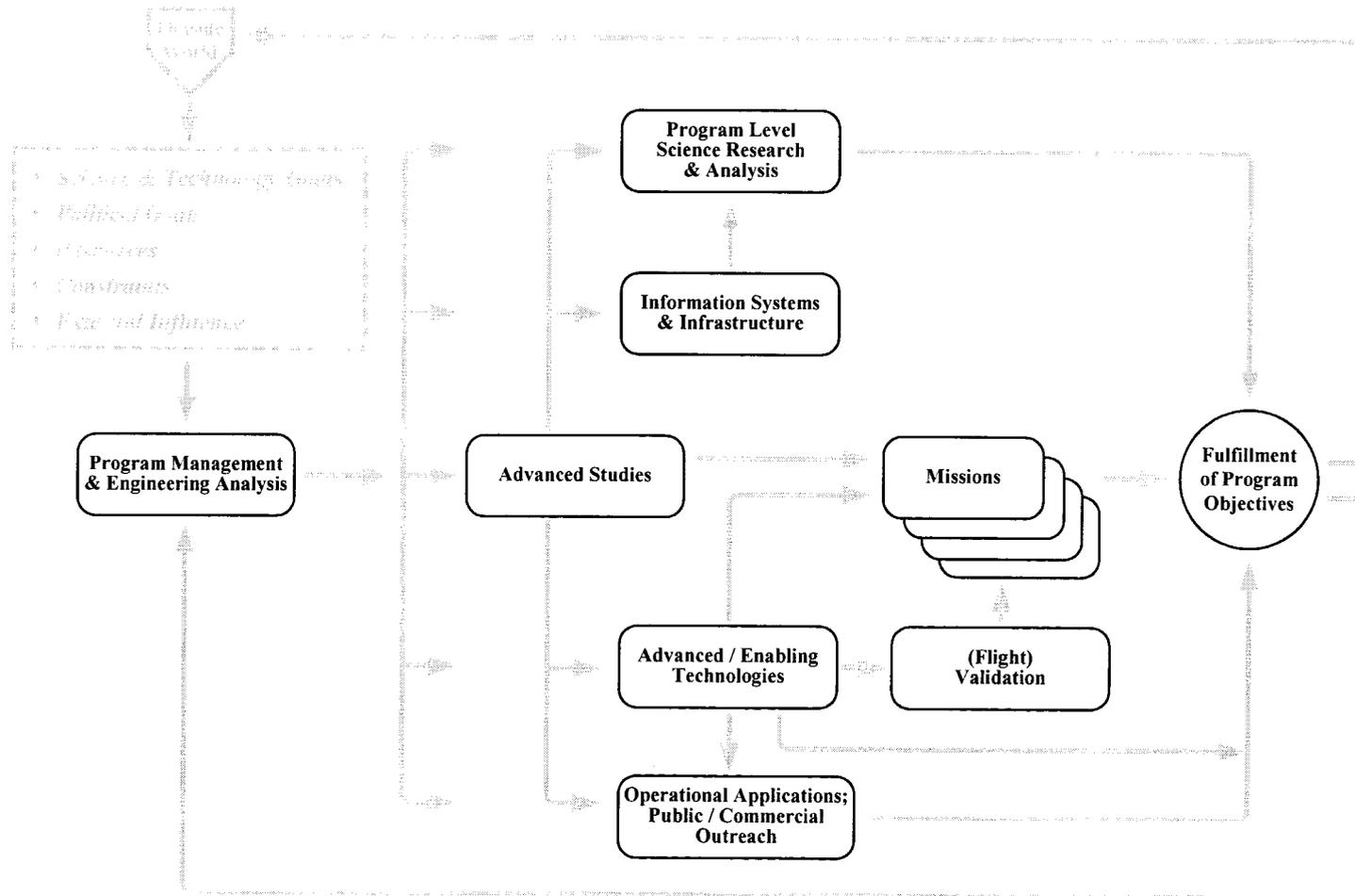
Layered model for System Engineering



Each level of system engineering may contain several elements of the next lower layer. That is, the various system engineering layers are considered to be fractal" or "nested."



Program Model – Principal Program Elements





Program Engineering Simplified Functional Chart

Formulation Phase

Architectural
Activities

- Develop a Program Architecture
("Purposeful arrangement of the
elements of the Program")

Analyze Systems Concepts &
Feasibility Trades; Cost Estimating
Synthesize Technical Requirements
Plan Technology & Commercialization
Assess Operational Requirements
Identify Capability Gaps

Planning, Integration
and Control Activities

- Develop PCA & Program Plans
and measures

C/S/T Performance Management
LCC Costing
Partnering, Commercialization, SOMO Use
Identify O&M Cost Drivers
Capture Knowledge

Implementation Phase

Define Technical Requirements
(Flowdown)
Assess & Review System Designs
Maintain Requirements Trace
Make Program Architecture Trades
Rebalance Risks

Maintain PCA, Program Plan, Performance
Measurements, Reports, Budgets,
Schedules, Risk Plan, Reviews, ...
Manage Technical Requirements
Design, Develop, Sustain Systems &
Technologies
Deliver Products; Operate Systems
Report Status; Lessons Learned
Reported
Update, Assess Metrics



System Engineering practice applied to Programs...



1. Objectives > requirements definition > flowdown
 - ✓ Navigator, Mars Exploration – challenges are to follow the discipline, and to address non-technical objectives and requirements
2. Use of models and scenarios
 - ✓ Mars Exploration, New Millennium, Earth Science – challenge is to develop models that are “big” enough (and the right kind) to be useful
3. Iterative optimization through trade analysis
 - ✓ Mars Exploration, New Millennium – challenge is visualization of Program elements, see #2 above
4. Defining and designing interfaces between elements
 - ✓ The challenge is understanding interfaces among varied types of elements (and among various programs, too...)
5. Product itself – how it is produced – how it is used



A hypothetical example: “Space Physics Program (SPP)”

- Major SPP Objective (Example): routine operational monitoring & warning of solar environmental hazards (mature operations by other Agencies).
- SPP Requirement (Example): “This system shall provide a 60-minute warning that harmful particles are heading towards the Earth after solar flares and coronal mass ejections.”
- SPP Architectural Elements (Examples):
 - Satellite or constellations of satellites (solar monitoring)
 - 24-hour ground system operation
 - Scientific research program (to better understand the phenomenon)
 - Advanced technologies (to support the above)
 - Long-term developmental and operational funding
 - Collaborative interagency and international agreements and processes



A hypothetical example: “Space Physics Program (SPP)”

- (Formulation Phase) Systems Engineering and Analysis:
 - Identify programmatic constraints (limits on funding, relevant public opinion, current scientific knowledge, political considerations, and so on)
 - Identify enabling technologies needed, available, and the GAP
 - Identify and claim SPP assets and resources available over time
 - Analyze trade-offs among existing assets vs. Future capabilities
 - Identify and analyze programmatic risks
 - Track and coordinate intra- and inter-organizational dependencies, relationships, interactions

- (Implementation Phase) Systems Engineering and Analysis:
 - Identify technical constraints (what kind?)
 - Respond to changes in requirements and constraints
 - Track program performance, resource use
 - Mitigate programmatic, performance risks
 - Facilitate intra- and inter-organizational relationships, interactions



Tools to Support Program Engineering

- Program Architecture Tools
 - Availability Analysis of Coverage / Functionality (GAP Analysis)
 - Interdependency Analysis
 - Risk Analysis (Decision Tree 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 Planning, Integration and Control Tools
 - Information Management System
 - Requirements Trace and Management
 - Budget and Schedule Reporting Standards and Rollups
 - Performance Metrics and Reporting
 - Program Plans, Policies, Processes
 - Integration Team



What is the value of Program Engineering?

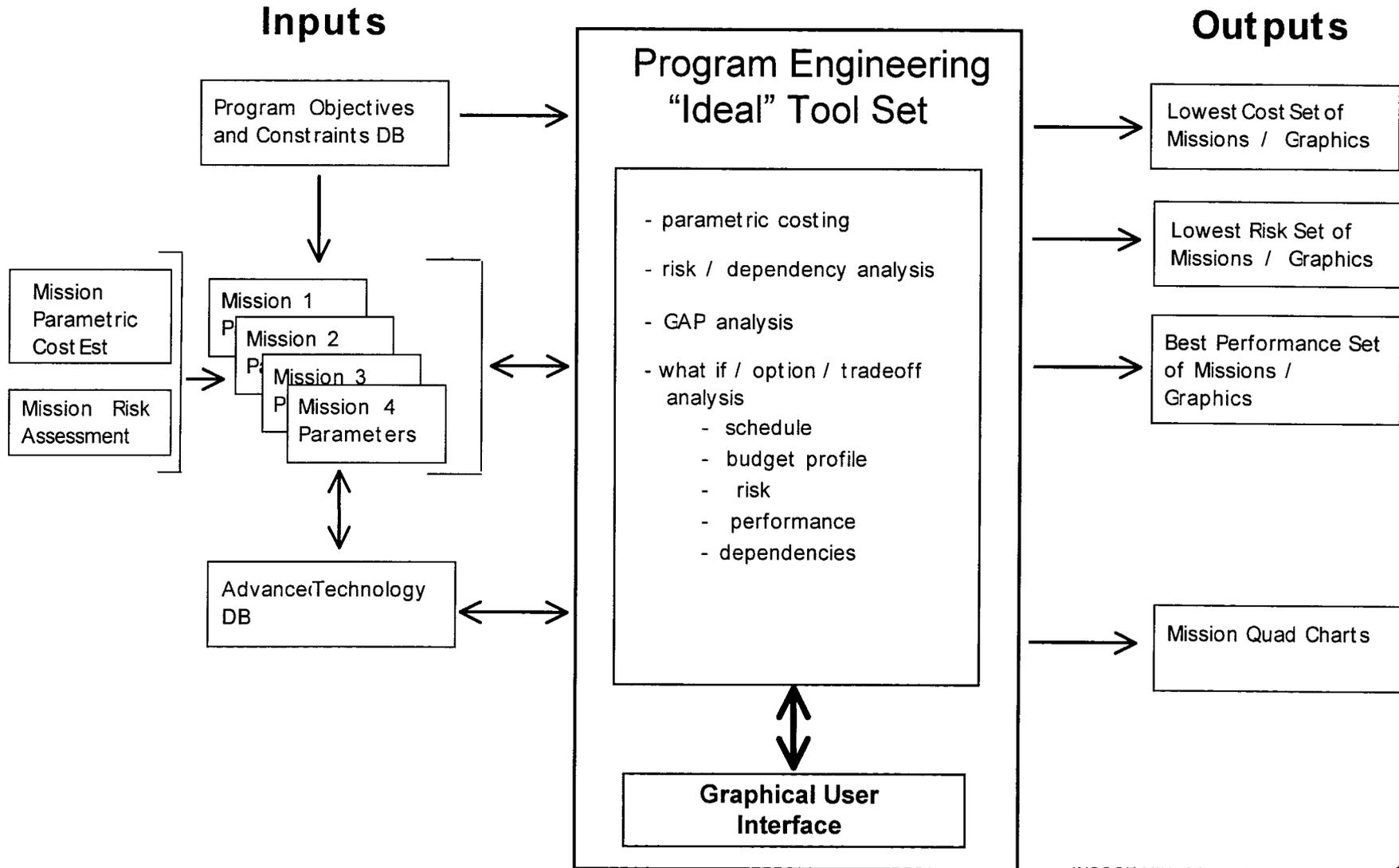
- Dynamic nature of NASA's space exploration environment
 - ↗ Changing knowledge base, scientific requirements
 - ↗ Advancing technologies and capabilities
 - ↗ Changing social necessities, users, stakeholders
- Need to leverage limited resources
 - ↗ Money, time, materials, technology, etc.
 - ↗ Knowledge & people (connecting the "stovepipes")
 - ↗ Attention! One of the most valuable resources
- Increasing complexity of fulfilling NASA's mission
 - ↗ Space exploration has more purposes to accomplish, more requirements to fulfill, more stakeholders to satisfy –
 - ↗ And the solutions aren't all technical...
because the problems aren't all technical



Some Extra Slides about the Tools...



Program Engineering Workbench Strawman Architecture





Program Engineering Workbench Functionality



-
- Program (Mission Set) Parametric Costing
 - Program (Overall) Costing
 - Budget & Schedule Manipulation
 - Availability (of Coverage and/or Functionality)
 - Risk (Probability of Success)
 - Decision Tree Analysis
 - Technology Investment Analysis – Methodology
 - Graphics-Oriented Front End for Tools
 - Program Data Management
 - Various Program Support Engineering How-to's, Templates, Procedures, Checklists
 - Mission Architecture Definition Tools
 - Program-Level Configuration Management
 - Program Integration
 - Trajectory / Satellite Constellation Analysis



Asset Availability Analysis

- Identify, analyze and track asset availability as a function of time, spectral coverage, spatial coverage, NASA assets, non-NASA assets.
- Use GAP and SOAP as predictors to investigate alternative options for mission sets, budget and cost constraints
- Identify and evaluate possible collaborative (“ridesharing” opportunities with other programs / missions / agencies
- Assess cost / benefit trade-offs between existing vs. future assets.



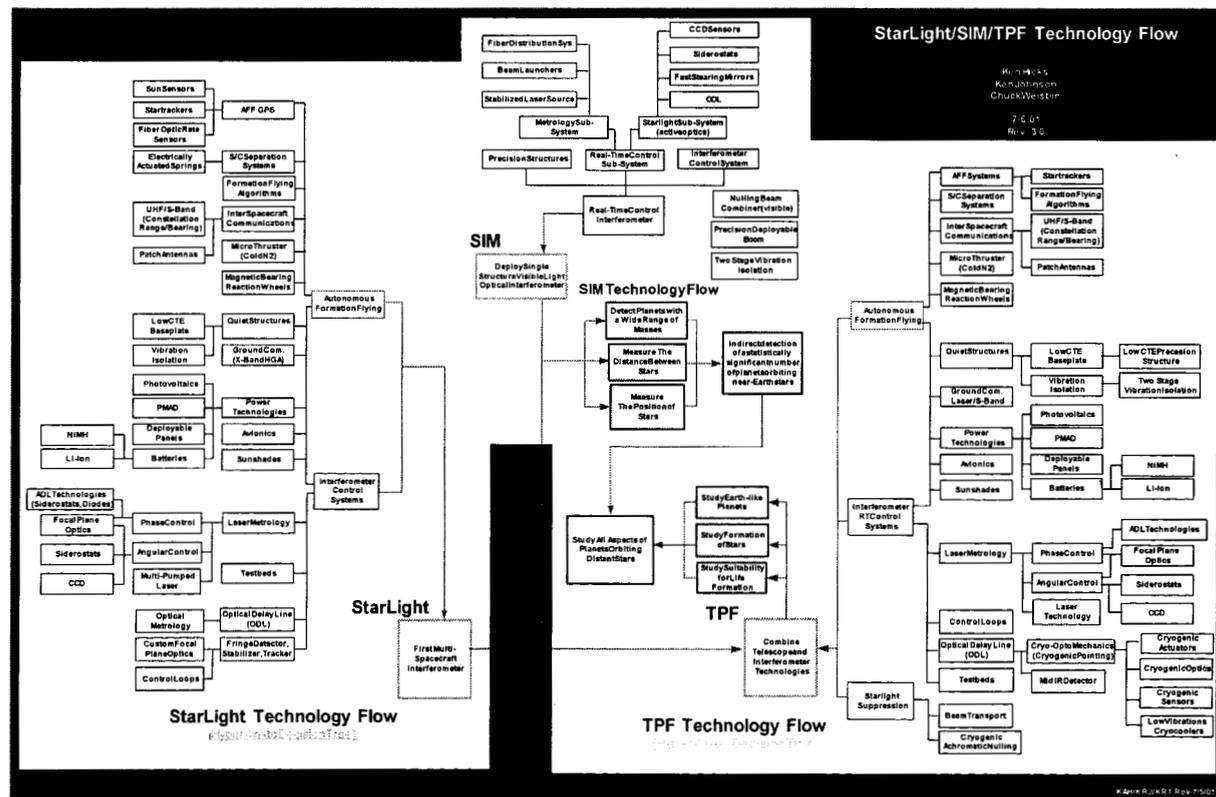
Availability Analysis – GAP Tool

- GAP Tool Developed by Aerospace Corp.
- Analyzes availability of orbital assets / functionality for satellite constellations.
- Currently used at JPL to analyze Mars outpost architectures and functionality.
- Identify architecture that optimizes science data set while achieving acceptable risk and cost levels.
- Used by military and civilian navigation, communication and weather satellite constellations.



Decision Tree Interdependency Analysis

StarLight/SIM/TPF Technology Development Relationships



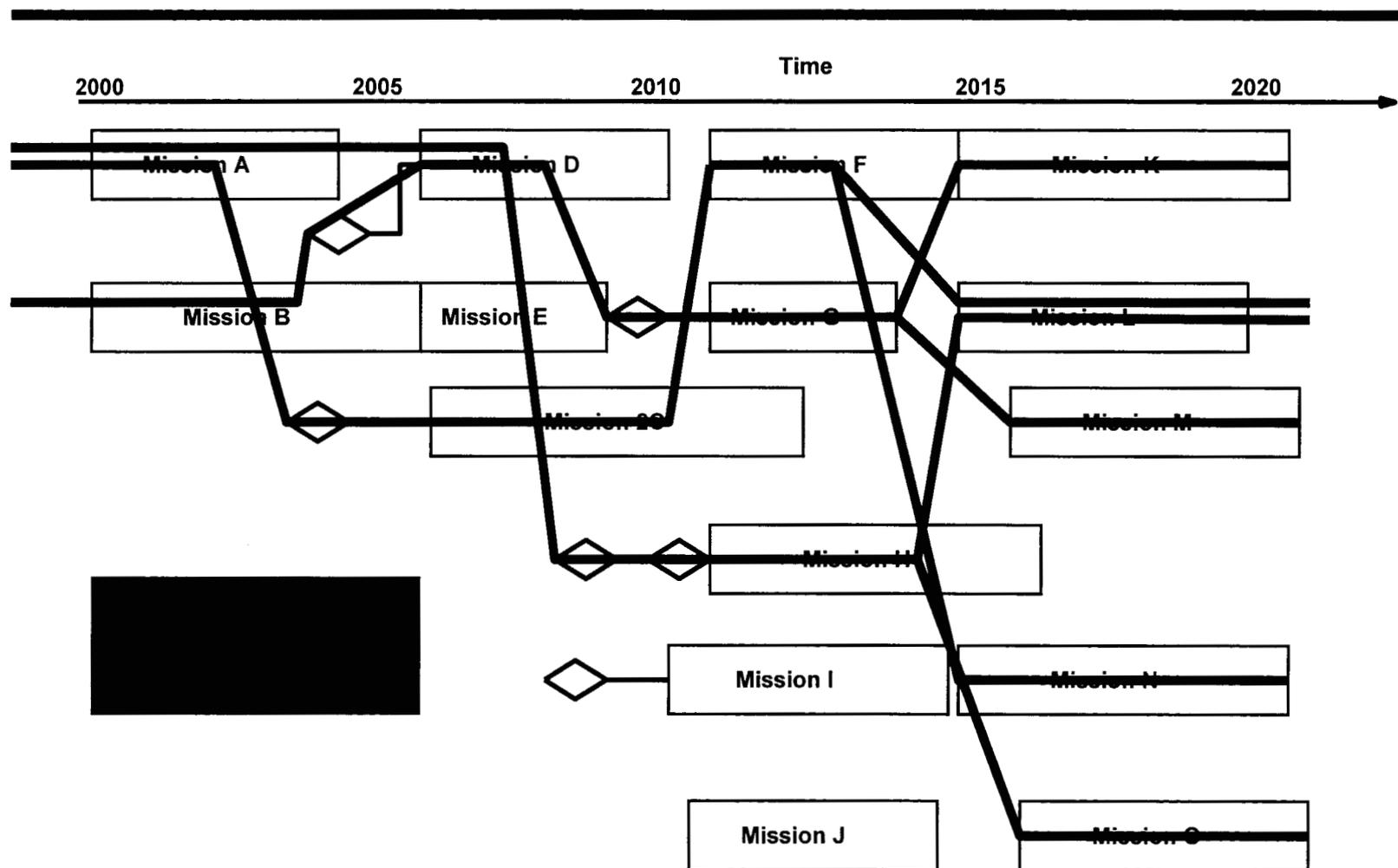


Interdependency Analysis

- Used to Identify, analyze, and track
 - How project and “Program” elements depend on one another
 - How risk changes as a function of changes in element dependencies
 - How changes in technology effect mission and spacecraft parameters, especially “program” cost.



Interdependency Analysis





Planning, Integration, and Control

- Support to Program Management
 - Assist in development of Program Documents (as applicable: Draft PCAs, Program Plans, Risk Mgmt. Plan, FADs, Program-level requirements).
 - Monitor activities in various elements (Advanced Studies; Mission Design, development & operations) via establishment of reporting requirements and review approaches.
 - Iterate, store, and compare Program elements' budget profile and schedule options from a program engineering perspective.
 - Analyze program elements' data to identify and flag budget and schedule inconsistencies across the theme.
 - Establish person-to-person relationships to help integrate program elements, e.g., Program Integration Team.



Technology Investment Analysis – Methodology



- Select advanced future mission(s) options
- Characterize and quantify science goals
- Articulate success criteria for study (e.g., highest probability of success for fixed cost; minimal cost for an acceptable threshold level of success, etc.)
- Deduce engineering requirements
- Lay out an event decision tree including advanced technology options, and associated probabilities and costs
- Show impact of technology investment on success criteria and order choices



Benefit/Cost/Risk Analysis (Probability of Success)



- 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
 - $bcr = B \times P / C$
 - 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. Differing implementations of given missions might be roughly compared by seeing which yields the higher bcr.



Technology Risk Analysis

- Risk Analyses used to
 - Assess Major Technology Issues: (e.g., how maturity of Solar Sail Propulsion impacts risk for all missions using it).
 - Assess cost / benefit trade-offs among technology alternatives and strategies (e.g., long-lived vs. small, cheap on-orbit spares).
 - Assess cost / benefit of alternative technology investments (e.g. instrument development, data analysis, visualization, autonomy).