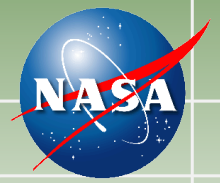

Systems Engineering:
From Technical Architect to Technical Authority
A Lifecycle Focus on Mission Success

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August 5, 2008

Credits
Mission Engineering and Systems Analysis Division - Code 590
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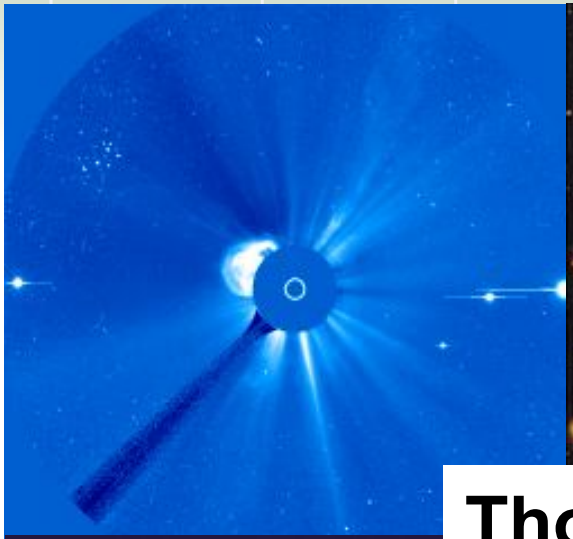
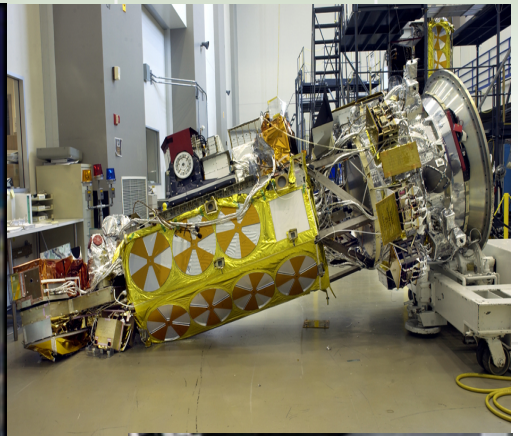
Maria So, Associate Chief
Ken Yienger, Mission System Engineering Branch

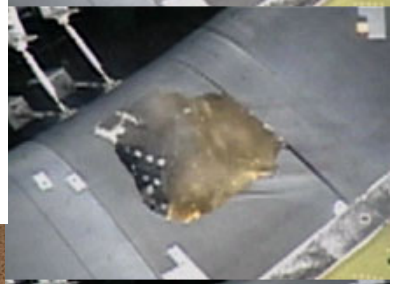
Exploring Space is Exciting and Challenging, But Unforgiving










Thousands of good decisions can be undone by an uninformed one, a single bad assumption, a design flaw, or a workmanship

Systems Engineering

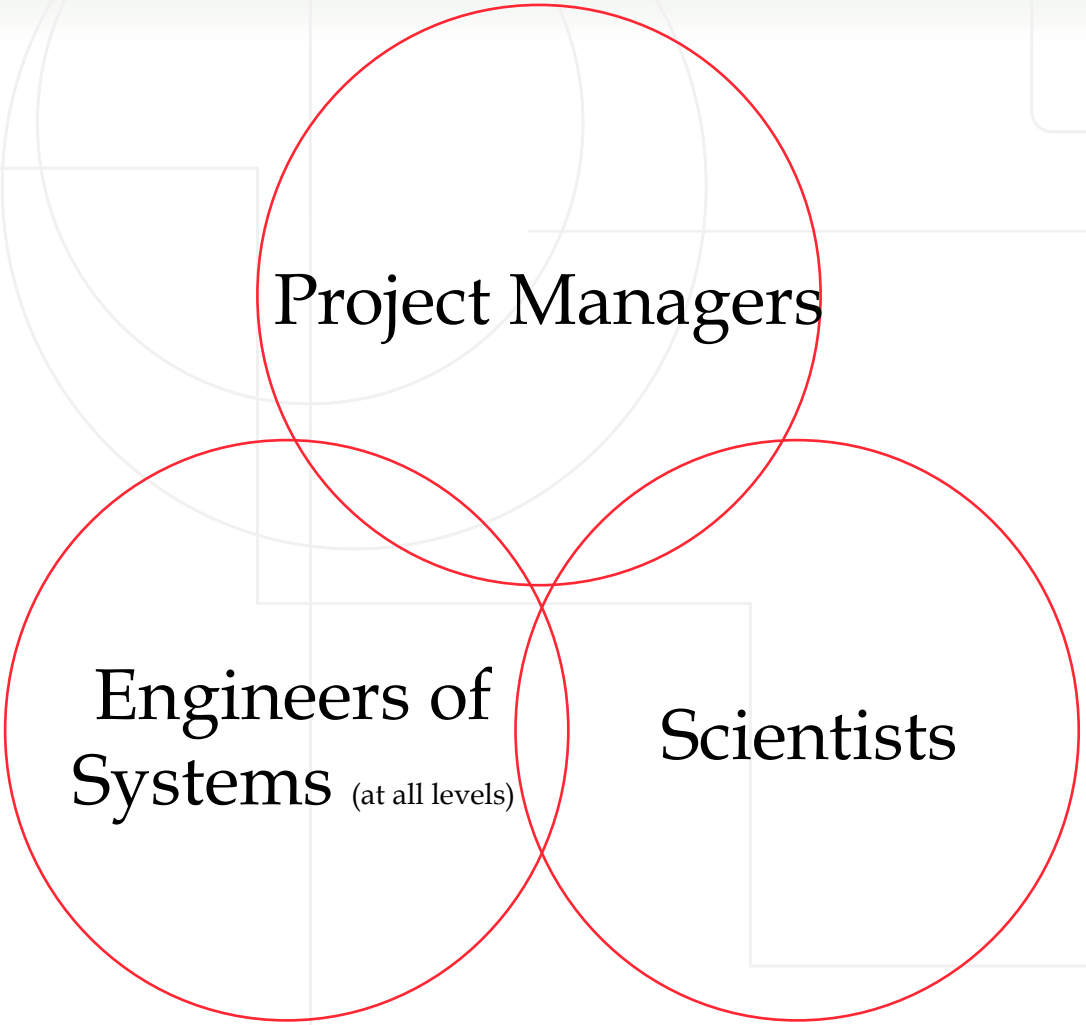
> **"The objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule and risk."**
>
> *NASA Systems Engineering Handbook SP6105*

- **Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system.**

- **A "system" is a collection of different elements that together produce results not obtainable by the elements alone.**
  - Elements can include people, hardware, software, facilities, policies and documents.
  - All things required to produce system level results.

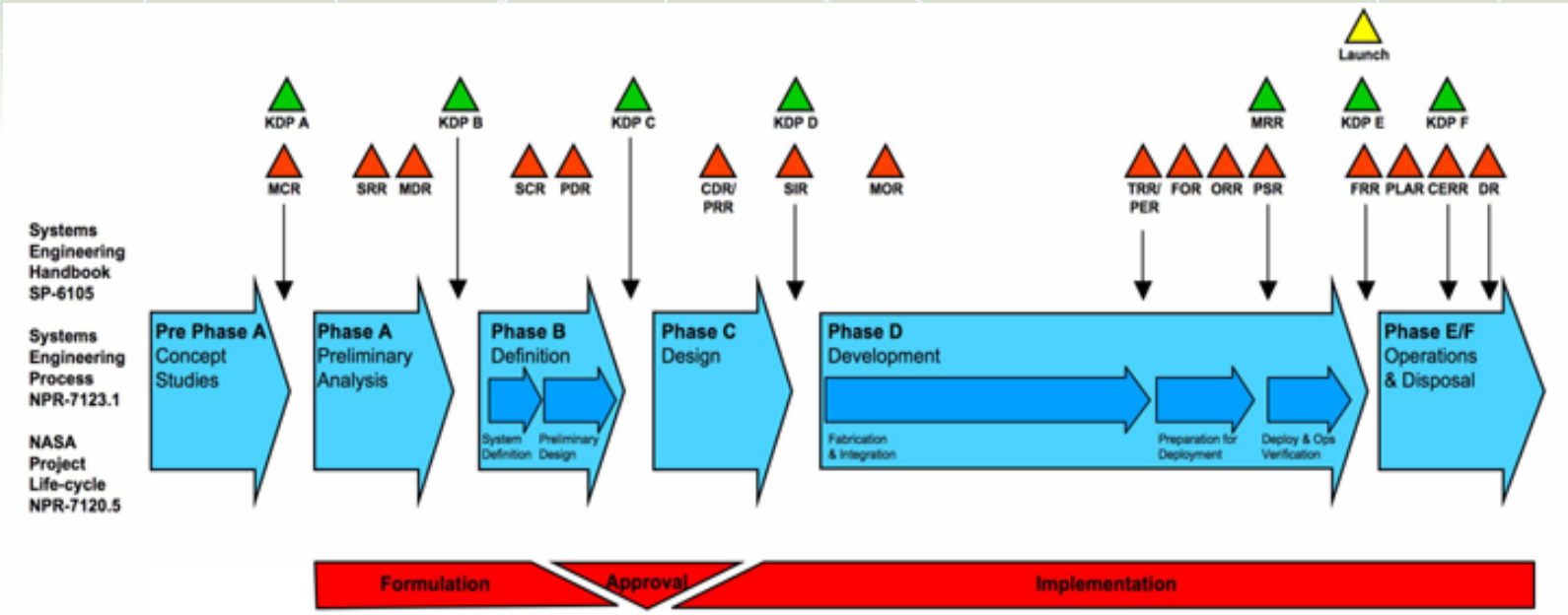
- **Systems engineering is the art and science of developing an operable system capable of meeting requirements within imposed constraints.**
  - Not dominated by the perspective of a single discipline.
  - The responsibility of engineers, scientists, and managers working together

Mission Triage



Systems Engineering Lifecycle

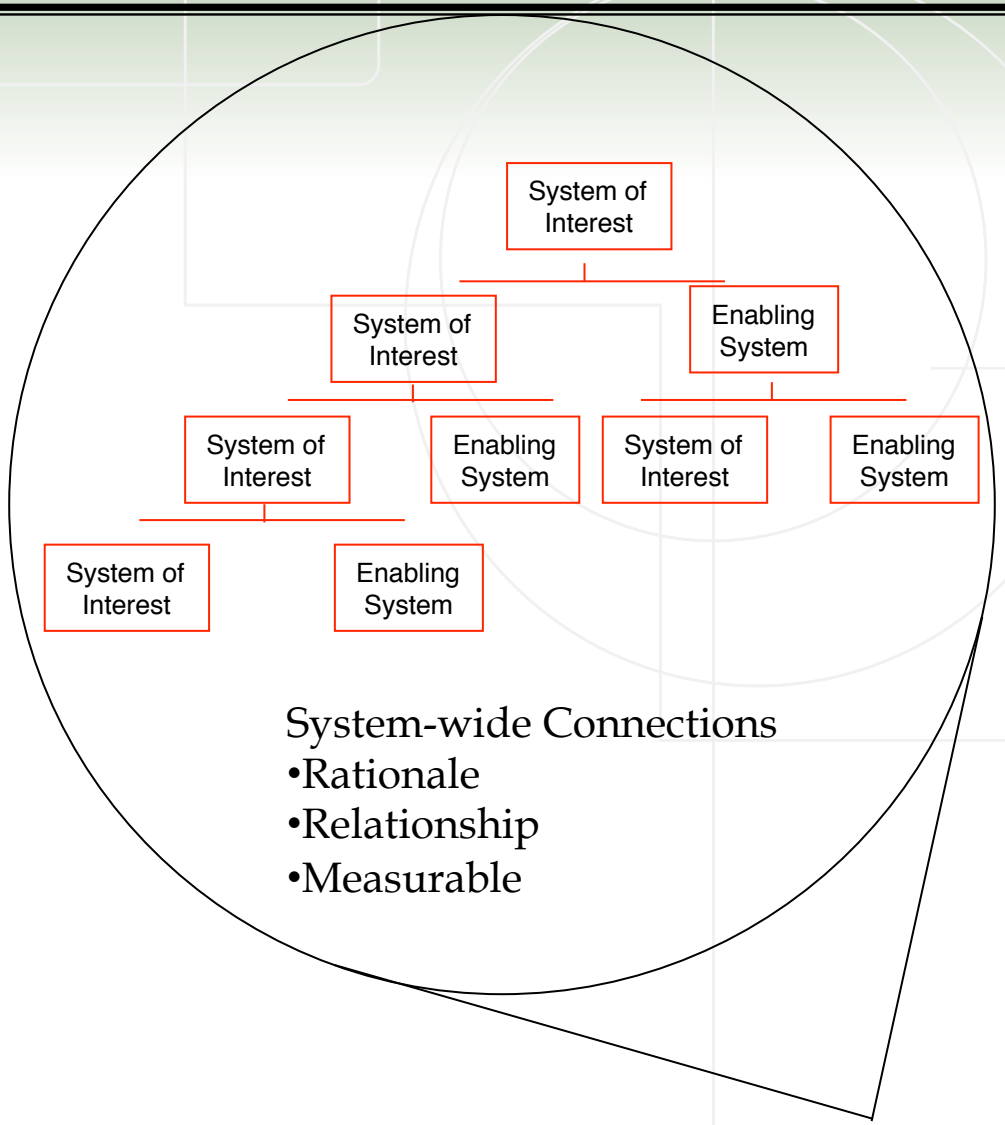
Planned activities grounded in established and proven methods to develop and operate systems

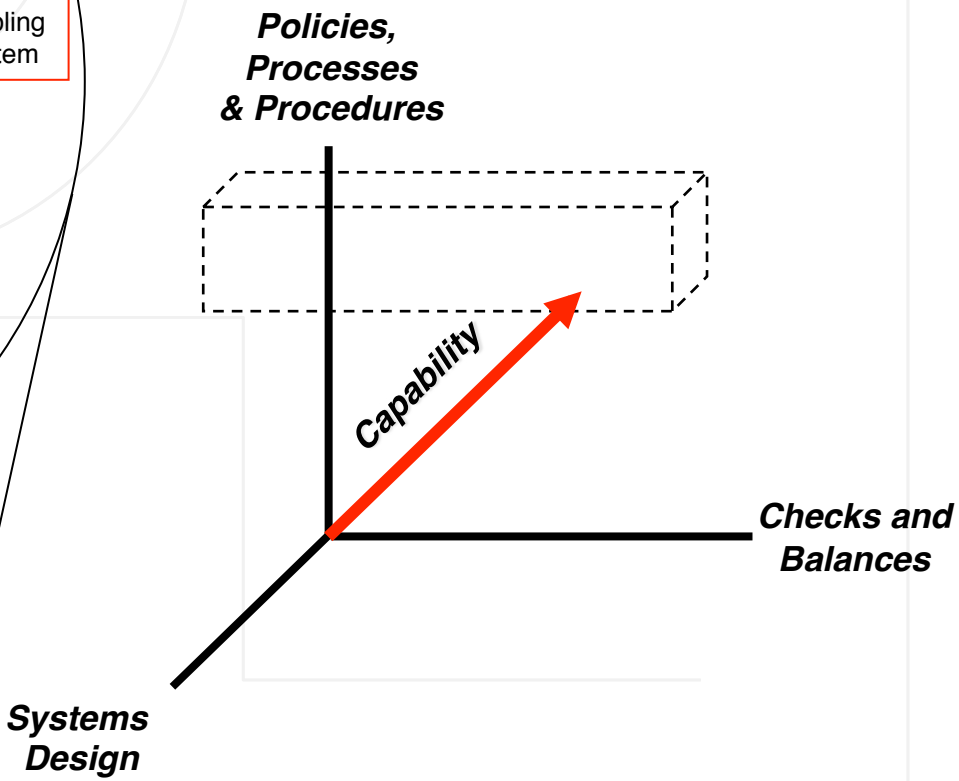


- **Logical Life Cycle, "Crawl before you Walk, Walk before you Run"**
  - A. Define Goals, Evaluate Multiple Approaches, Select a Single Best Approach
  - B. Decompose System to Lower Elements, Validate (Build the Right System)
  - C. Detailed Design (Build the System Right)
  - D. Build, Integrate, Verify
  - E. Operate
  - F. Dispose

- **Requirements, Design and Operations Concept Consistent with Cost, Schedule and Acceptable Risk** ***(Objective of NPR 7123.1 and Systems Engineering SP6105)***
  - Achieving this balance is the heart of the "Engineering" Activity.
  - Where creativity of the multidiscipline team is necessary

Engineering Capability





Systems Engineer Responsibilities Across the Mission Lifecycle

Systems Engineer

Lifecycle Focus on Mission Success

Technical Architect

- Requirements Identification
- Architecture and Design
- Operations Concept

Technical Authority

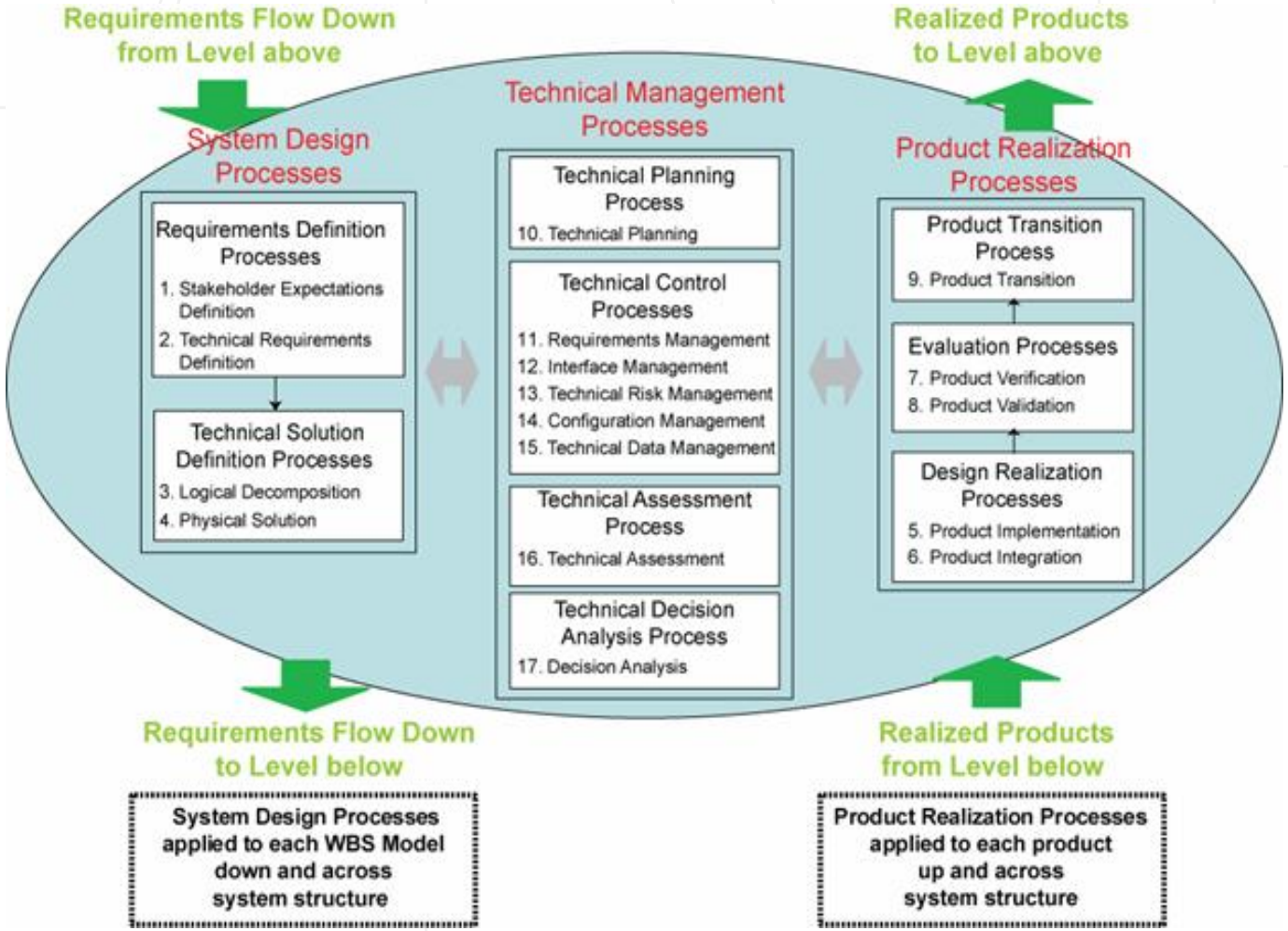
- "Proper Paranoia"
- Track Resources and Margins
- Verification and Validation
- Anomaly Resolution (Make it Work!)

System Engineering Processes/Training

System Engineering Handbook (SP-6105), GPR 7123.1 Systems Engineering

(CM, Risk Mgmt, Req'ts Mgmt, I/F Mgmt, Anomaly Resolution)

Systems Engineering Processes



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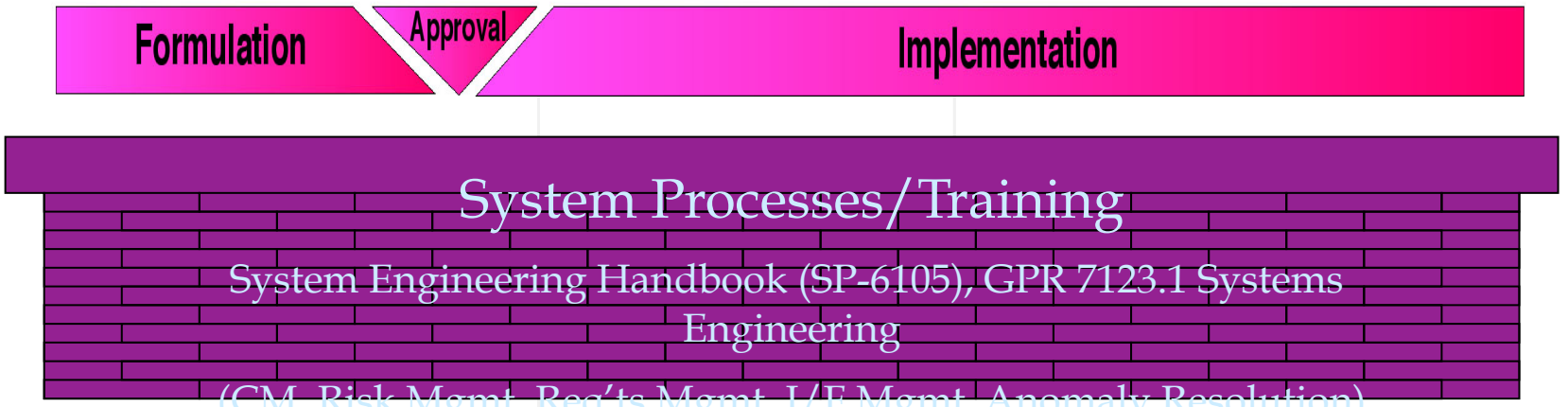
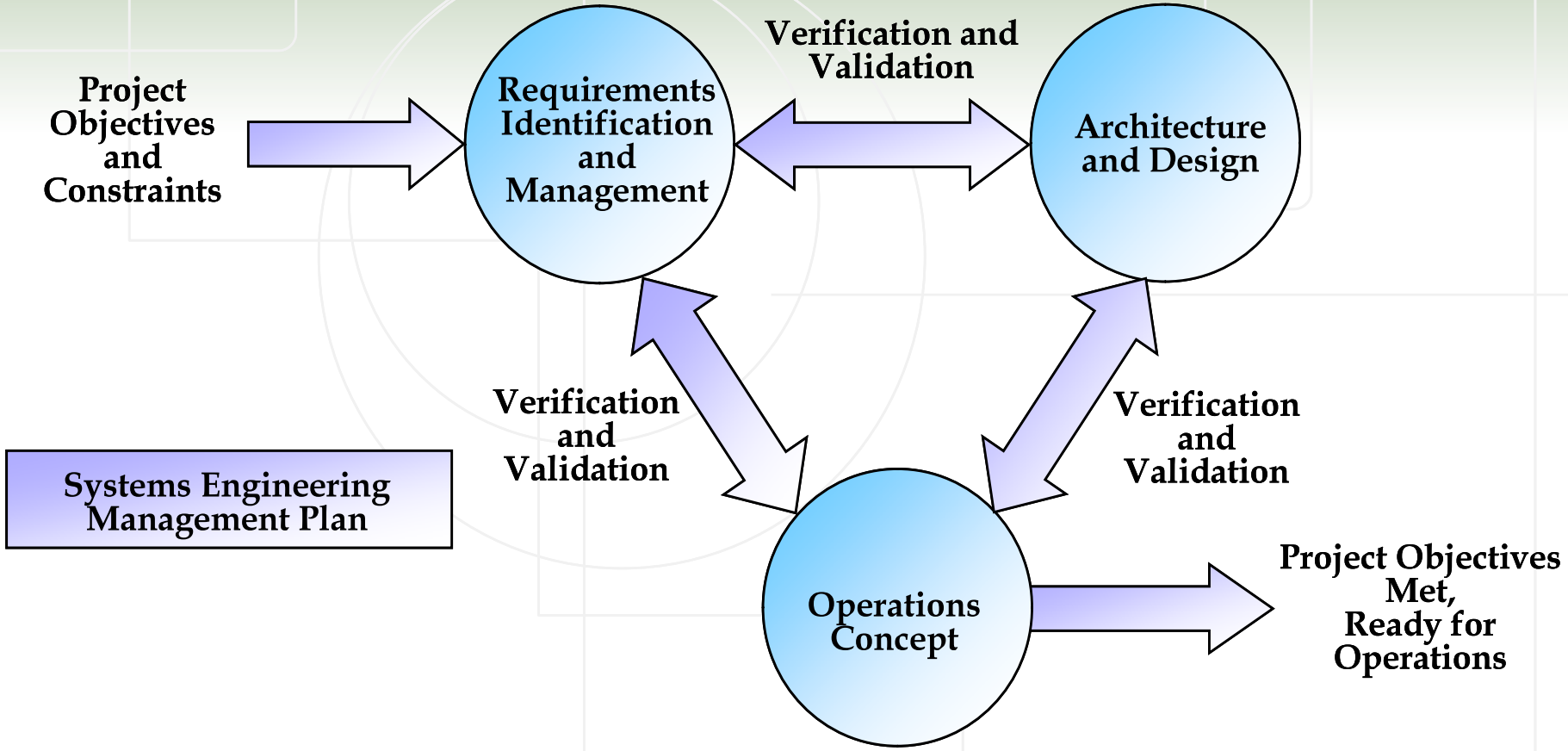
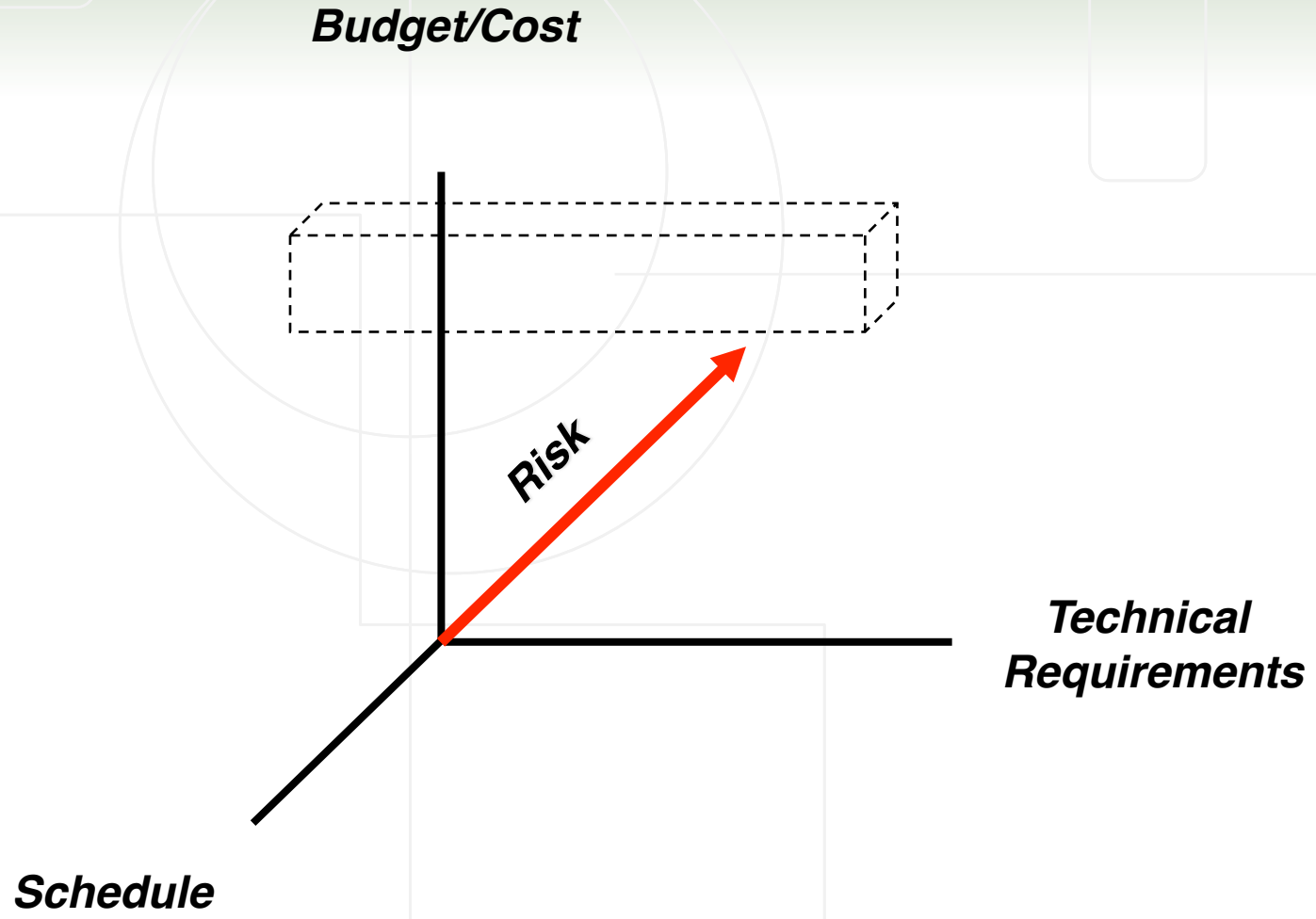


Systems Engineer as Technical Architect
Mission Architecture and Design



- **Early role is to coordinate the engineering, design and development of a Mission Architecture that:**
  - Meets the Principal Science Objectives
  - Is Consistent with the Mission Operations Concept,
  - Includes Instrument(s), Spacecraft, Ground Systems and Launch Vehicle
  - Survives/Operates in the Intended Mission Environments
  - Can be developed on schedule and within cost

The Integrity of the System, and Management of "The Square Box"



The challenge is to design the smallest square box possible.
An Even Bigger challenge is to keep it that way, and square

Let's Apply Systems Engineering Formulation Exercise

- **Observation/Statement of the Problem**
  - Garage is too full, car will not fit. Wife hates Scraping Windows in Winter.
  - Access to lawn equipment (chairs, grill, mower) in garage is awkward!

- **Needs & Objective**
  - Develop a cost-effective solution to allow car into garage, improves accessibility to lawn equipment, and can be implemented before Next Winter

** Adapted from exercise developed by Michael Bay/Bay Engineering Innovations

Formulation Exercise
Let's Apply Systems Engineering

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Candidate solutions

- **Rent Dumpster/Clean out Garage**
  - Hire Lawn Service
- **Sell Seldom Used Equipment**
  - Rent when needed
- **Use Tarps to Cover Equipment in Back Yard**
- **Rent Storage Facility for Equipment**
- **Extra Door to Basement, Store Stuff There**
- **Build an Addition to Garage**
- **Build a Shed**

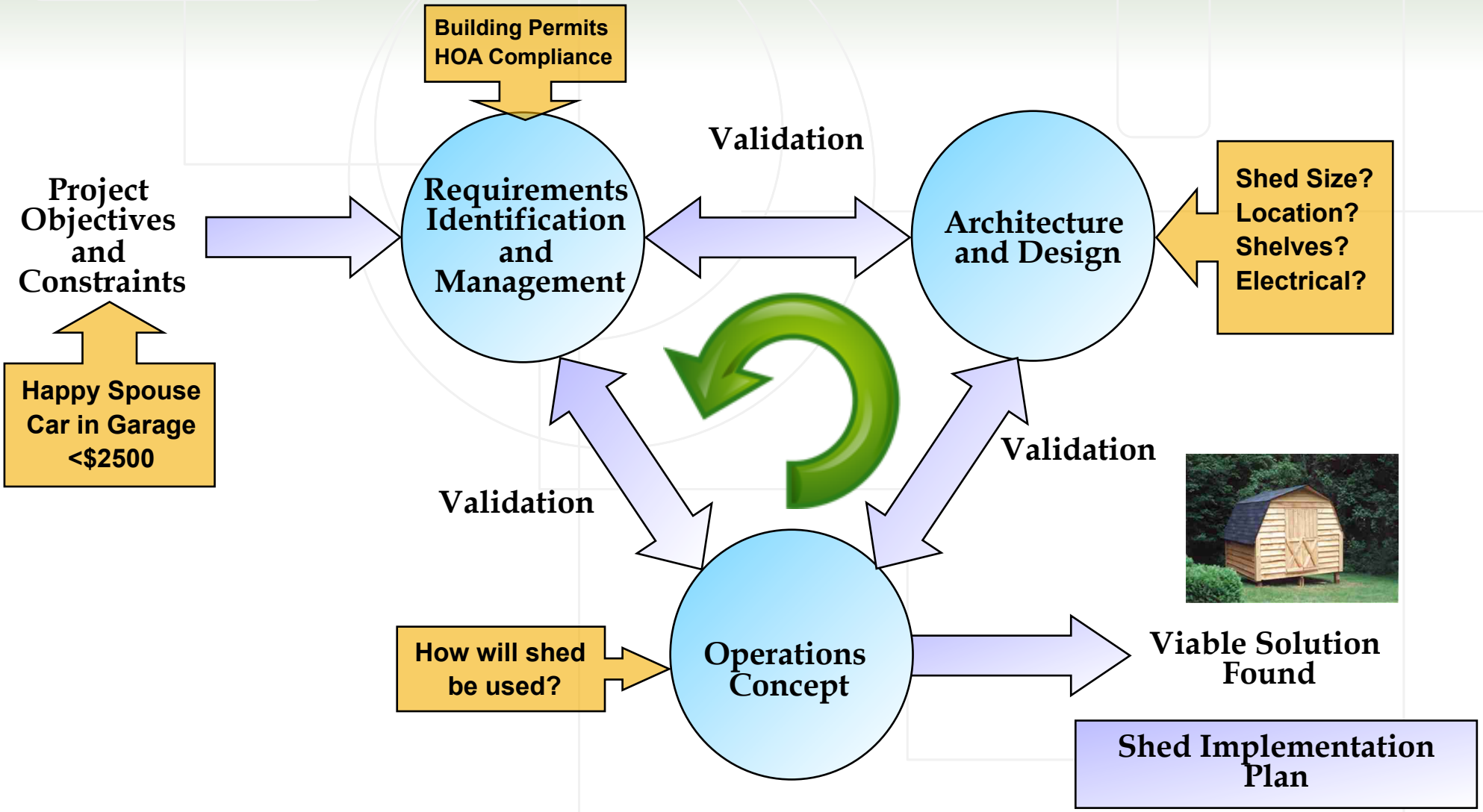
Decision-Maker Direction: Pursue Shed Solution

How do you know when you have the right Shed?

- Viable Solution = Meets Performance Needs, Within Schedule, and Within Budget (With Margin!)

- **How will Shed be used?**
  - Will Use Evolve over lifetime?
- **What does it look like?**
  - Size of Shed, Style, Location
  - Internal (Shelves, Floor, Walls)
  - Utilities (Electric, Water, FIOS)
- **What does it have to comply with?**
  - Building Permits, HOA Rules
- **How will Shed be Implemented?**
  - Make It / Buy Kit / Hire Contractor
- **What Cost? When Complete?**
  - Any Potential Collateral Impacts?

Using System Engineering Process: Formulating Shed Solution



Formulation Study
Shed Concept and Implementation Plan

- **Guiding Objectives**
  - Garden Tools, **New Lawn Mower**, Chemicals/Fertilizer, No Tractor
  - ~$2500 (Total Cost)
  - Spring/Summer Implementation

- **Ops Concept**
  - Two Doors to fill shed completely
  - One door access to Garden tools
  - Storage Shelves for "stuff"
  - Roll mower in and out
  - **Path from House to Shed**
  - Keep Mice and Squirrels out
  - No Electrical Services, No HVAC

- **Derived Requirements (Decisions)**
  - 8x12 Foot Print, 7' Headroom
  - Wood Floor on Concrete blocks
  - 2 - 30" Doors, Ramp?
  - 2x4 Walls, Small Storage under Roof
  - 1 Wall of Shelves

- **Shed Implementation Plan**
  - DYI Kit ($1650)
  - Misc. Hardware ($500)
  - Labor from Brother-In-Law (Beer$)
  - Memorial Day Weekend
  - **Collateral Impacts (Un-Scoped)**
    - **New Lawn Mower (Sell Tractor?)**
    - **New Path to Shed, Ramp**
    - **Loss of Yard Space – *Less mowing***

Systems Engineer Responsibilities Across the Mission Lifecycle

Systems Engineer

Lifecycle Focus on Mission Success

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- Track Resources and Margins
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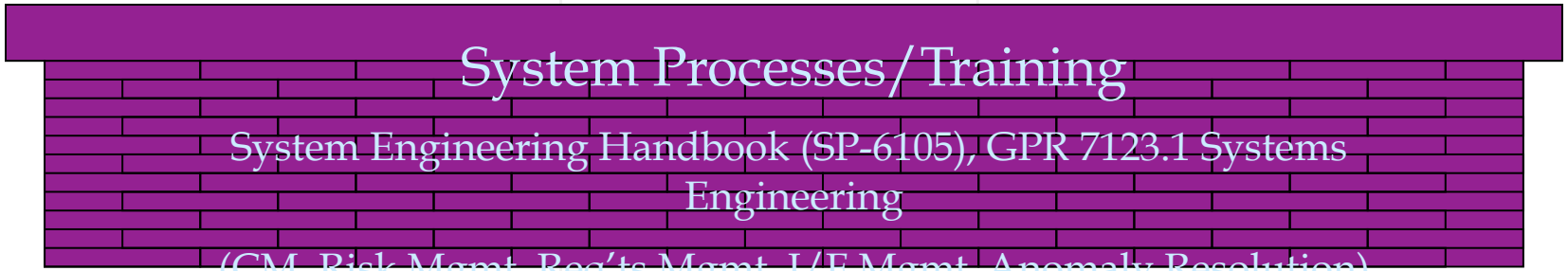
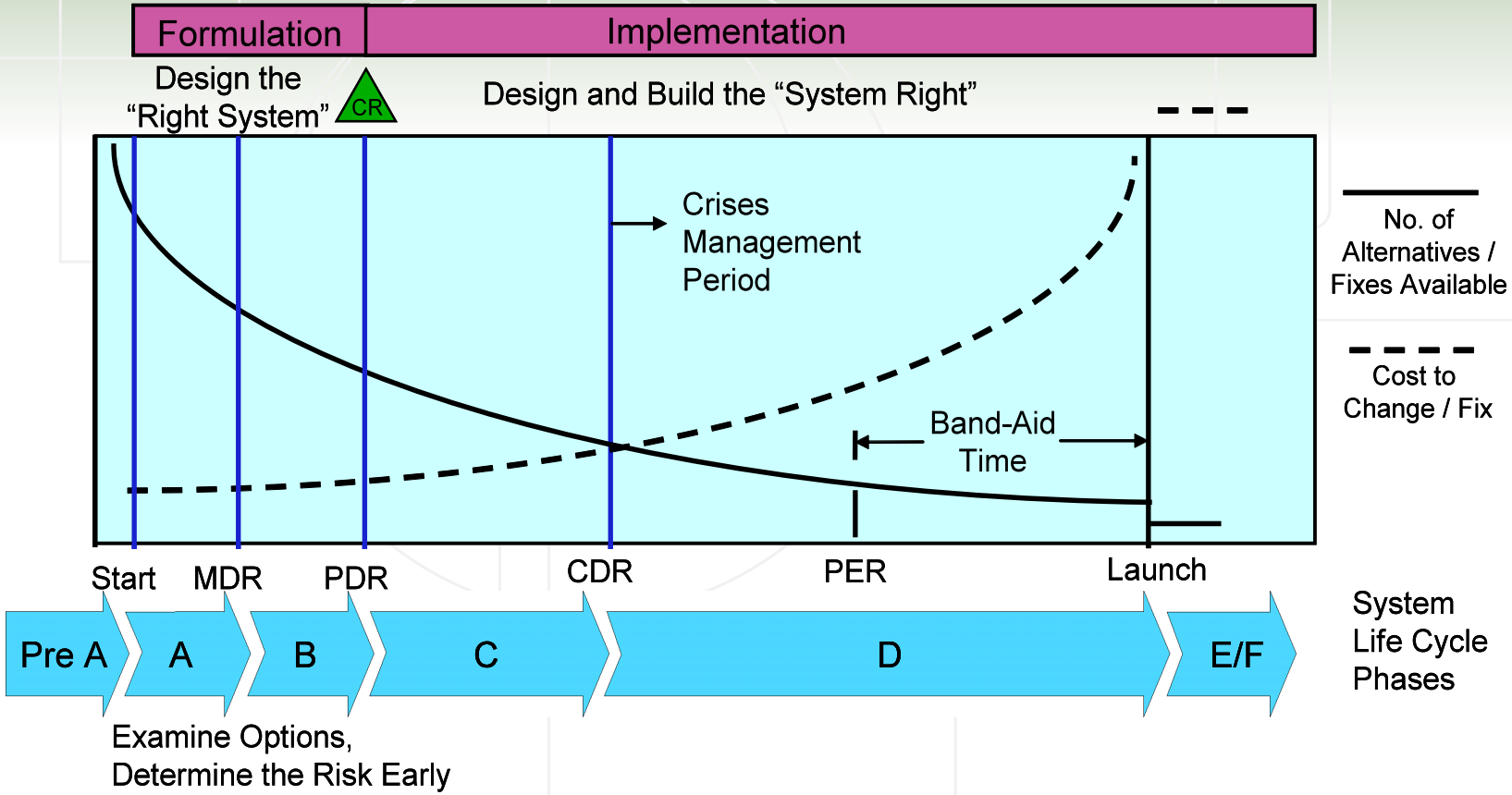


Mission Implementation: From Technical Architect to Technical Authority



Technical Architect (to CDR)

- **Refine the Mission Architecture**
  - Conduct Trade Studies, Refine Operations
  - Allocate Resources (Mass, Power, etc)
- **Set the Requirements Baseline**
  - Science Requirements ("Mission Success")
  - Applicable "Design Standards"
- **Validate Design Solution(s) Constantly**
  - Is this "Right System"?

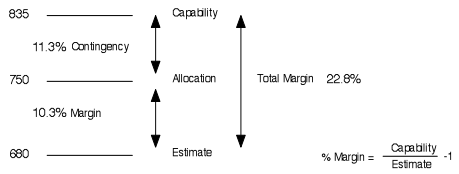
Technical Authority (CDR to Launch)

- **"Proper Paranoia": Singular Focus on Mission Success**
- **Technical Leadership**
  - Track Technical Resources and Margins
  - Anomaly Investigation and Resolution (Make it Work!)
  - Verify and Validate System Functions as Intended
- **Great Communicator**

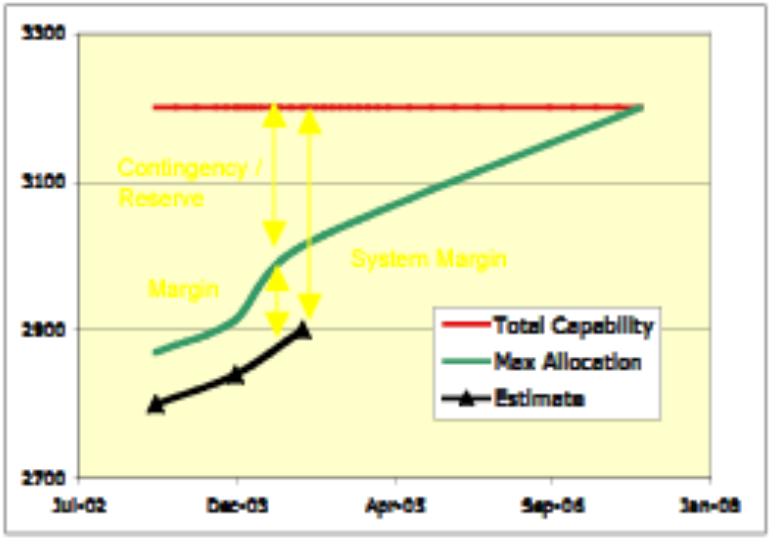
Technical Resource Budget Tracking Example
(Each Project Tailors Specifics)

Total Margin Progression	SCR	PDR	CDR	Flight
Mass	35-25%	20-30%	15-20%	0
Power (solar array, battery, load)	25-35%	15-25%	15-20%	0 at EOL
Fuel	3 Sigma + Uncertainty			3 Sigma
Memory	50%	30%	25%	5%
CPU	50%	30%	25%	20%
Telemetry and Commands	20%	15%	10%	0
RF Link	3dB	3dB	3dB	3dB

Margin Factors	Estimate	Calculated	Measured
Mass	20%	15%	3%
Power (solar array, battery, load)	20%	15%	3%
Fuel	10%	5%	3%
Memory	30%	15%	3%
CPU	50%	30%	25%
Telemetry and Commands	20%	15%	10%
RF Link	2dB	1dB	.5dB

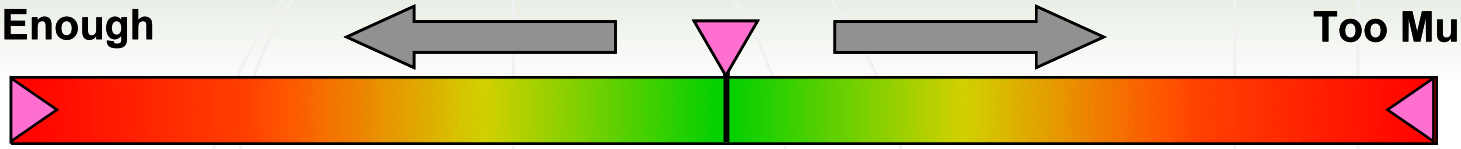


Tracking Estimates (Mass)



- **Allocations Defined at SRR for appropriate Total Margin**
- **Estimates Tracked Monthly**
- **Changes to Allocation via CCR**
- **Estimates Over Total Allocation Trigger Risk Reduction Activities**

"Proper Paranoia" – Gentry Lee, JPL



Complacent Infallibility

It has never failed before!
What can go wrong?
It can't fail!

Proper Paranoia

Know and Learn "How" and "Why" System works (or fails!)
"Closet Optimist!"
"Great Communicator"

Paralyzing Fear of Failure

It will never work!
The sky will fall!
We have never done this before!
We do not do this anymore!

What is "Proper Paranoia"? (Taken from Gentry Lee's JPL Lecture)

- **Challenge Technical Inputs/Claims with Appropriate Vigor**
  - Good News and Bad News Treated with Equal Emphasis
- **Analyze and Get to Know System, Including Failure Modes and Contingencies**
  - Know Essential Requirements for Mission Success (Pointing, Stability, Repeatability, etc.)
  - Failure Modes and Effects Analyses (FMEA's) Great Tools
- **Get to Bottom of All Anomalies – Especially in Critical/High Risk Areas**
- **Minimize the "Known Unknowns" – Reducing Uncertainties Reduces Risk**
- **Listen to Everyone – Managers, Engineers, Technicians, QA, Safety**
  - Effective Communication is **Paramount** to Ensuring Mission Success

Conclusion

- **Sound engineering design and implementation does not occur by accident.**
  - The orchestra directors (manager, investigator, system engineer(s)) must have the right experience, or an effective mentoring system must be put in place.
  - There must be complete understanding upfront of the job at hand, the resources available, the approach, and the risk posture

- **Systems Engineering is both a science and an art**
  - Designing and managing “the box” to keep it square requires a deep understanding of the science, and mastering of the art of systems engineering.
  - Good systems engineering is about being able to make the connections from top to bottom, and bottom to top at all times.