Effecting the Transition to Concept Design

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The Basic Question?

- What is the Systems Engineering community doing to enhance the development of systems our Warriors need to execute their missions?
- Without:
  - Being late to need
  - Costing too much
  - Failing at the wrong time and the wrong place
  - Being too hard to:
    - Operate
    - Sustain
- Does our Defense Acquisition system maintain a long-term focus on development and acquisition of our warfighting systems?

Observations (by some smart people)

- NDIA Systems Engineering Committee
- Undersecretary of Defense for Acquisition, Technology and Logistics
- Department of the Air Force Directorate for Science and Technology

NDIA Systems Engineering Committee

- **Issue Number ONE:**

Key Systems Engineering practices and procedures known to be effective are not consistently applied across all phases of the program life cycle!

Why?

- “Inconsistent SE practices for program planning and execution”
  - Training and Development of career Systems Engineers
  - Retirement of the “gray beards”
  - Too busy doing the “day job” to take the necessary time to deal with the basics
- Short-term focus
  - Programs working toward the next big event
  - Public law on appropriations and contracting
  - “Will this get me promoted?”
- Bureaucracy
  - Well-intentioned policies hinder vice help
  - Non-technical bureaucrats in key positions

Undersecretary of Defense (AT&L)

- **The Honorable James Finley – Keynote address to the NDIA Systems Engineering Conference (10/23/07)**

Programs usually fail because they are not properly initiated

Why?

- Requirements not well defined
  - Requirements Creep
- Inadequate early technical planning
- Inadequate funding and schedule realism
- Lack of technical maturity
- Insufficient focus on support and sustainment
  - Reliability the most critical current problem
    - The services must pay this bill every year
  - Support and sustainment as critical elements of Total System Effectiveness
- Need for a skilled, clearable workforce

Air Force Office of Science, Technology and Engineering

- **Mr. Terry Jaggers – address to the NDIA SE Conference (10/23/07)**

DoD needs to improve its ability to perform Concept SE!

Why?

- What is Concept SE?
  - Translate needs into a set of requirements describing a concept solution
- How does Concept SE relate to the "traditional life cycle SE definition"?
  - Architecture
  - Engineering Design
  - Test and Evaluation
  - Production and Deployment
- Concept SE leads to better military utility assessments to evaluate concept alternatives

Personal Observations

- Misapplication of DoDAF
  - Fundamental misunderstanding of "The A-Word"
  - Emphasis of Product over Process
  - Architecture views over Architecture model
- Viewing JCIDS as a bureaucratic control mechanism as opposed to an engineering opportunity
  - Emphasis of the artifact over the analysis

DoDAF Contributions to SE

Good Architecture → Effective Design

- A good architecture model IS NECESSARY for good systems design
  - Model traces back to Requirements; traces forward to design
  - Architecture views ARE NOT limited to those prescribed by DoDAF
    - DoDAF presents the C^4ISR Viewpoint, but is this sufficient?
    - What are the other relevant viewpoints?
  - Architecture model is fundamental for Concept SE

JCIDS Contributions to SE

Good SE → Effective JCIDS

- IF the engineering is done right and the analysis is thorough, THEN the JCIDS will be effective
  - JCIDS Functional (Area, Needs, Solutions) Analyses are critical SE activities.
    - Artifacts will reflect the analysis
- This is MATERIAL SOLUTIONS ANALYSIS
  - New DoD 5000 Pre-MS A

Consider the Fundamentals of SE

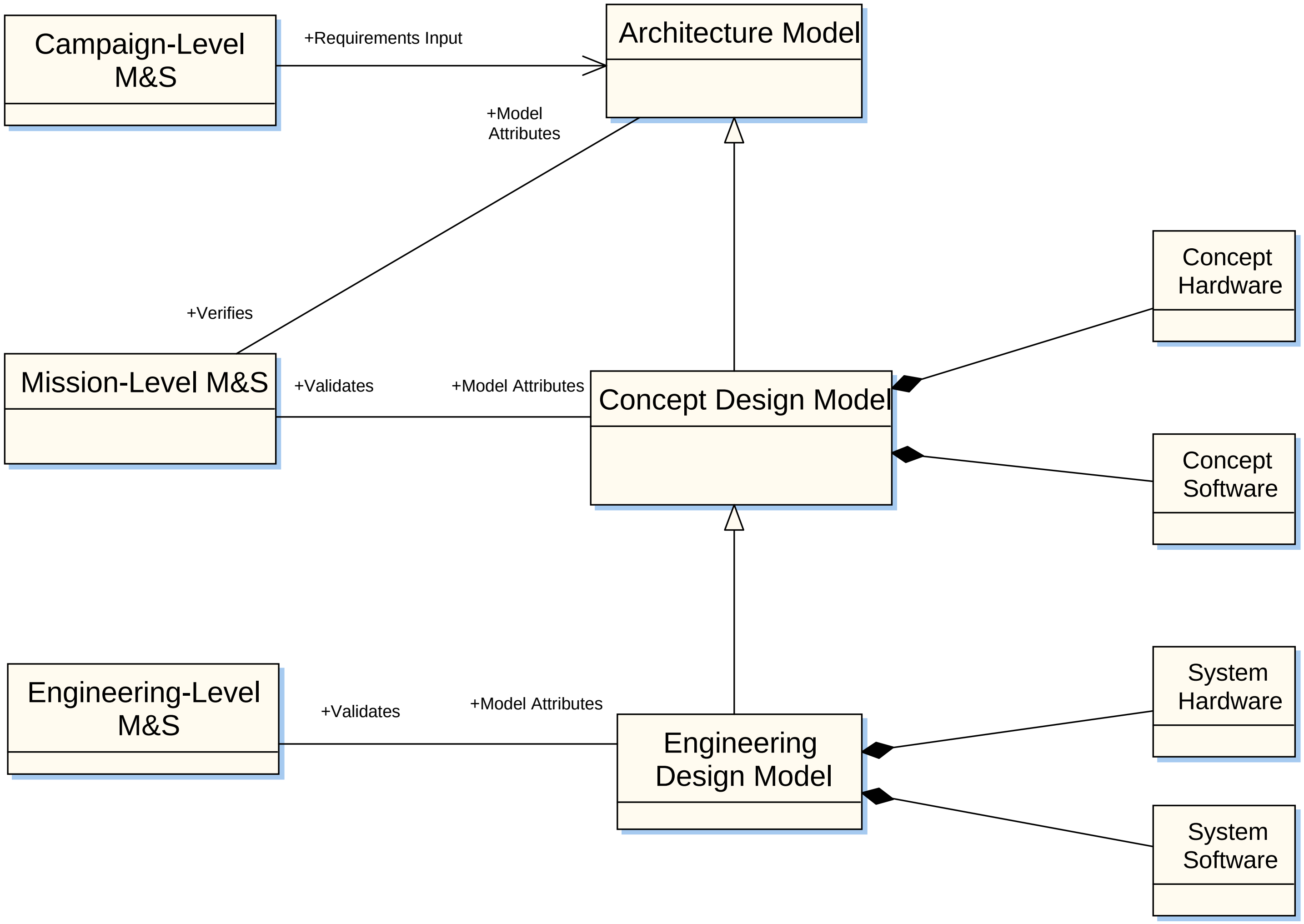
- Applying the "Key Systems Engineering Practices known to be effective"
  - Needs Analysis
  - Concept definition and development
    - Analyses of alternatives
  - Engineering and Development
    - Advanced development, system design and integration
  - Production and Post-deployment Support

Concept SE forms the foundation for system development AND deployment

Model-Based SE

- Modeling is fundamental to Concept SE
  - Captures operational and system requirements
  - Foundation for operational and system architecture
  - Details conceptual and engineering design
  - Facilitates Software development
  - Basis for M&S environment
  - Details information exchanges and data elements
- Text artifacts (i.e. specs) don’t go away
  - Included in the model as parameters, constraints

Model Evolution and Relationships



What is a Model?

- A simplified representation of reality
  - Used to mimic the appearance or behavior of a system or part (Kossiakoff & Sweet)
  - Abstracts features of situations relative to the problem being analyzed (Blanchard and Fabriky)
  - Promote understanding of the real system (Underhill)

If you don't model it, you won't understand it!

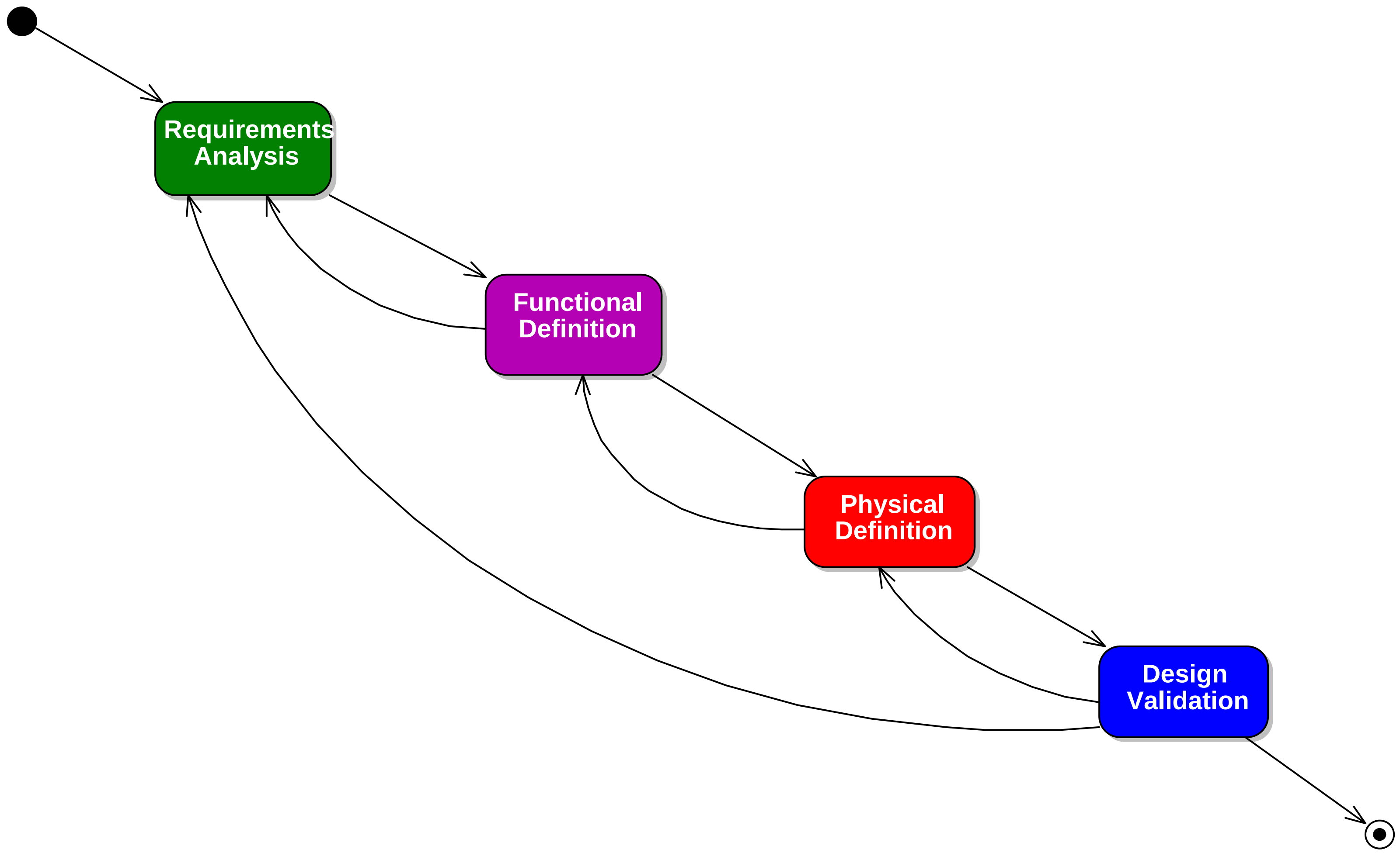
Jacobson

Systems Engineering Method

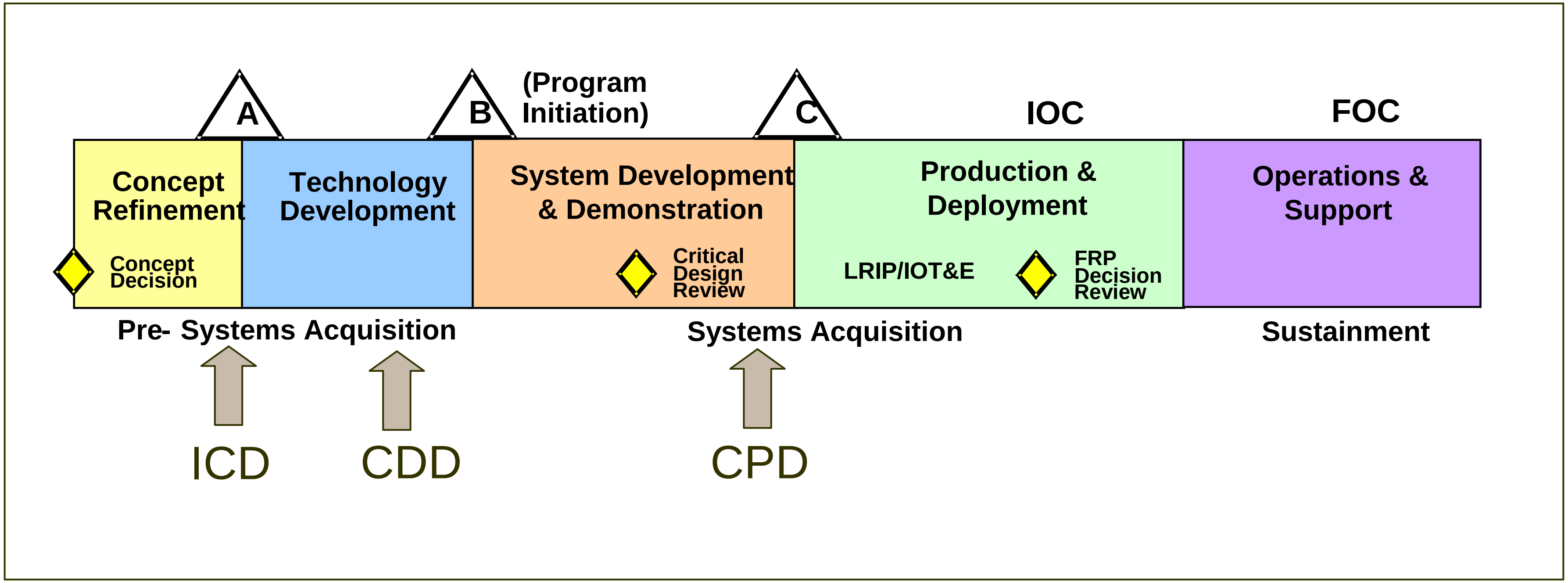
- Every phase of the System life cycle has some form of:
  - Requirements Analysis
  - Functional Definition
  - Physical Definition
  - Design Validation
- A more fundamental form of the SE “VEE”, but a little more iterative
  - Particularly within a given life cycle phase

Source: Kossiakoff & Sweet

SE Method

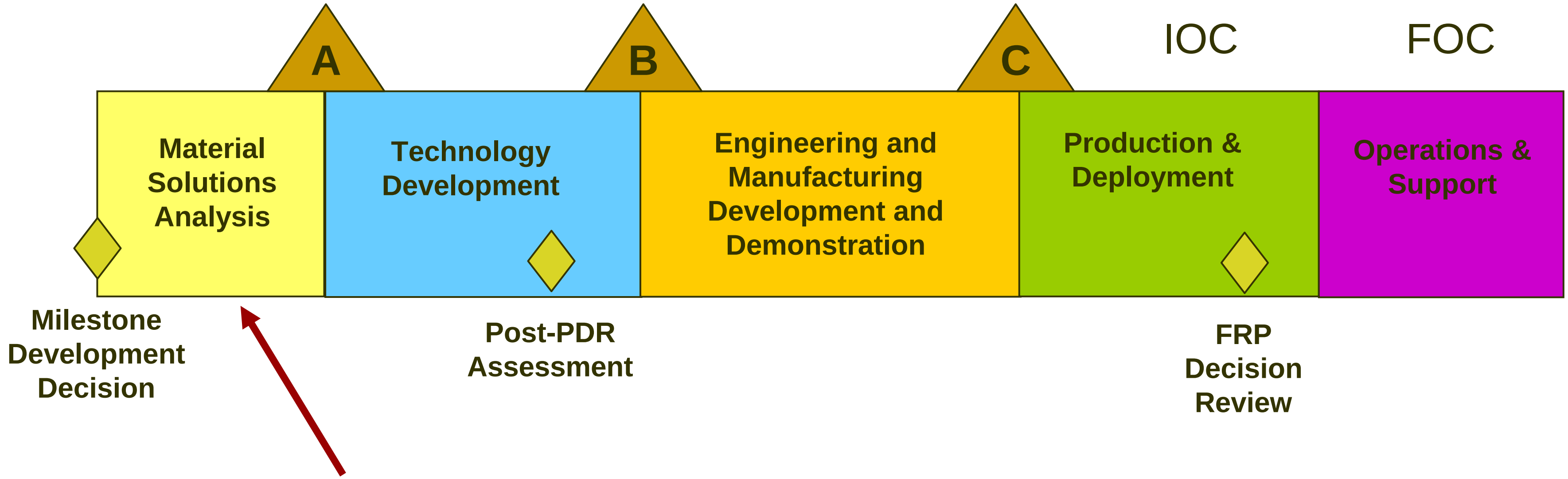

Requirements
Analysis
Functional
Definition
Physical
Definition
Design
Validation

DoD Product Life Cycle (Simplified)



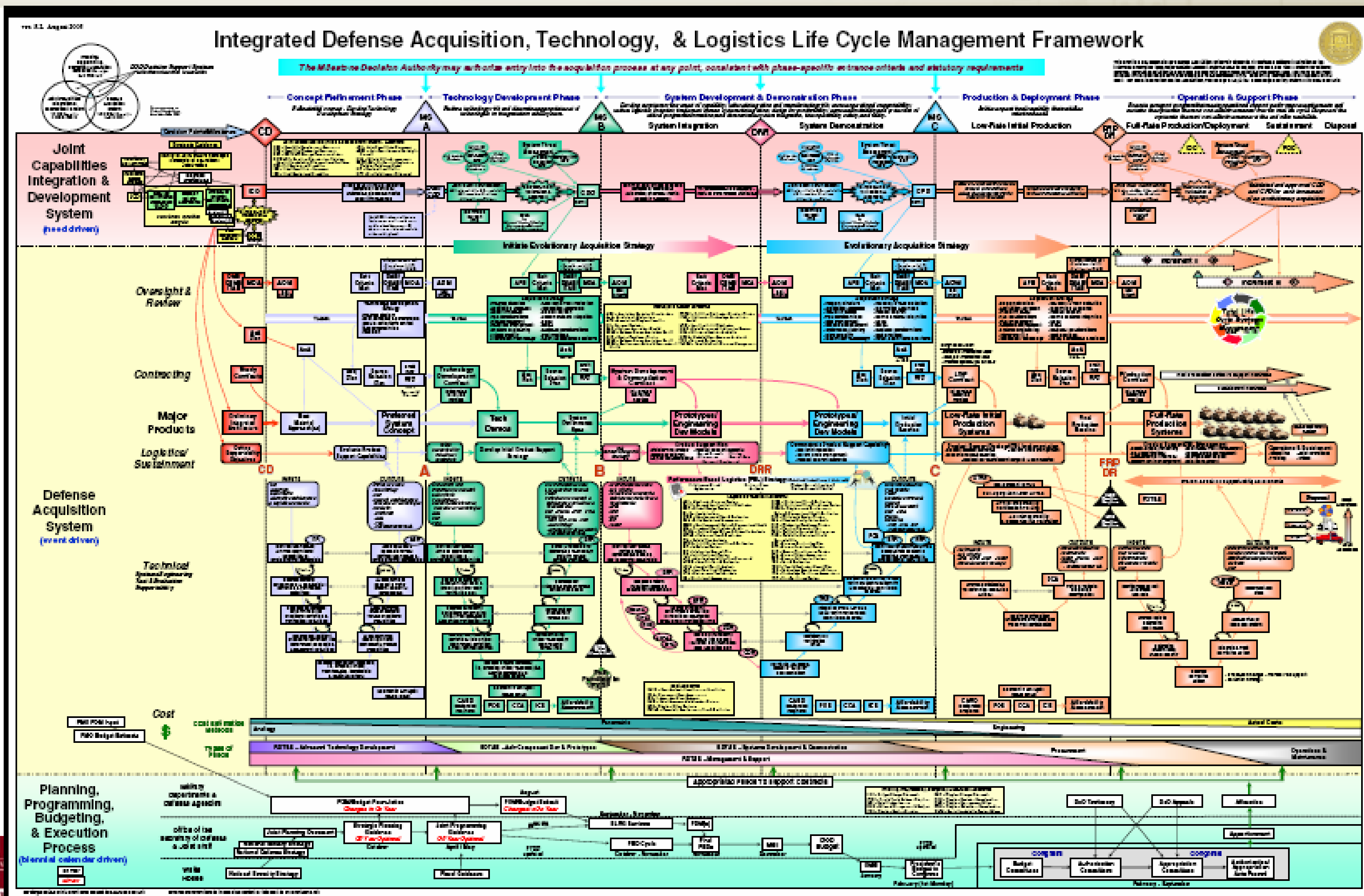
ICD = Initial Capability Document
CDD = Capability Development Document
CPD = Capability Production Document
IOC = Initial Operational Capability
FOC = Full Operational Capability

Proposed DoD Life-Cycle

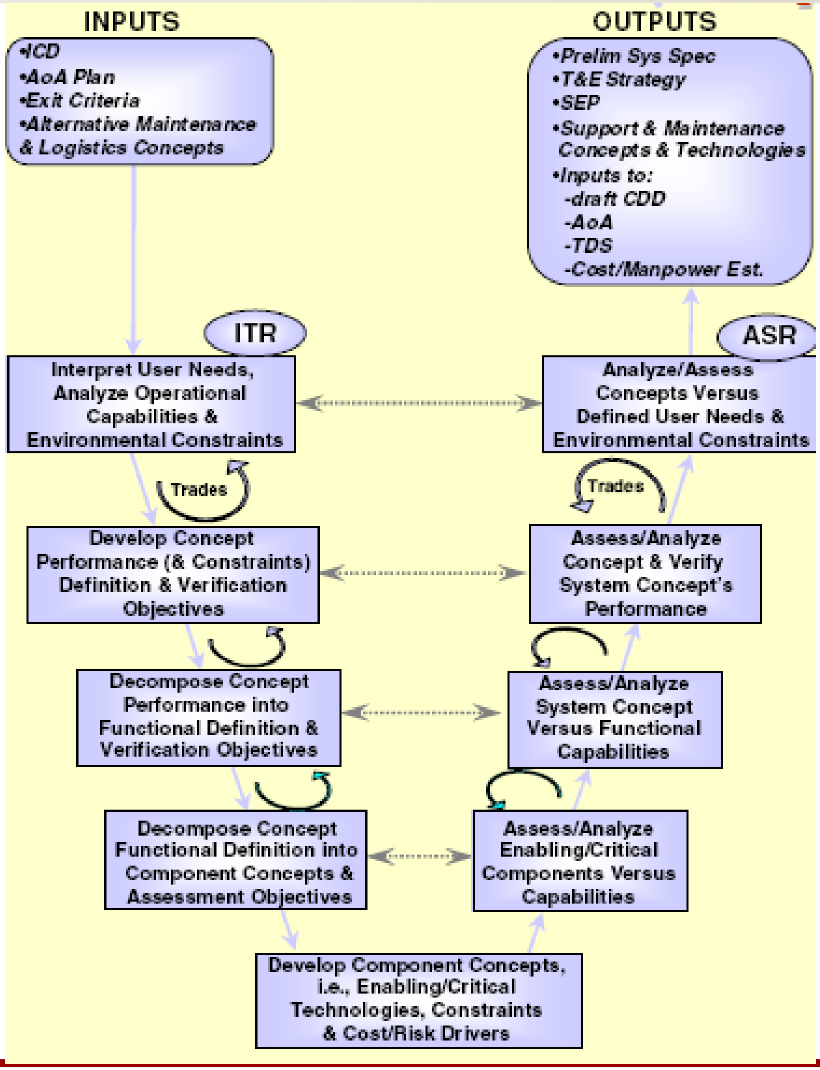


Up-front SE Required for JCIDS

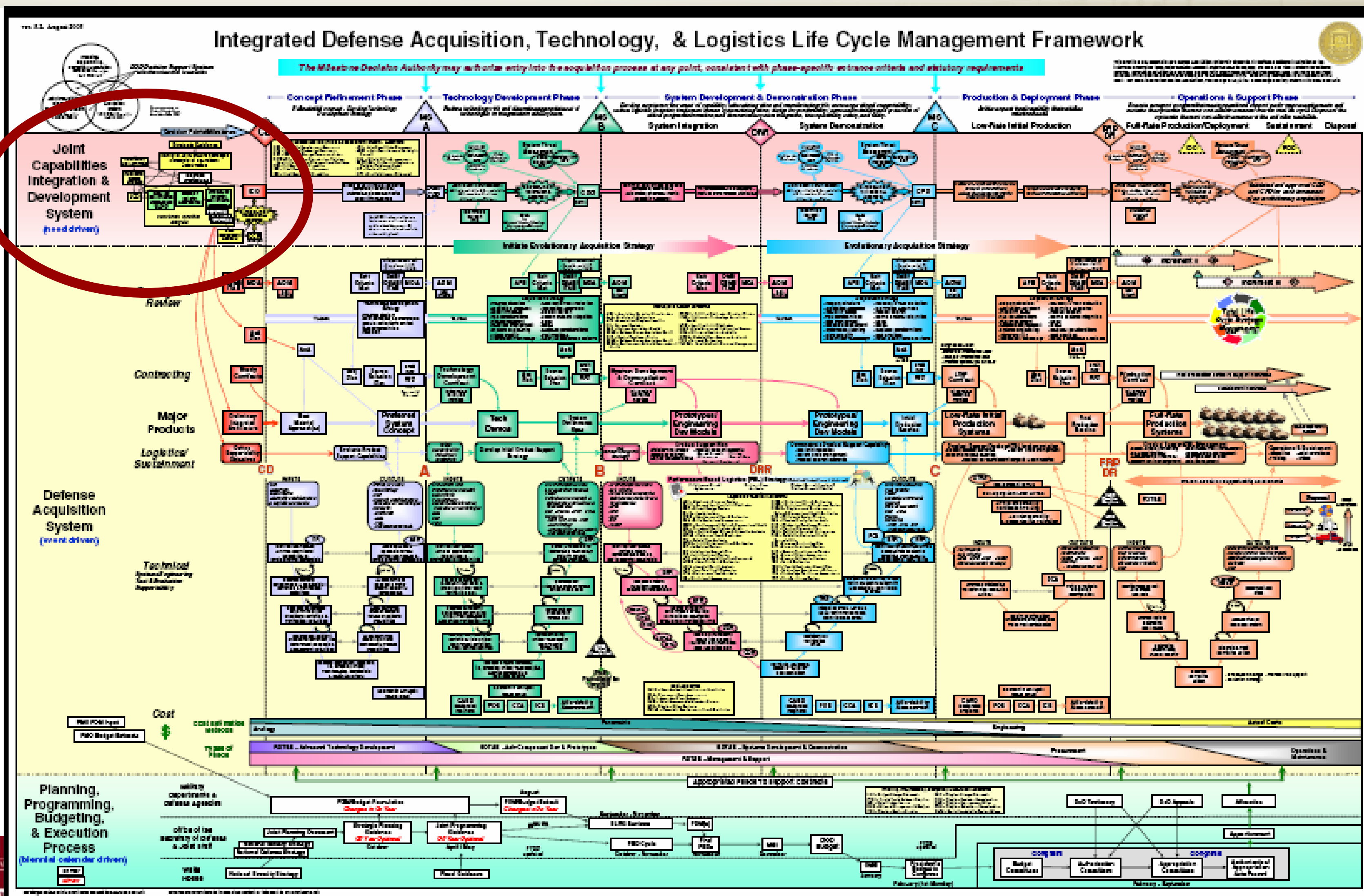
DoD Product Life Cycle (Not Simplified)



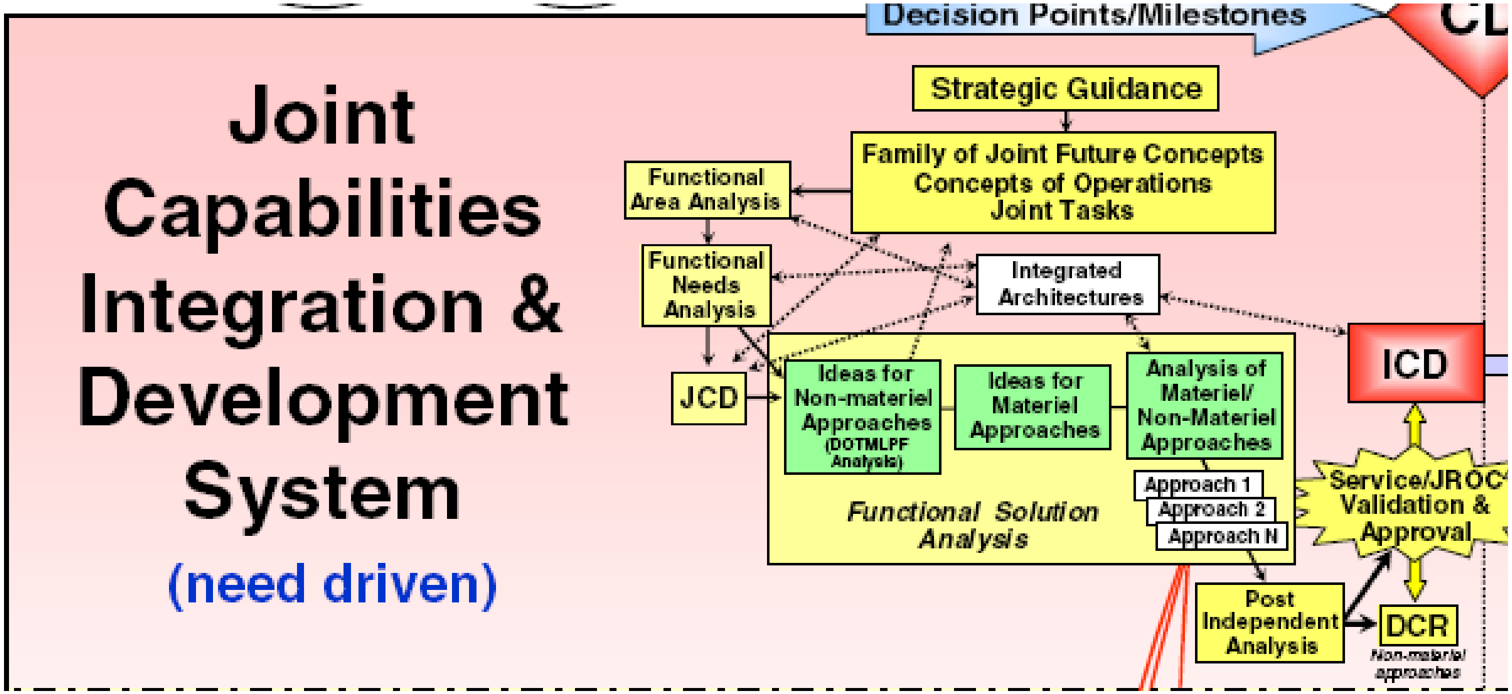
SE VEE (Concept Refinement)



The DoD Product Life Cycle



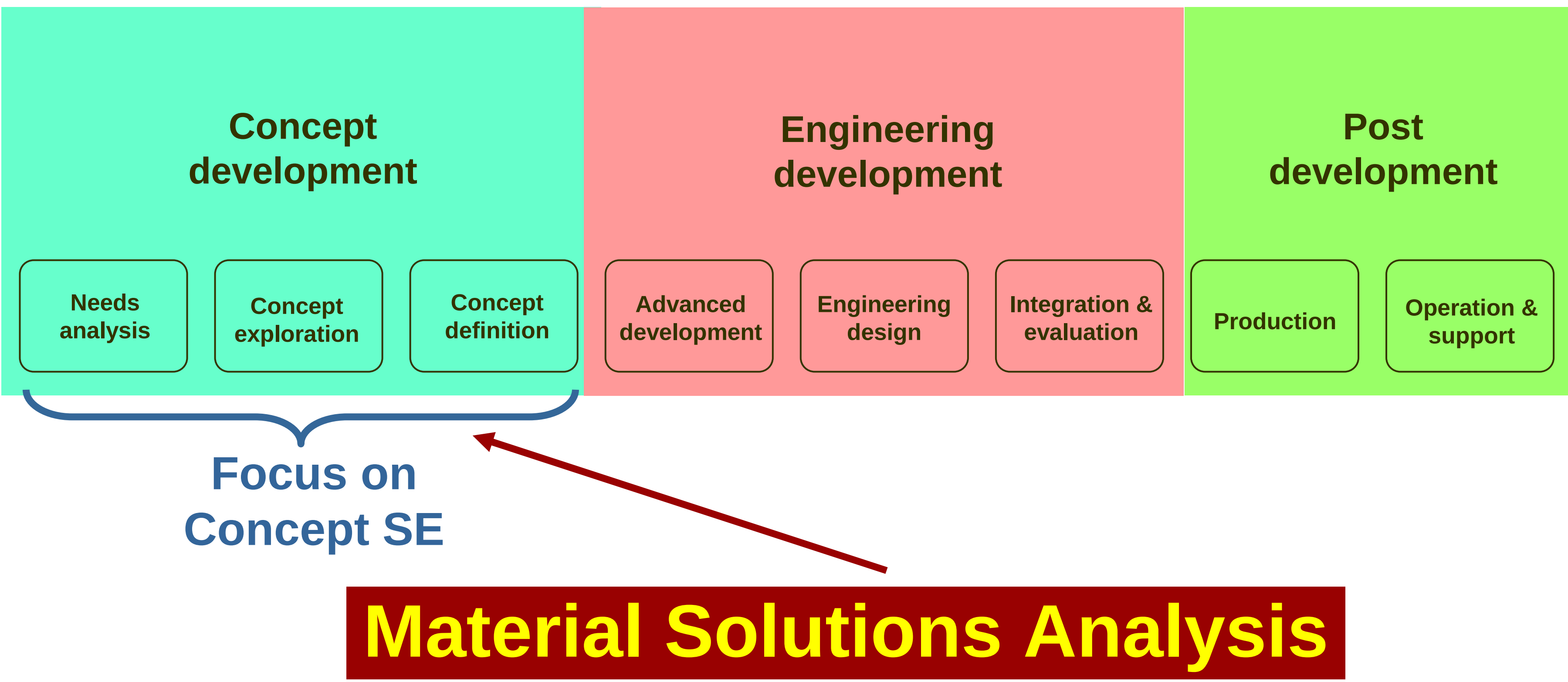
Pre-MS A JCIDS Functional Analyses



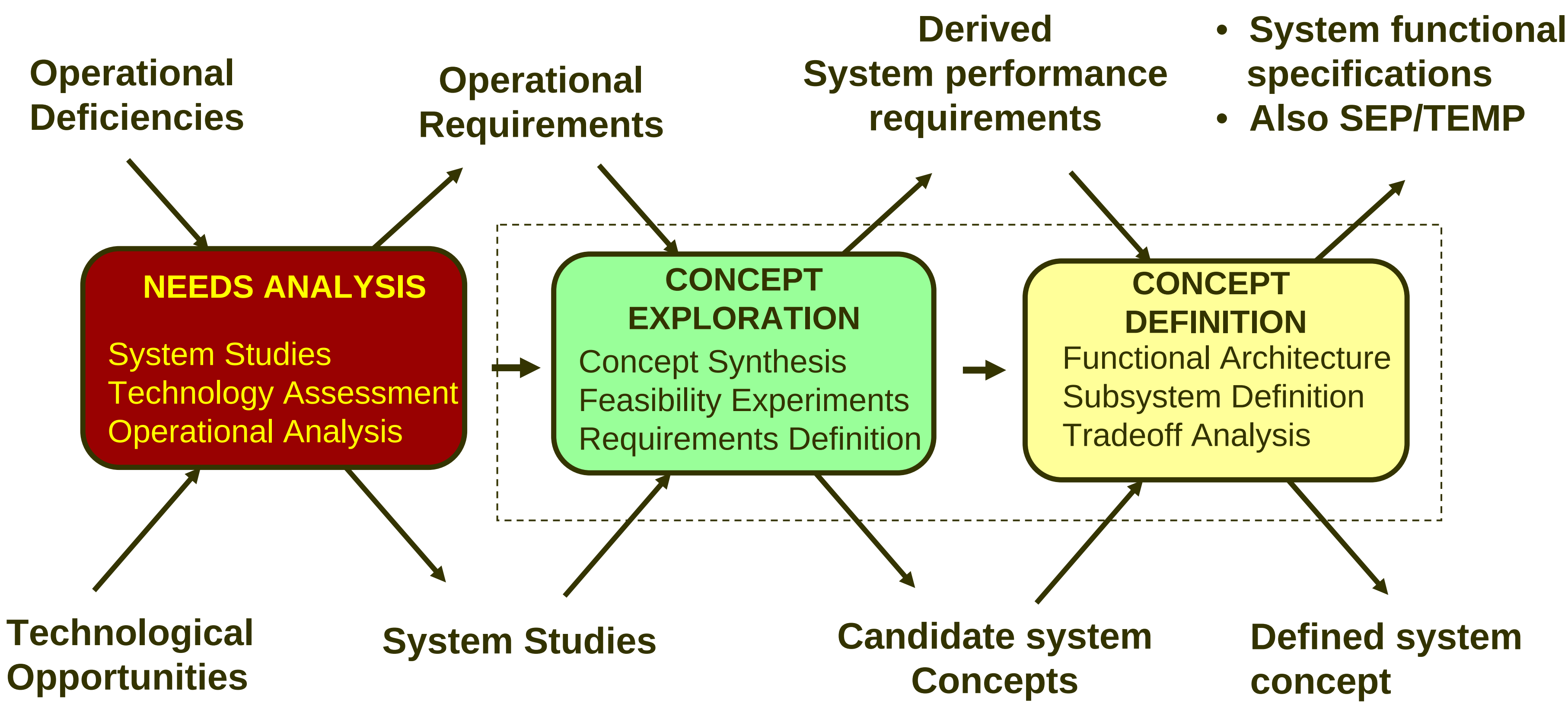
There is no "VEE" during this CRITICAL SE Phase

System Life Cycle Model

(Kossiakoff & Sweet)



Concept Development

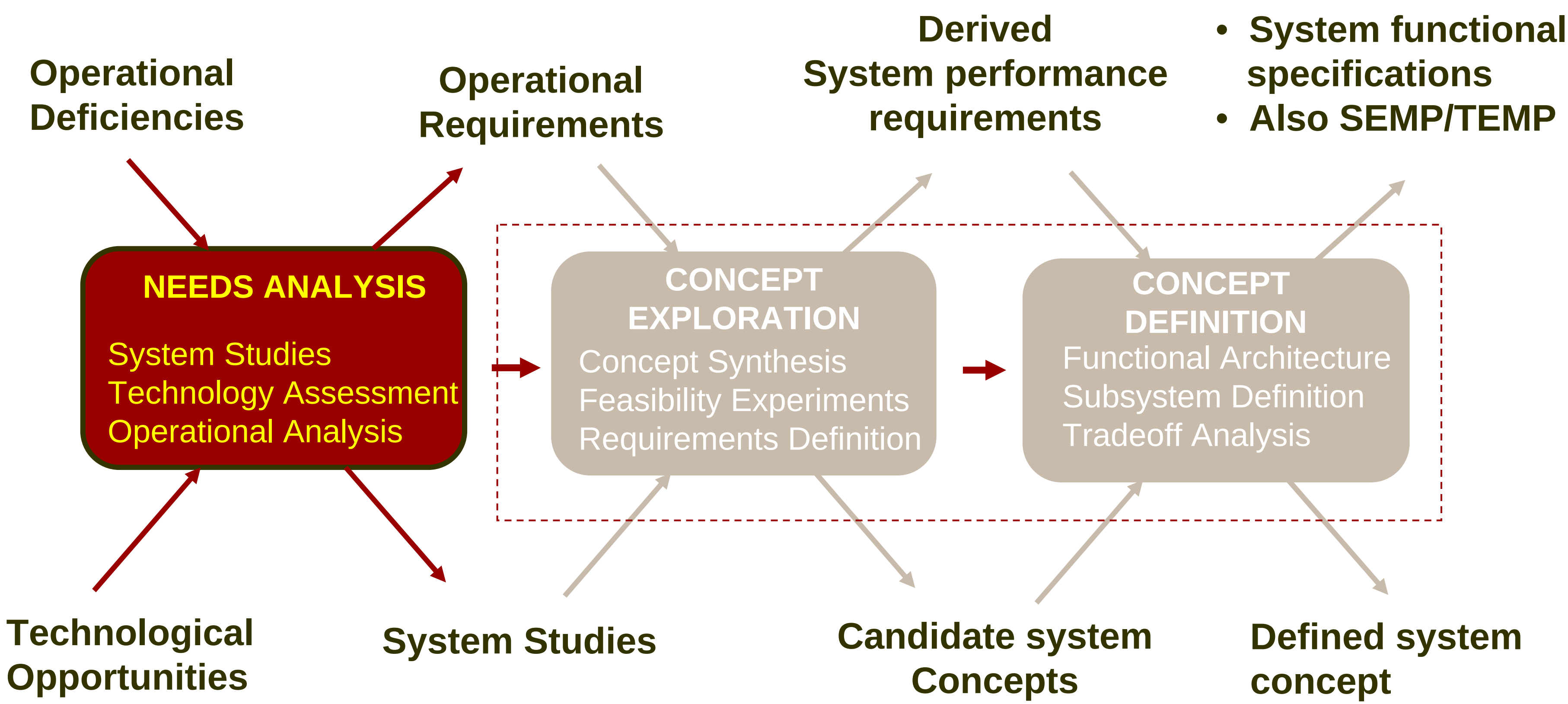


Source: Kossiakoff & Sweet

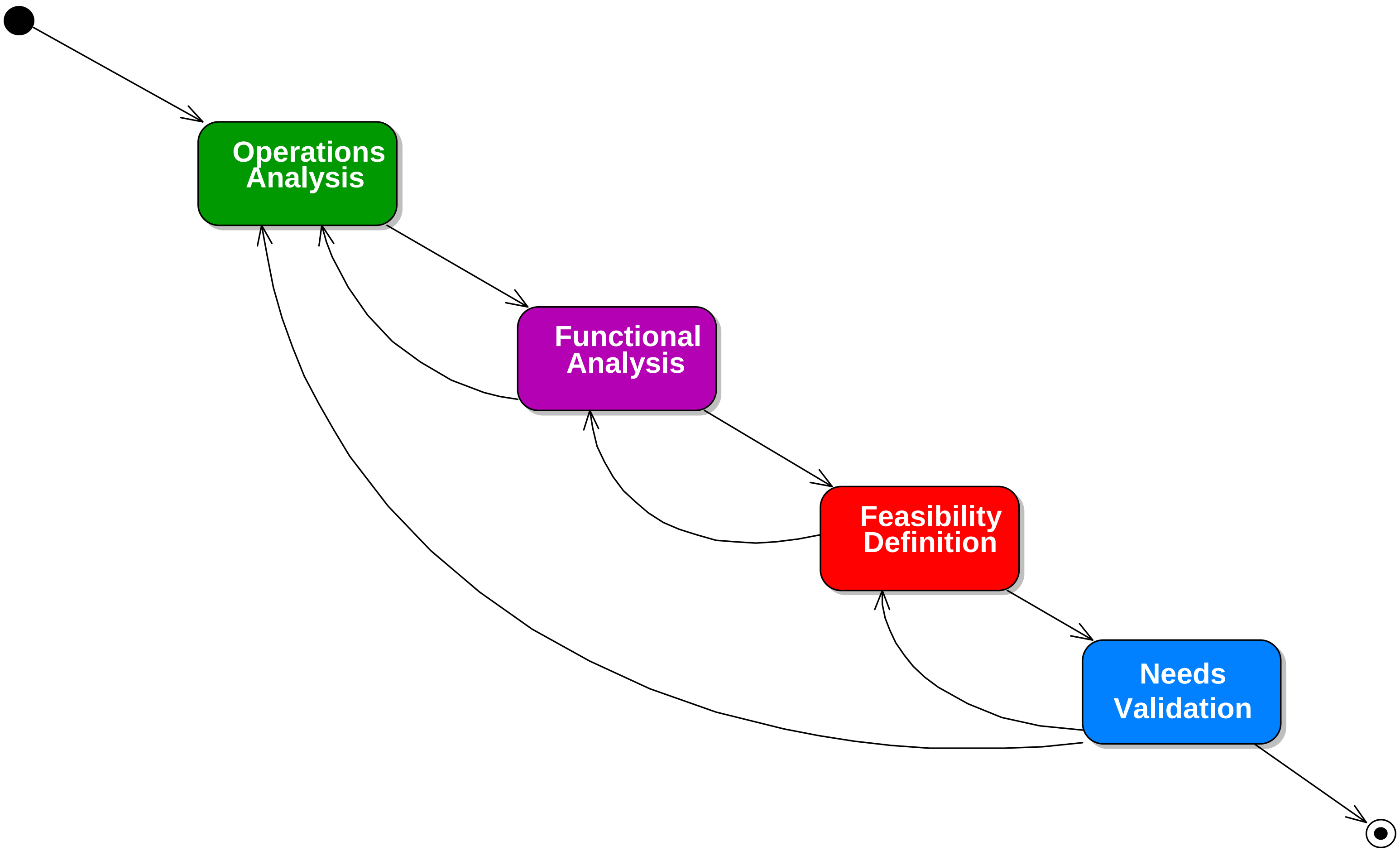
Needs Analysis

(Kossiakoff & Sweet)

Requirements Analysis *Defining the System*



Needs Analysis



Needs Analysis

- Operations Analysis – Clearly state OBJECTIVES
  - Several iterations of analysis before objectives transform to REQUIREMENTS
- Functional Analysis/ Feasibility Definition
  - Objectives → Functions → "Things"
    - "Physical" objects are initially logical abstractions
  - Assessing technological opportunities
    - Including production and support

Architecture Model originates in Needs Analysis

NDIA NATIONAL DEFENSE INDUSTRIAL ASSOCIATION STRENGTH THROUGH INDUSTRY & TECHNOLOGY

APL

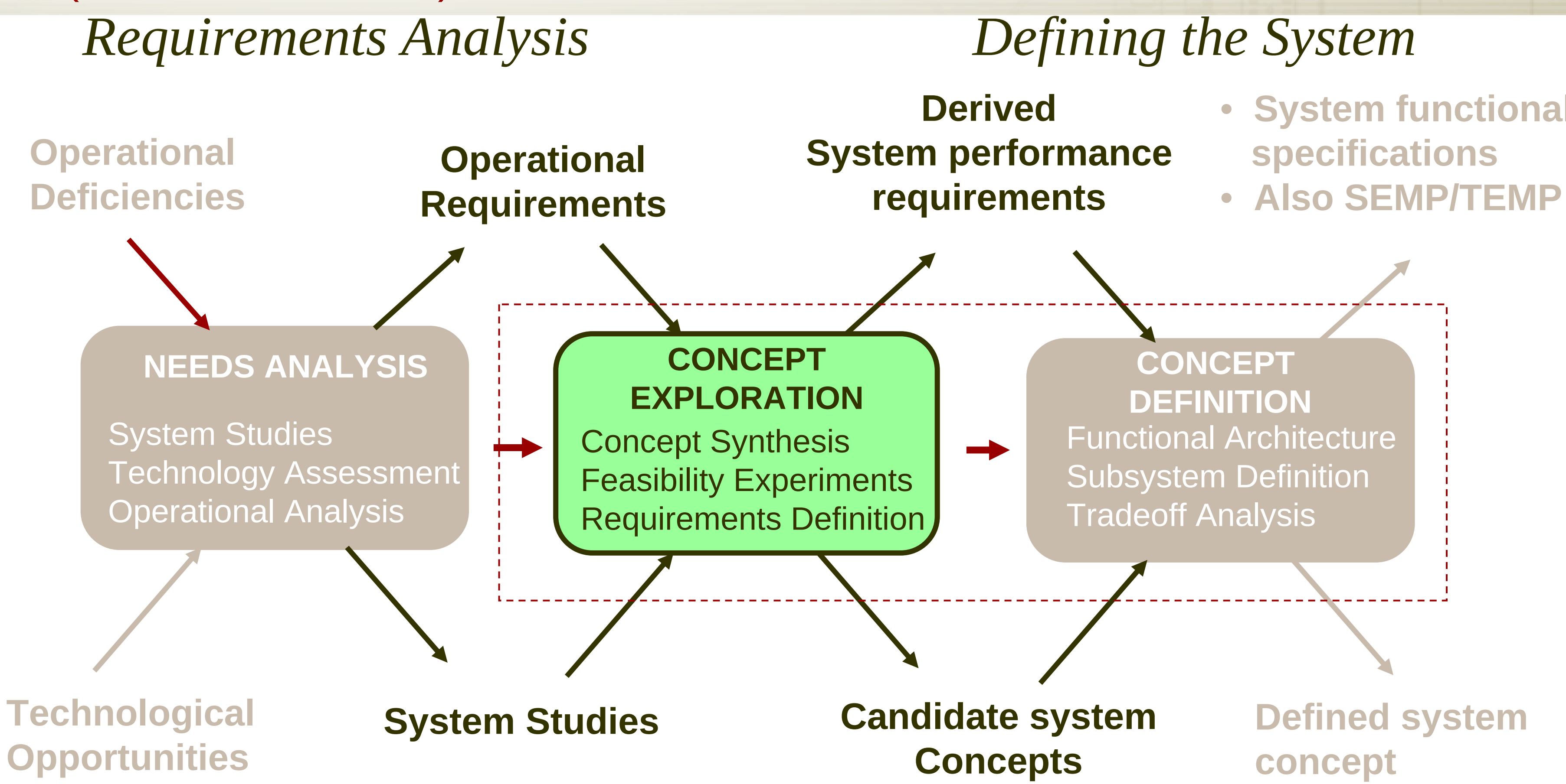
Needs Validation

- Model-based operational effectiveness analysis
  - Quantify the operational environment in both normal and “stressing” conditions
- System performance parameters and constraints critical to the model
- How does the “new” system compare with the legacy system?
  - Is the need based on overcoming a deficiency or leveraging technology
- Outcome – Fully validated Operational Architecture Model

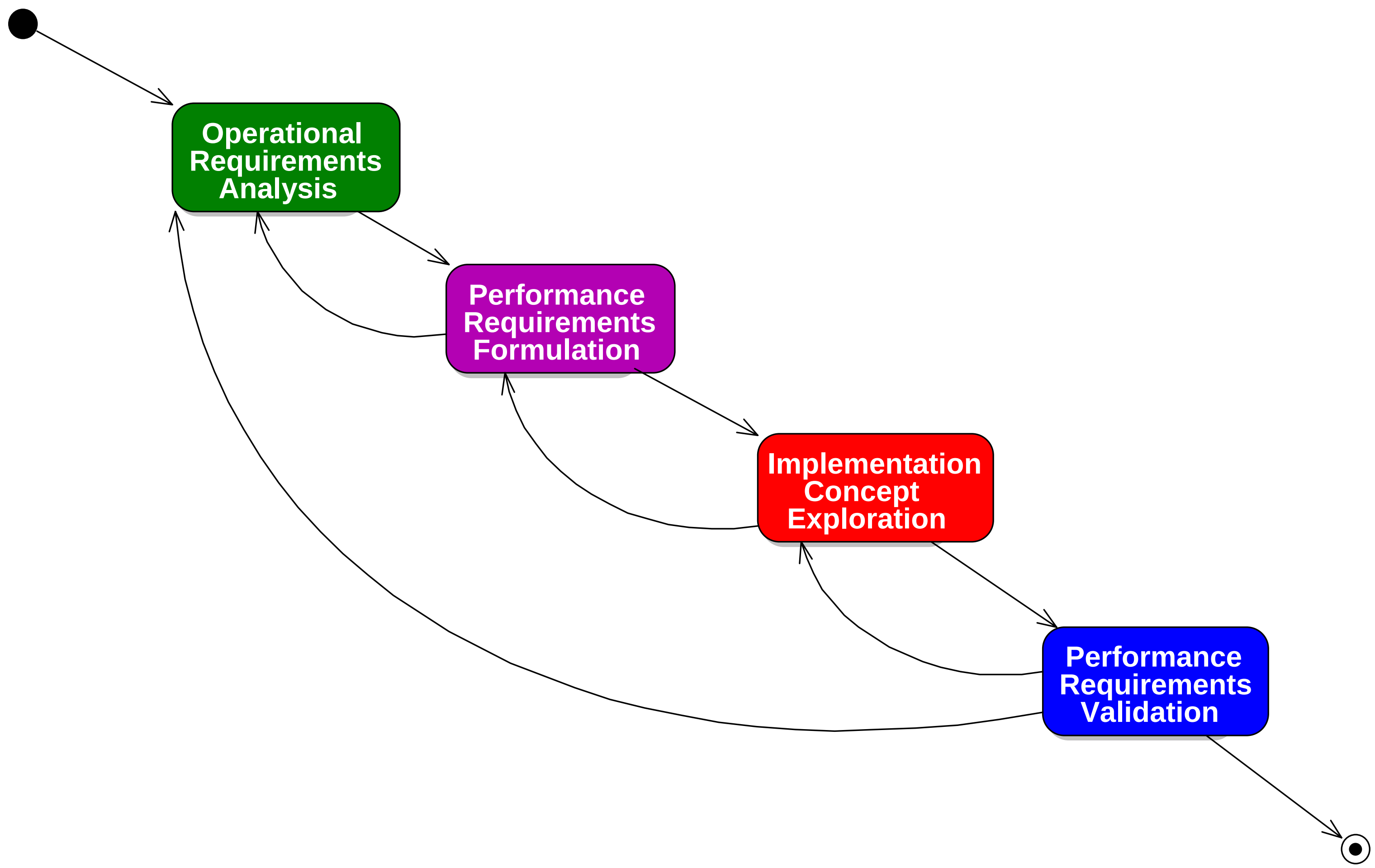
Does the Functional Needs Analysis result from sound Concept SE practices?

Concept Exploration

(Kossiakoff & Sweet)



Concept Exploration



Transform Operational to System Focus

- What does the SYSTEM have to do
- Convert the Operationally oriented view of the system to an Engineering oriented view
  - Baseline for subsequent phases of development
- Significant "exploratory research and development" (Kossiakoff & Sweet)
  - This must be completed BEFORE system performance requirements are quantified

Discover and analyze critical issues and gain insight into the design task

(Kroll et al)

Operations Requirements Analysis

- Ensure operational objectives are clear and the requirements meet the engineering standards of "goodness"
- Understanding compatibility with related Systems of Systems and/or Families of Systems
  - Data and information exchanges
- CONOPS is essential for this phase
  - If the new system is technology driven, how does the new technology factor into the CONOPS?

Performance Requirements Formulation

- Achieving operational functionality with system functions
  - Measurable Results of Value (RoV)
- Conceptual allocation of system functions to abstract "Functional Building Blocks"
- Setting bounds of system performance requirements
  - Design team must set the "limits of behavior" (Rechtin)
  - If the RoV exceeds the acceptable constraints, a "design trap" can result

Physical Implementation Exploration

- "Involves the examination of different technological approaches, generally offering a more diverse source of alternatives." (Kossiakoff & Sweet)
- Evaluating concept alternatives
  - Setting parametric boundaries and constraints
- Iterating with functional stage
  - "Bad or incorrect functional analysis adversely affects physical implementation" (Kroll et al)
  - Complexity of physical elements driven by functionality
  - Physical interfaces correspond to functional interfaces

The Architecture Model begins transformation to the Concept Design

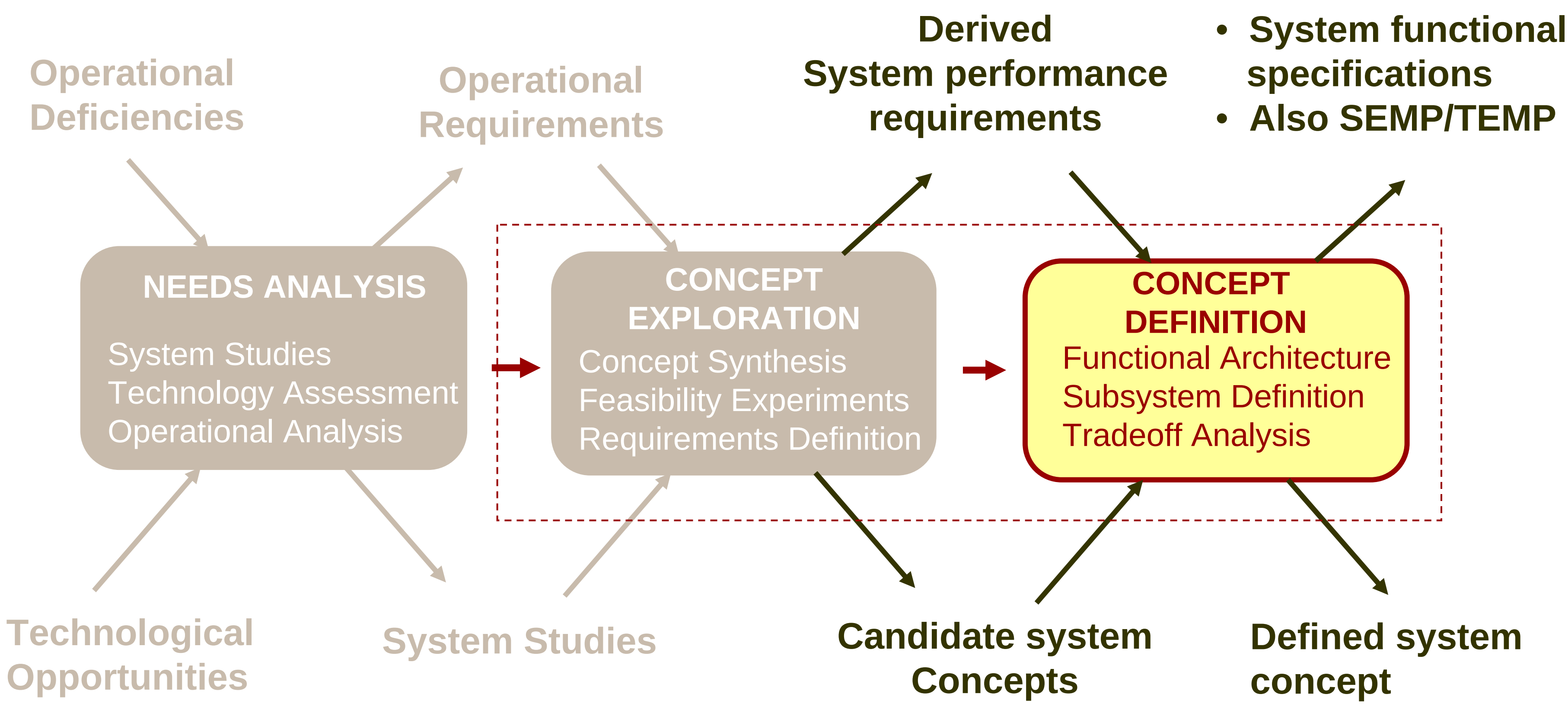
Performance Requirements Validation

- Performance Requirements Validation process is a “closed loop” process that results in “system performance characteristics”
  - Define WHAT the system must do
  - Define characteristics in engineering terms that is verified by analytical means or experimental tests
  - Completely and accurately reflects the system operational requirements and constraints including external interfaces and interactions

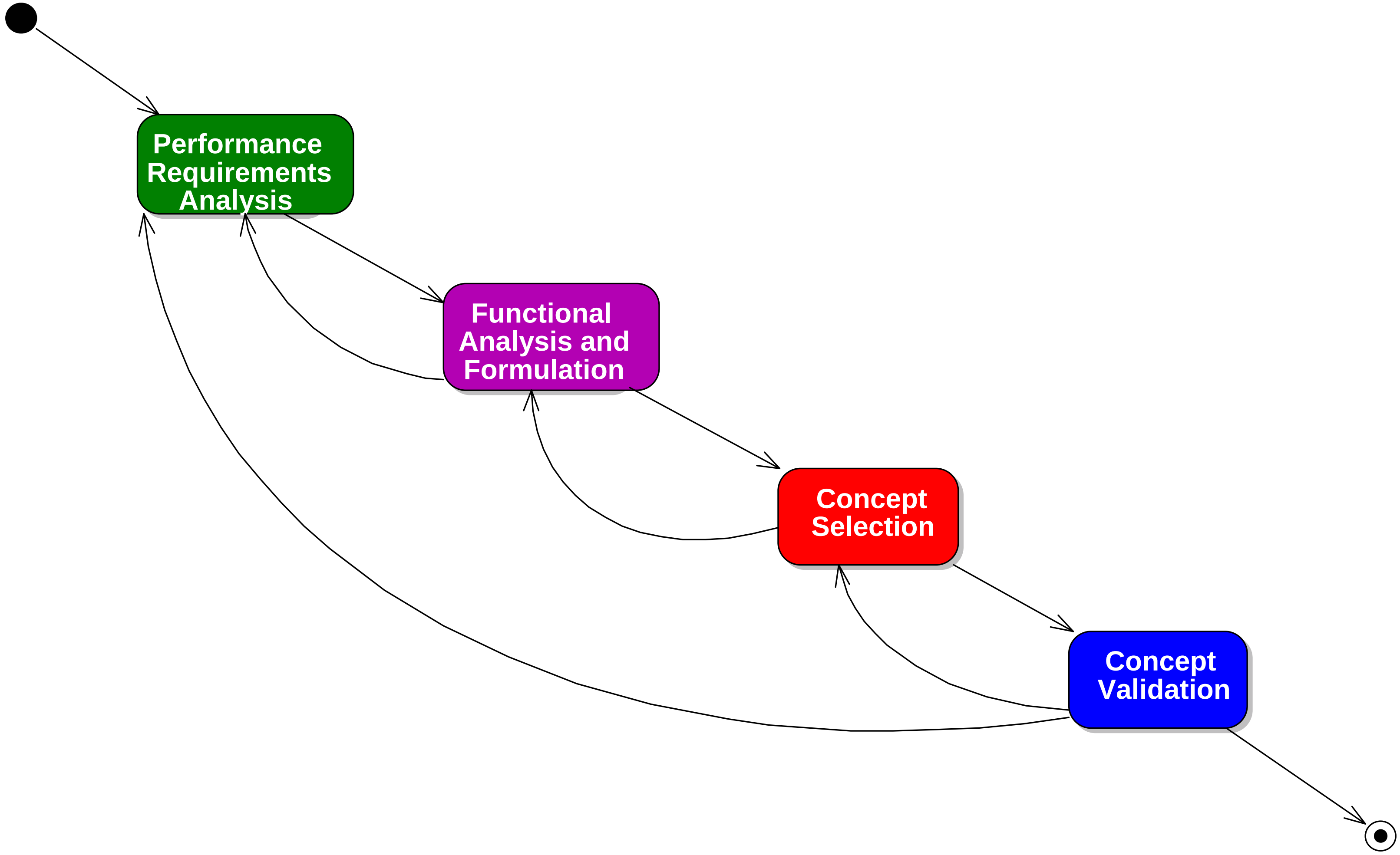
Concept Definition Stage

(Kossiakoff & Sweet)

Requirements Analysis *Defining the System*



Concept Definition



Conceptual Design

- Concept transforms into a preferred solution
  - Concept still involves sufficient alternatives, but among the choices, a final decision is made
- The design results from a fully validated conceptual design model with some preliminary drawings
- Consistent with system performance, cost and schedule goals
  - With acceptable risk
- Fully considers support and sustainment – Total System Effectiveness

Cautions during Concept Development

- Extreme Requirements
  - Meeting the requirements exceed the state of the technology
  - Meeting these extremes significantly add to cost and schedule
- Scope Creep
  - Taking on too many operational tasks
    - Adding scope during development
    - Tightly coupled with Extreme Requirements
- Production
  - The production line is usually just as complex as the system it builds
    - Software and test laboratories
- Not paying attention to Supportability and Sustainment

Transition to TD and SDD

- Industry should be a part of an integrated process during Concept SE
  - Each competitor will base own concept model on from a single architecture
  - Government SE IPT verify that developer's concept traces to the architecture
- During TD & SDD, the Developer's engineering design should evolve from the concept design
  - If it doesn't, traceability to requirements will be difficult to prove

Transition to TD & SDD is a major step, but a good architectural and conceptual models will enhance this transition

Conclusion

- "Best practices" for Concept SE involves a model-based design approach that begins at Needs Analysis/ Requirements Definition and results in the conceptual design model
- Architecture is the basis for design
  - Architecture is more than just DoDAF views
- JCIDS is a critical ENGINEERING task where sponsors, requirements officers and project engineers work together to instantiate the model
  - The artifacts are natural outputs of Good Systems Engineering

References

- **Ambler, Scott W.; *Process Patterns*; Cambridge, UK; Cambridge University Press; 1998**
- **French, Michael; *Conceptual Design for Engineers*; London, UK, Springer-Verling; 1999**
- **Kossiakoff, Alexander and Sweet, William; *Systems Engineering Principles and Practice*; Hoboken, NJ; John Wiley and Sons; 2001**
- **Kroll, Ehud; Condoor, Sradhar and Jansson, David; *Innovative Conceptual Design*; Cambridge, UK; Cambridge University Press; 2001**
- **Richtin, Eberhardt; *Systems Architecting*, Englewood Cliffs, NJ; Prentice Hall; 1991**
- **Underhill, David; Lecture on Modeling and Simulation presented to Johns Hopkins University Introduction to Systems Engineering; 3 March 2008**

Biography

- Chris Ryder is a member of the Johns Hopkins University Applied Physics Laboratory’s Principal Professional Staff. He is a supervisory systems engineer in the Aviation Systems Analysis Group where he works primarily on strike weapons systems. Chris is also an Adjunct Lecturer in the JHU Whiting School of Engineering Systems Engineering and Technical Management department. He has a BS degree from Miami University, an MBA from Old Dominion University and an MS from George Mason University.

Backup

Constructing the Model

- Four basic steps
  - Translating requirements into ideas into understanding
  - Embedding the ideas into the model to reflect the requirements
  - Continuous iteration until the model is sufficient for advancement
  - Verifying and validating the model for further action
- Continue the basic steps in each stage of the system's life cycle

Ref: Rechtin and Jacobs

MBSE – Initiating the Model

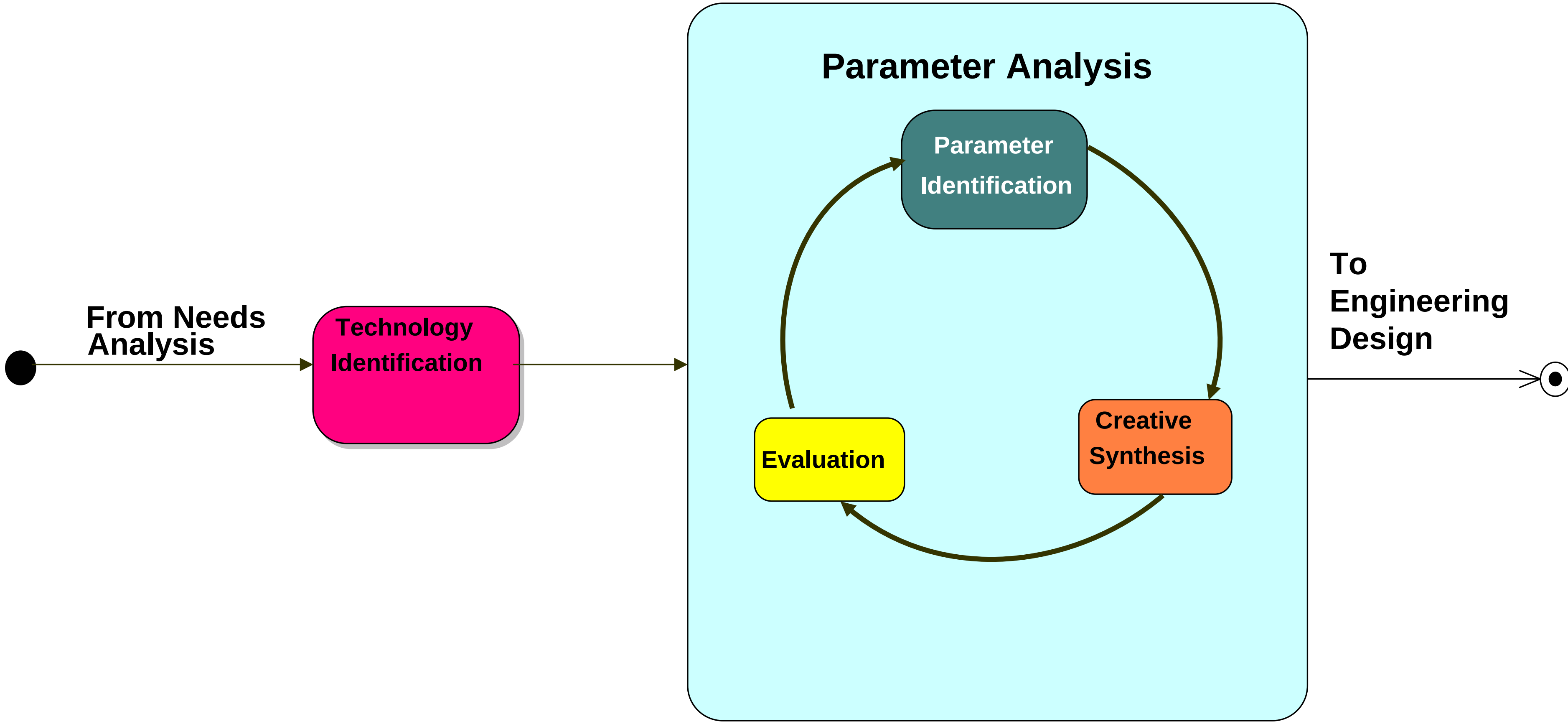
- MBSE assumes the existence of a well-structured set of requirements
  - The designer does not have to know the specific "end"
    - Only a prioritized understanding of variables that can produce a "Result of Value"
  - Modeling can assist the designer discover requirements that are missed, misunderstood or overlooked
- The initial model is "rough" and often abstract
  - But the model facilitates a logical analysis of what will become a complex system
  - Facilitates stakeholder discussions on future trade-offs

Source: Rechtin

Advantages of MBSE

- Model documents the evolution of the system from requirements definition through architecture development and into conceptual design
- Available modeling tools match detailed graphics with powerful data-bases
- Evolution of SysML as a standardized family of graphical presentations that contain necessary data including:
  - Requirements, parametrics and constraints
- Evolution of AP-233 standard for data portability across models and data bases
- Models LIVE!
  - Today's "As Is" is the baseline for tomorrow's "To-Be"

Another View of Concept Design



Source: Kroll et al

Parameter Analysis

- Parameter Identification
  - Examine all information about the design task, the alternative configurations that lead to “best and final”
  - Parameters influence the outcome and the optimal outcome may differ from “current solution paradigms”
- Creative Synthesis
  - Craft a resulting concept that “solves, satisfies and embodies conceptual parameters.”
- Evaluation
  - Quantifying strengths and identifying weaknesses
  - Does this system meet the requirements
  - Is this the right configuration?

Source: Kroll et al

SE for Concept Development

- Methodical analysis from identification of the initial operational objectives to a validated concept design
- System elements trace to operational elements
- Technology is feasible for advanced development and engineering design
- JCIDS Functional Analyses is accomplished within the scope of Concept SE
- SE Model originated in Needs Analysis matures into Concept model that traces back to the architecture and requirements models and forward to the design model

Aren't We Doing This Already?

- Yes, but
  - Is Concept SE an integrated ENGINEERING activity that includes requirements analysis, architecture formation and conceptual design?
  - Are the artifacts we develop during concept development used throughout the process?
    - And are they a suitable baseline for Engineering Design
  - Is the Concept SE team employing MBSE?
    - If not, there is likely a fundamental misunderstanding of the problem which correlates to an incorrect solution