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Concept Maturity Levels

Lou Wheatcraft, Requirements Experts
Layne Lewis, Willowview Consulting, LLC

Session 11.5.3

Goals/Objectives

- Expand on a method proposed in a JPL paper: “Space Mission Concept Development Using Concept Maturity Levels (CMLs)” (Wessen, R. R. et al 2013)
- Introduce the benefits and need for organizations to include the concept of CMLs in their systems engineering processes
- Define and explain the activities and outcomes for each CML
- Map CMLs to the SE development lifecycles as well as to the concept of Technology Readiness Levels (TRLs)
- Introduce tools to help implement, manage, and mature the project through the various CMLs
- Discuss the need to establish collaborative teams for early concept maturation

SE Lifecycle (INCOSE SE HB 2015 v4e)

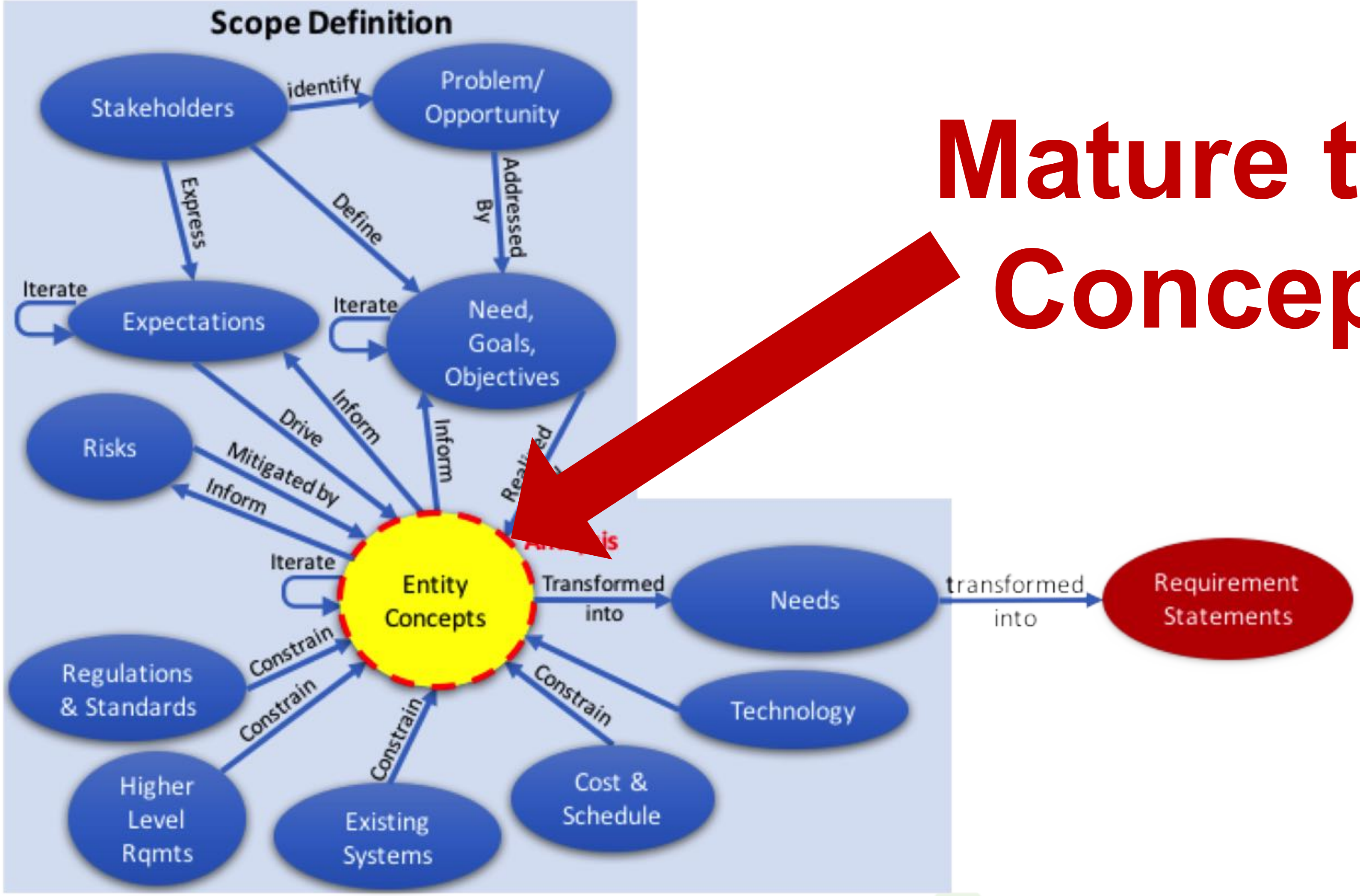
TABLE 3.1 Generic life cycle stages, their purposes, and decision gate options

Life cycle stages	Purpose	Decision gates
Concept	Define problem space 1. Exploratory research 2. Concept selection Characterize solution space Identify stakeholders' needs Explore ideas and technologies Refine stakeholders' needs Explore feasible concepts Propose viable solutions	Decision options • Proceed with next stage • Proceed and respond to action items • Continue this stage • Return to preceding stage • Put a hold on project activity • Terminate project
Development	Define/refine system requirements Create solution description—architecture and design Implement initial system Integrate, verify, and validate system	
Production	Produce systems Inspect and verify	
Utilization	Operate system to satisfy users' needs	
Support	Provide sustained system capability	
Retirement	Store, archive, or dispose of the system	

Purpose/Problem

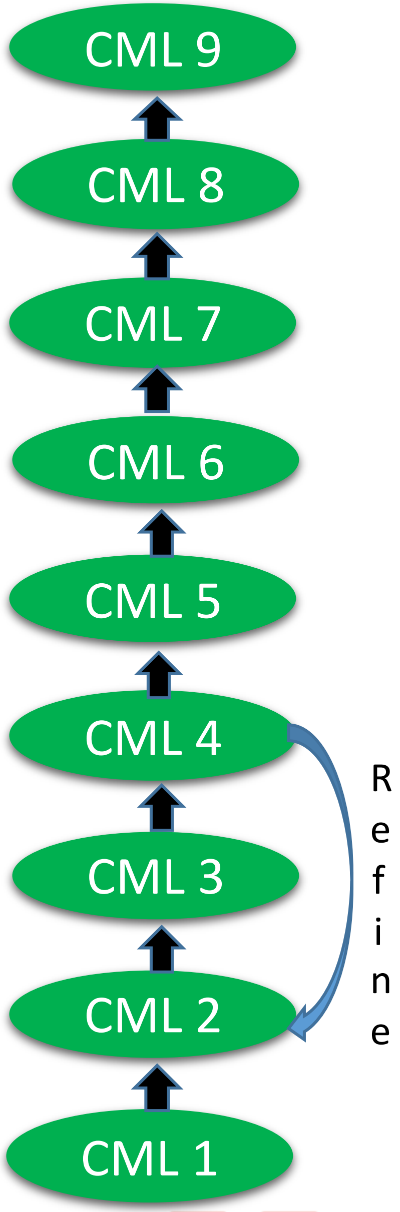
- A dilemma faced by many organizations when deciding whether a project is mature enough to fund or proceed to the next life cycle is how to:
  - evaluate the feasibility (cost, schedule, technology) of a concept (project, product, system, mission) and its fulfillment of the project's Need, Goals, and Objectives (NGOs) and stakeholder expectations within the defined drivers and constraints
  - assess whether or not the project in on track to deliver an acceptable ROI with acceptable risk
  - determine if the maturity of the system concept, critical technologies, available resources, and associated planning are sufficient to:
    - approve additional funding, or
    - conduct the gate review, baseline the deliverables associated with the review (scope, requirements, design, project and technical plans), and proceed with the next lifecycle phase of product development

There is a lot of work to be done before writing requirements!



Mature the Concept

CMLs Defined

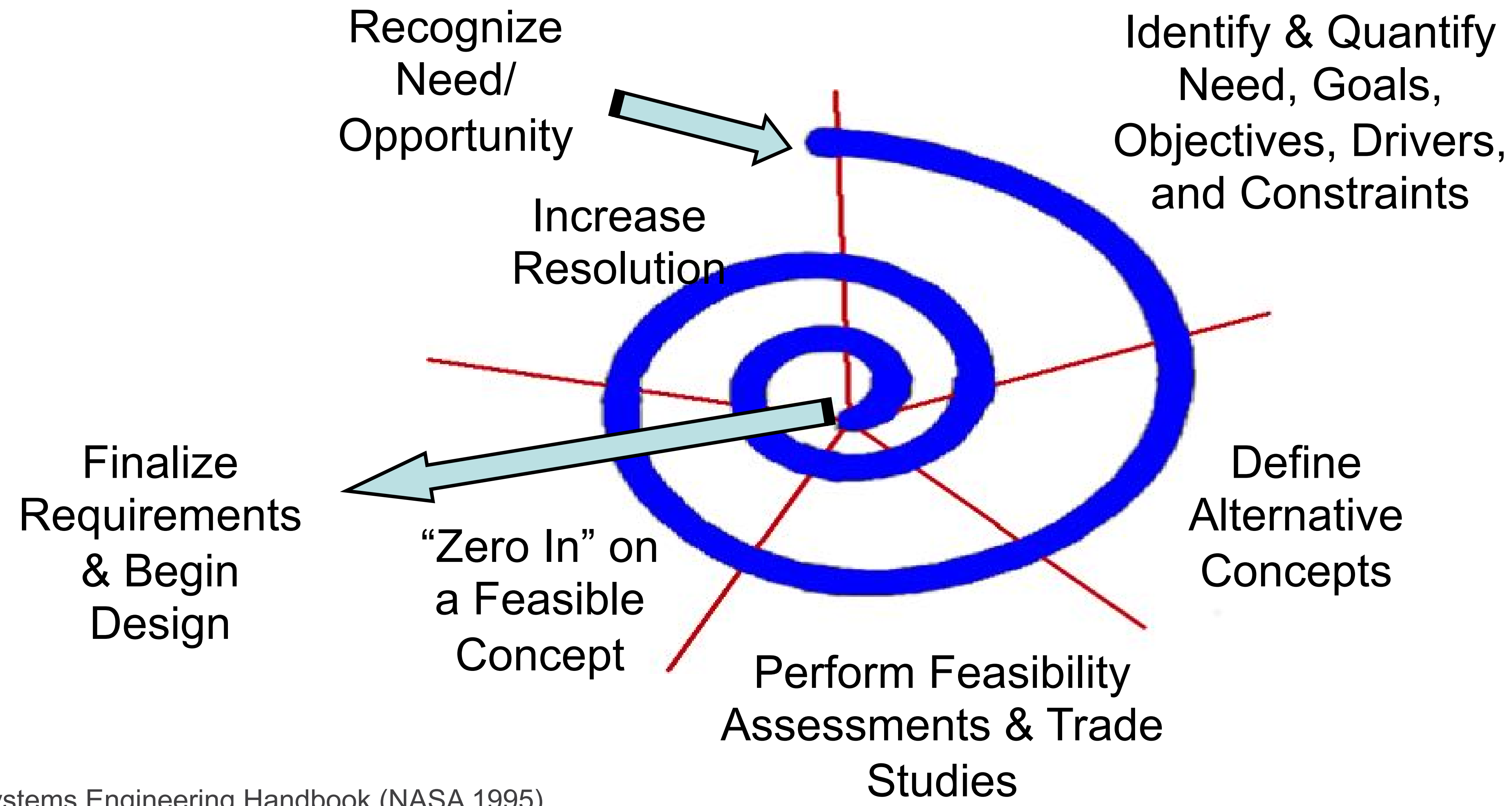


- **Critical Design Review (CDR), TRL 7,** “build-to” requirements and drawings are 80%-90% complete. ICDs are complete
- **Preliminary Design review (PDR), TRL 6,** “build-to” requirements and drawings are 10%-20% complete, interfaces defined, final integrated cost-schedule-design is baselined
- **System Design Review (SDR), TRL 5**: trades completed, feasible design identified
- **System Requirements Review (SRR), TRL 4:** stakeholder needs transformed into technical requirements.
- **Scope/Concept Review Baseline, TRL 3:** system concept baselined, stakeholder needs baselined
- **Point Design:** Candidate system physical architectures are identified TRLs defined, prototyping
- **Trade Space:** Functional architecture defined, candidate physical architectures evaluated for feasibility, TRA
- **Initial Feasibility:** initial concepts, risks, external interfaces, key measures, stakeholders engaged
- **“Cocktail Napkin”:** Overview and Advocacy; problem; Need, goals, objectives; drivers & constraints defined

Advantages of using CMLs

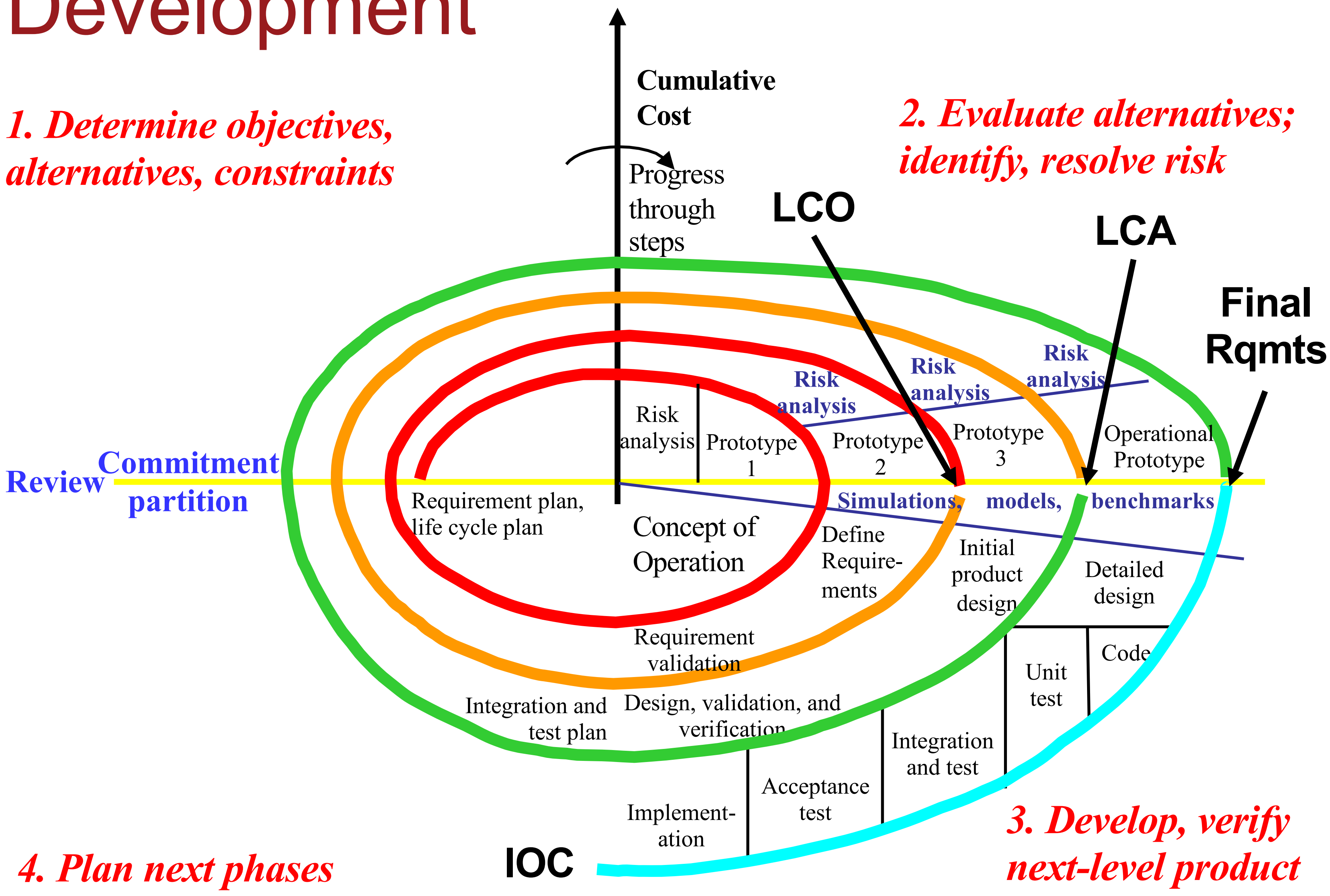
- The feedback loop is a key advantage of using the CML approach to mature a project's system concepts.
  - Allows study/design teams to return to an earlier stage of concept development if system implementation issues are encountered.
- Trade space exploration is a key part of concept maturation and is needed to provide an increased likelihood that a global optimum is identified in selection of a viable system concept architecture.
- Without first having done sufficient trade space exploration often results in system concepts that
  - do not have a maximum ROI,
  - has inefficient system and support system designs, and
  - has a less efficient overall system concept because trades between NGOs, [organizational ROI] expectations, the system, risks, and support system design for a particular cost point never occurred.

Doctrine of Successive Refinement



NASA Systems Engineering Handbook (NASA 1995)

Spiral Development



CMLs

- The CML structure corresponds to an increasing level of maturity as the system concept, planning (project and technical), design, architecture, and risks are analyzed and evolve
- The CMLs apply to the left side of the SE “Vee” Model
- Using CMLs go a long way in minimizing problems and cost over runs that often occur on the right side of the SE Vee Model during system integration, verification, and validation
- CML(s) provide the ability to measure a system concept’s maturity guided by an incremental set of maturity criteria
- This defined maturity criteria can be tailored to correspond to the processes specific to a particular organization, domain, and project within that domain

CML Matrix

- The intent of the CML matrix is to serve as a high-level guide for study/design and proposal teams through the stages of system concept maturation and architecture selection.
- The matrix can be used by management and the study/design team in several ways to:
  1. Determine the maturity of a system concept at the time of a particular gate review.
     - As an example, by looking at the contents of the cells in the CML 5 column, a system architect can quickly see the material that is needed for a study/design team to pass their Mission Concept or Scope Review.
  2. Understand the deliverables and their maturity required as a function of time.
  3. Use the contents of each column to generate a CML checklist.

Figure 3. Example CML Matrix described in the JPL reference paper.

Life Cycle Phase	Pre-Phase A					Phase A	
	Advanced Studies			Concept Development		Early Formulation	
CML	1	2	3	4	5	6	7
Name	Cocktail Napkin	Initial Feasibility	Trade Space	Point Design	Baseline Concept	Integrated Concept	Preliminary Implementation Baseline
Life Cycle Gate	—	—	—	Concept Gate (Draft AO Out / Mission Study Report)	Baseline Commitment Gate / MCR	Step 2 Submittal	PMSR / MDR
Science							
Attribute							
Science Objectives & System Requirements	Science objectives described in one sentence	Objectives described to levels that allow comparison with previous investigations and NASA science community documents	Objectives linked to investigations and measurements Science return as a function of cost, risk and programmatics quantified	Produce draft Science Traceability Matrix Initial Level 1 requirements considered Specifying one Baseline and one Threshold Science investigation Key Performance Parameters listed	Science Traceability Matrix (or equivalent) produced Preliminary PLRA produced (assigned projects)	Proposed Level 1 requirements documented Level 2 & 3 driving requirements listed Full and minimum success criteria defined Baseline PLRA submitted @ SRR (assigned projects)	Update PLRA if necessary Preliminary Level 2 & 3 requirements listed
Science Data System	—	Identify science data drivers	Science data rates and volume included in trade space analysis	Science data system sizing	Science data processing architecture, release and archive approach defined	Science data management approach (includes Level 0, 1, 2 data products) defined	Same as for CML 6

CML Checklists

The CML Checklists:

- Allow management and the study/design team to quickly measure the system concept's maturity,
- Are reusable, i.e., the checklists can be applied to any project that is maturing their concepts, providing the same level of maturity score for concepts with the same level of maturity and,
- Identify deficiencies and provide clear information as to what areas of the concept need additional work to get to the overall mission concept to the desired level of maturity.

	CML 4 Checklist Sheet	
	2013 April 11	
Functional Area	**Criteria**	**Status (RYG)**
	SCIENCE	
Science Objectives & Driving Requirements	o Draft Science Traceability Matrix produced	G
	o Initial Level 1 requirements considered	G
	o One Baseline and one Threshold Science investigation specified	G
	o Key Performance Parameters listed	G
Science Data System	o Science data system sized	R
	TECHNICAL	
Mission Development	o Driving requirements documented	G
	o Initial high-level scenarios, timelines and operational modes documented	G
	o Propellant load and delta-V requirements determined	G
	o Power generation and distribution approach defined	G
	o Telecommunication approach defined	G
	o Data processing approach documented	Y
	o Descope and backup options identified as needed	G
	o Launch period is 20 days long	G
Spacecraft or Instrument System Design	o System architecture & instrument designs (Earth Science & Astrophysics missions only) described by mechanical configuration drawings	G
	o System architecture & instrument designs (Earth Science & Astrophysics missions only) described by block diagrams	Y
	o Descope options compiled	G
	o Instrument performance requirements traced to level 1 requirements	Y
Ground System & Mission Operations System Design	o MOS / GDS architecture based on ops scenarios described	
Technical Risk Assessment & Management	o Risk drivers listed	
	o Top risks documented in 5 x 5 matrix (includes selected mitigation options)	
Technology	o Technology options characterized and baseline options selections and justified	
	o TRL for new technologies explained	
	o Fallback options for all new technologies identified	
Inheritance	o Major inherited assembly items tentatively selected	
Master Equipment Lists	o Assembly level (e.g., antenna, propellant tank, star tracker, etc.) MEL documented	

Figure 4. Example CML checklist described in the JPL reference paper.

Establishing a collaborative work environment

- To support "rapid development and acquisition" philosophies, organization's need to provide a collaborative work environment conducive to the activities that take place during CML 1 - 4.
- Team members are often collocated and are provided the tools, data, and supporting information technology infrastructure in an integrated support environment that can be immediately used by the team.
- Organizations that are pursing this approach may call the team and associated work environments various names: Team X, A Team, Rapid Mission Architecture, Integrated Design Center, Advance Concepts Office, Concept Design Center, Concurrent Design Facility, Skunk Works, etc.

Establishing a collaborative work environment

Examples include:

- NASA's Glenn Research Center's COMPASS (Collaborative Modeling for Parametric Assessment of Space Systems)
  - established to meet the need for rapid mission analysis and multi-disciplinary systems design for in-space and human missions.
  - is a multidisciplinary, concurrent engineering group whose primary purpose is to perform integrated systems analysis, but it is also capable of designing any system that involves one or more of the disciplines present in the team.
- US Special Operations Command (SOCOM) – SOFWERX
  - creates a network of collaborators enabling a very agile and rapid acquisition process
  - goal is to create processes and venues to make it easier for individuals with innovative ideas and technologies to collaborate to solve a problem and rapidly identify, procure, and release the solution into the field

Parting Thoughts

CMLs provide a standardized method to allow management to:

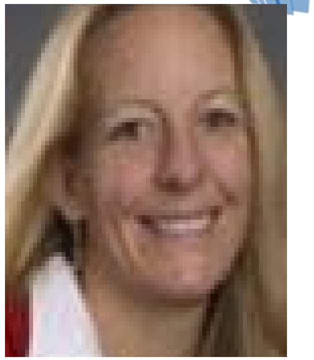
- Determine how much effort (resources and funding) has been placed into the definition and maturation of a system concept;
- Compare competing project system concepts in terms of relevance to meeting the organization's strategic goals, objectives, and ROI with acceptable risk;
- Determine which system concepts have had the same level of effort and can be compared on the same terms;
- Understand the maturity of critical technologies needed to meet the project's goals and objectives,
- Understand how much future effort will be required to mature the system concept;
- Have the information needed to determine when a proposed project's system concept is mature enough to proceed to the next system development lifecycle stage.

Questions?

Lou Wheatcraft

- Senior Product Manager for Seilevel/Requirements Experts (RE)
- Has taught over 190 requirement seminars over the last 18 years.
- 22 years in the US Air Force
- Heavy involvement in space systems (DoD launch vehicles and spacecraft, NASA Space Shuttle, International Space Station)
- Worked in the Astronaut Office at Johnson Space Center for 6 years.
- Works with both government and industry clients.
- Chair of the INCOSE Requirements Working Group
- Member of PMI, the Software Engineering Institute (SEI), the World Futures Society, International Institute of Business Analysis (IIBA), and the National Honor Society of Pi Alpha Alpha.
- Has a BS degree in Electrical Engineering, MA degree in Computer Information Systems, MS degree in Environmental Management, and has completed the course work for an MS degree in Studies of the Future
- Author of numerous papers and presentations concerning requirement development and management
- Is the primary contributor to RE's blog on requirements best practices.
  The blog can be assessed at: http://www.reqexperts.com/blog .

Layne Lewis



Layne Lewis runs Willowview Consulting, LLC where she works as a Systems Engineer consulting for commercial companies, the Department of Defense, and other Federal agencies. **Layne** also works with small companies to help them enter the world of government contracting. Previously, she founded Motionetics, Inc., a company developing innovative energy harvesting and sensor technology products for military and commercial applications. **Layne** started her entrepreneurial journey as the co-founder and chief operations officer of TenXsys, Inc., which developed small devices for monitoring human health and tracking animal movements. Prior to that, she was a program and project manager and software development engineer for Hewlett Packard, where she developed firmware for HP's LaserJet printers. **Layne** worked as a senior systems engineer for Booz Allen & Hamilton Inc., where she worked on various NASA projects, including the Space Station communications systems monitor and control subsystem for the NASA enhanced mission communications system, and the interface for the Space Shuttle aft flight deck to the Space Station docking module. **Layne** holds a BS in aerospace engineering from the University of Arizona and an MBA from the University of Washington.

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