# Using the Incremental Commitment Model (ICM) to Help Execute Competitive Prototyping (CP)

## —Charts with Notes—

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# Outline

- Motivation and Context
- Nature of the ICM
- Applying ICM Principles to CP
- Conclusions, References, Acronyms
  - Copy of Young Memo

# Motivation and Context

- DoD is emphasizing CP for system acquisition
  - Young memo, September 2007
- CP can produce significant benefits, but also has risks
  - Benefits related to incremental commitment
  - Examples of risks from experiences, workshops
- The risk-driven ICM can help address the risks
  - Primarily through its underlying principles

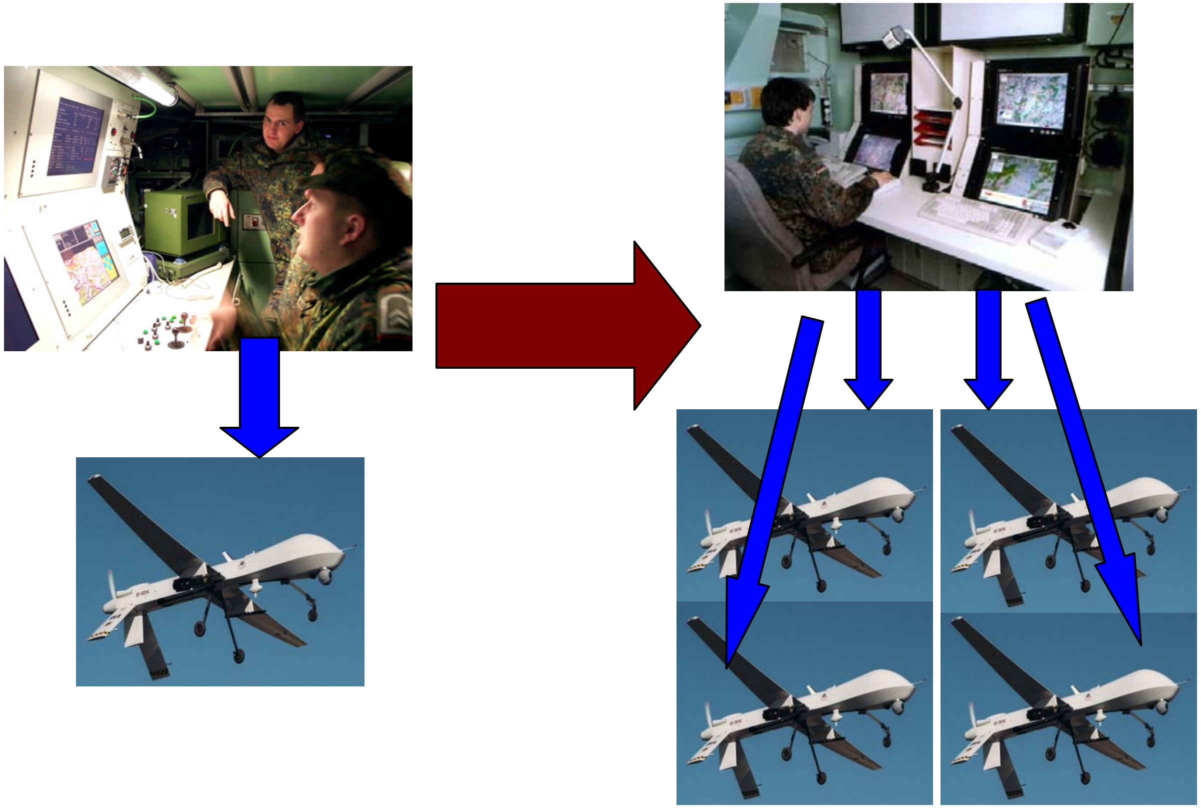
# Young Memo: Prototyping and Competition

- Discover issues before costly SDD phase
  - Producing detailed designs in SDD
  - Not solving myriad technical issues
- Services and Agencies to produce competitive prototypes through Milestone B
  - Reduce technical risk, validate designs and cost estimates, evaluate manufacturing processes, refine requirements
- Will reduce time to fielding
  - And enhance govt.-industry teambuilding, SysE skills, attractiveness to next generation of technologists
- Applies to all programs requiring USD(AT&L) approval
  - Should be extended to appropriate programs below ACAT I

# Incremental Commitment in Gambling

- Total Commitment: Roulette
  - Put your chips on a number
    - E.g., a value of a key performance parameter
  - Wait and see if you win or lose
- Incremental Commitment: Poker, Blackjack
  - Put some chips in
  - See your cards, some of others' cards
  - Decide whether, how much to commit to proceed

# Scalable remotely controlled operations



# Total vs. Incremental Commitment – 4:1 RPV

- **Total Commitment**
  - Agent technology demo and PR: Can do 4:1 for $1B
  - Winning bidder: $800M; PDR in 120 days; 4:1 capability in 40 months
  - PDR: many outstanding risks, undefined interfaces
  - $800M, 40 months: "halfway" through integration and test
  - 1:1 IOC after $3B, 80 months

- **CP-based Incremental Commitment [number of competing teams]**
  - $25M, 6 mo. to VCR [4]: may beat 1:2 with agent technology, but not 4:1
  - $75M, 8 mo. to ACR [3]: agent technology may do 1:1; some risks
  - $225M, 10 mo. to DCR [2]: validated architecture, high-risk elements
  - $675M, 18 mo. to IOC [1]: viable 1:1 capability
  - 1:1 IOC after $1B, 42 months

# Example Risks Involved in CP

## Based on TRW, DARPA, SAIC experiences; workshop

- Seductiveness of sunny-day demos
  - Lack of coverage of rainy-day off-nominal scenarios
  - Lack of off-ramps for infeasible outcomes
- Underemphasis on quality factor tradeoffs
  - Scalability, performance, safety, security, adaptability
- Discontinuous support of developers, evaluators
  - Loss of key team members
  - Inadequate evaluation of competitors
- Underestimation of productization costs
  - Brooks factor of 9 for software
  - May be higher for hardware
- Underemphasis on non-prototype factors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# Milestone B Focus on Technology Maturity Misses Many OSD/AT&L Systemic Root Causes

1 Technical process (35 instances)

- V&V, integration, modeling&sim.

2 Management process (31)

3 Acquisition practices (26)

4 Requirements process (25)

5 Competing priorities (23)

6 Lack of appropriate staff (23)

7 Ineffective organization (22)

8 Ineffective communication (21)

9 Program realism (21)

10 Contract structure (20)

- Some of these are root causes of technology immaturity
- Can address these via evidence-based Milestone B exit criteria
  - Technology Development Strategy
  - Capability Development Document
  - Evidence of affordability, KPP satisfaction, program achievability


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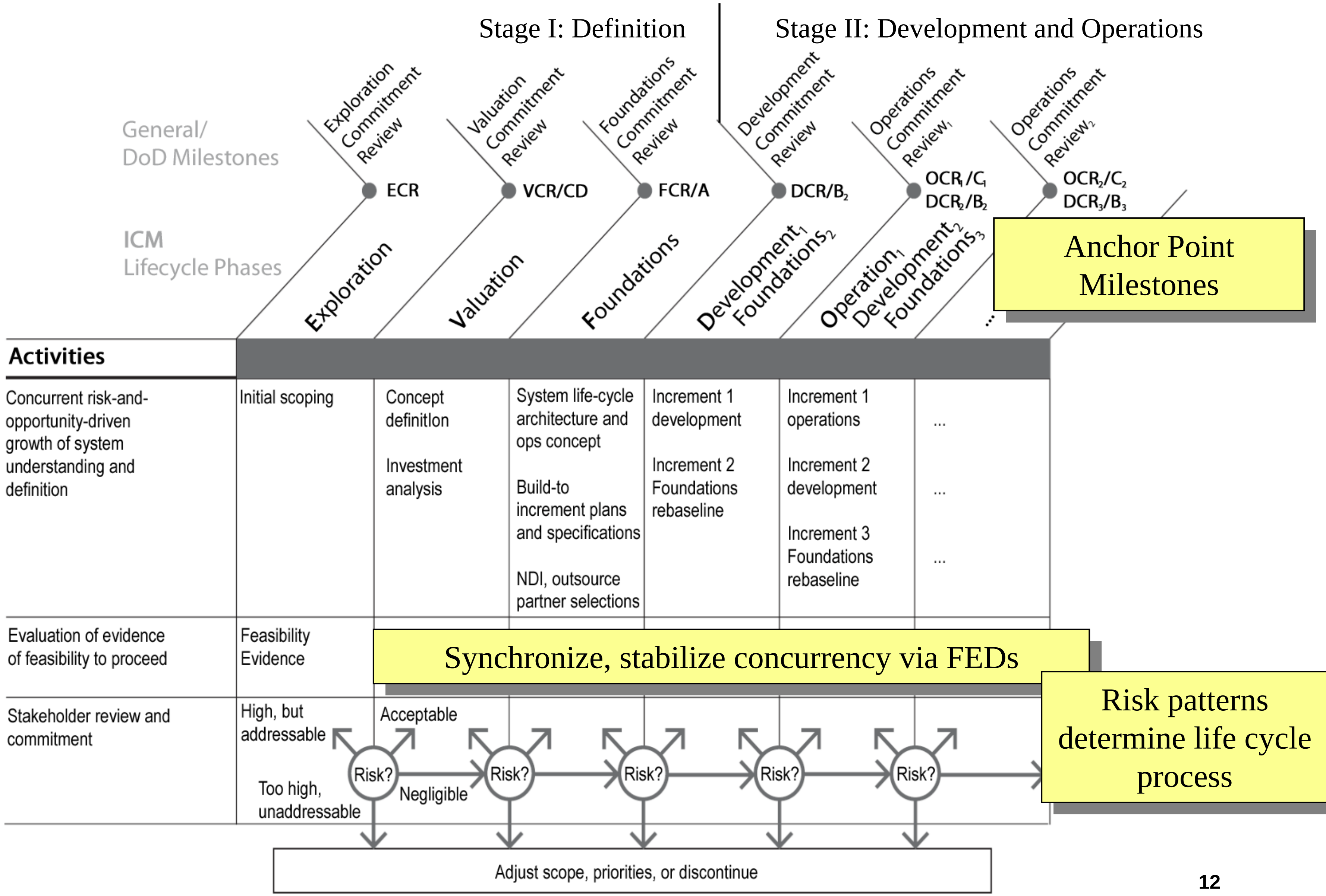
# What is the ICM?

- Risk-driven framework for tailoring system life-cycle processes
- Integrates the strengths of phased and risk-driven spiral process models
- Synthesizes together principles critical to successful system development
  - Commitment and accountability of system sponsors
  - Success-critical stakeholder satisficing
  - Incremental growth of system definition and stakeholder commitment
  - Concurrent engineering
  - Iterative development cycles
  - Risk-based activity levels and evidence-based milestones

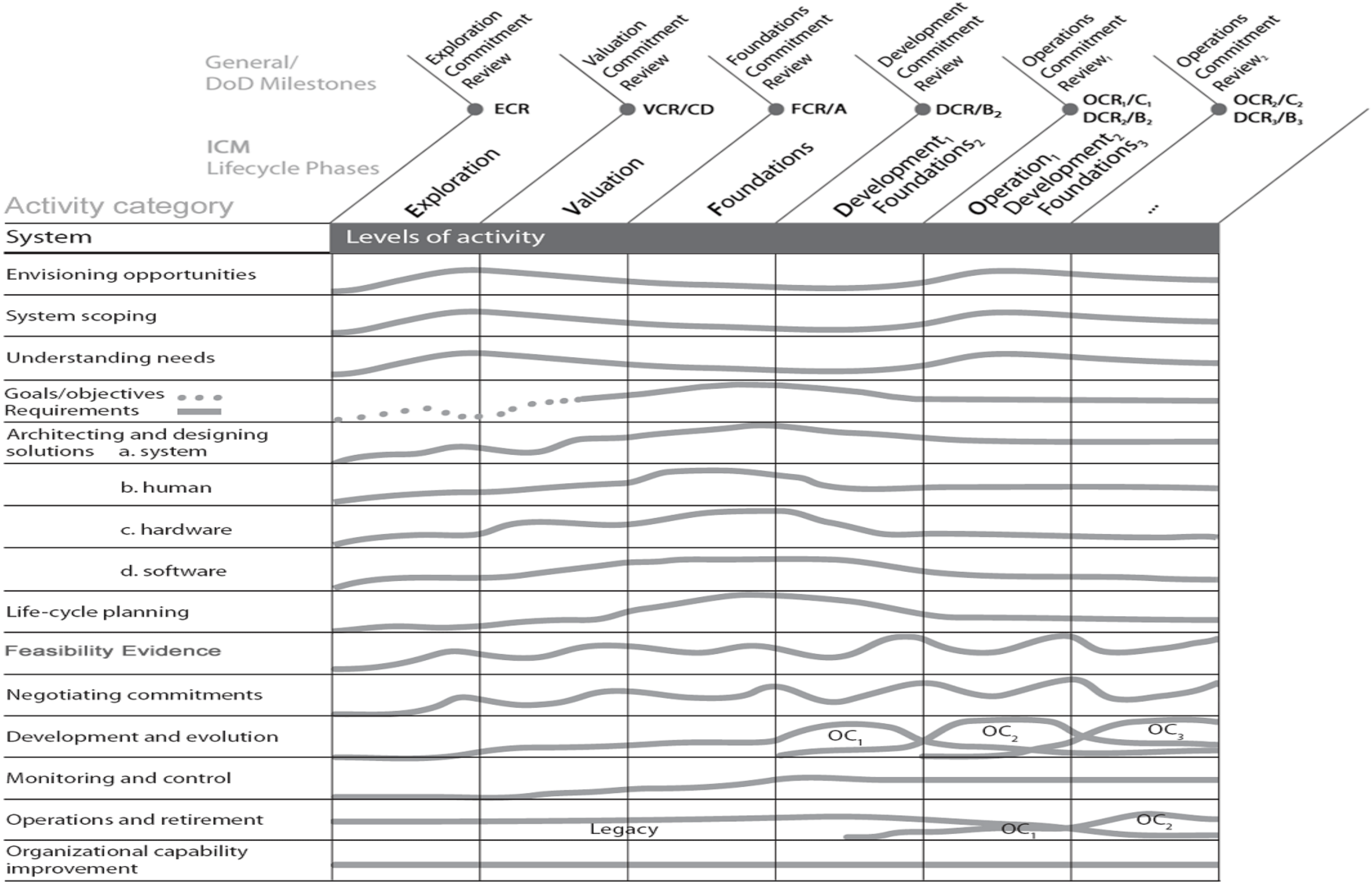
*Principles trump diagrams…*

**Principles Used by 60-80% of CrossTalk Top-5 projects, 2002-2005**

# The Incremental Commitment Life Cycle Process: Overview



# ICM HSI Levels of Activity for Complex Systems



# Anchor Point Feasibility Evidence Description

- **Evidence provided by developer and validated by independent experts that:**

  If the system is built to the specified architecture, it will
  - **Satisfy the requirements: capability, interfaces, level of service, and evolution**
  - **Support the operational concept**
  - **Be buildable within the budgets and schedules in the plan**
  - **Generate a viable return on investment**
  - **Generate satisfactory outcomes for all of the success-critical stakeholders**
- **All major risks resolved or covered by risk management plans**
- **Serves as basis for stakeholders' commitment to proceed**

***Can be used to strengthen current schedule- or event-based reviews***

# ICM Nature and Origins

- Integrates hardware, software, and human factors elements of systems engineering
  - Concurrent exploration of needs and opportunities
  - Concurrent engineering of hardware, software, human aspects
  - Concurrency stabilized via anchor point milestones
- Developed in response to DoD-related issues
  - Clarify "spiral development" usage in DoD Instruction 5000.2
    - Initial phased version (2005)
  - Explain Future Combat System of systems spiral usage to GAO
    - Underlying process principles (2006)
  - Provide framework for human-systems integration
    - National Research Council report (2007)
- Integrates strengths of current process models
  - But not their weaknesses

# ICM Integrates Strengths of Current Process Models
## But not their weaknesses

- V-Model: Emphasis on early verification and validation
  - But not ease of sequential, single-increment interpretation
- Spiral Model: Risk-driven activity prioritization
  - But not lack of well-defined in-process milestones
- RUP and MBASE: Concurrent engineering stabilized by anchor point milestones
  - But not software orientation
- Lean Development: Emphasis on value-adding activities
  - But not repeatable manufacturing orientation
- Agile Methods: Adaptability to unexpected change
  - But not software orientation, lack of scalability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# Applying ICM Principles and Practices to CP

- ***When, what, and how much to prototype?***
  - ***Risk management principle: buying information to reduce risk***
- **Whom to involve in CP?**
  - **Satisficing principle: all success-critical stakeholders**
- **How to sequence CP?**
  - **Incremental growth, iteration principles**
- **How to plan for CP?**
  - **Concurrent engineering principle: more parallel effort**
- **What is needed at Milestone B besides prototypes?**
  - **Risk management principle: systemic analysis insights**

# When, What, and How Much to Prototype?
## – Buying information to reduce risk

- When and what: Expected value of perfect information
- How much is enough: Simple statistical decision theory

# When and What to Prototype: Early RPV Example

- **Bold approach**

  **0.5 probability of success: Value $VB_S$ = \$100M**

  **0.5 probability of failure: Value $VB_F$ = - \$20M**

- **Conservative approach**

  **Value VC = \$20M**

- **Expected value with <u>no</u> information**

  $EV_{NI} = \max(EV_B, EV_C) = \max(.5(\$100M)+.5(-\$20M), \$20M)$

  $= \max(\$50M-\$10M, \$20M) = \$40M$

- **Expected value with <u>perfect</u> information**

  $EV_{PI} = 0.5[\max(VB_S, VC)] + 0.5[\max(VB_F, VC)]$

  $= 0.5 * \max(\$100M, \$20M) + 0.5 * \max(-\$20M, \$20M)$

  $= 0.5 * \$100M + 0.5 * \$20M = \$60M$

- **Expected value of perfect information**

  $EVPI = EV_{PI} - EV_{NI} = \$20M$

- **Can spend up to \$20M buying information to reduce risk**


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# If Risk Exposure is Low, CP Has Less Value

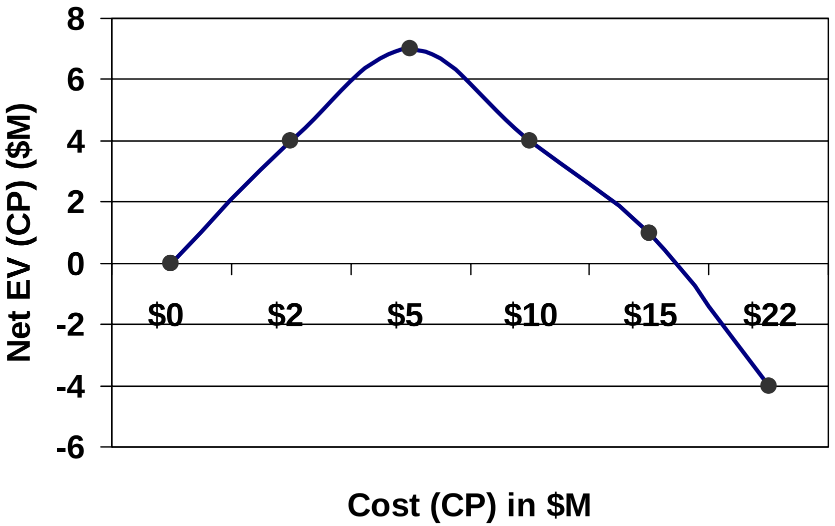
- Risk Exposure RE = Prob(Loss) * Size(Loss)

- Value of CP (EVPI) would be very small if the Bold approach is less risky
  - Prob(Loss) = Prob ($VB_F$) is near zero rather than 0.5
  - Size(Loss) = $VB_F$ is near $20M rather than -$20M

# How Much Prototyping is Enough?
## – Value of imperfect information

- Larger CP investments reduce the probability of
  - False Negatives (FN): prototype fails, but approach would succeed
  - False Positives (FP): prototype succeeds, but approach would fail
- Can calculate EV(Prototype) from previous data plus P(FN), P(FP)

| CP Cost | P(FP) | P(FN) | EV(CP) | EV(Info) | Net EV(CP) |
|---|---|---|---|---|---|
| 0 | | | $40M | 0 | 0 |
| $2M | 0.3 | 0.2 | $46M | $6M | $4M |
| $5M | 0.2 | 0.1 | $52M | $12M | $7M |
| $10M | 0.15 | 0.075 | $54M | $14M | $4M |
| $15M | 0.1 | 0.05 | $56M | $16M | $1M |
| $22M | 0.0 | 0.0 | $60M | $20M | -$2M |




- Added CP decision criterion
  - The prototype can cost-effectively reduce the uncertainty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# Summary: CP Pays Off When

- The basic CP value propositions are satisfied
  1. There is significant risk exposure in making the wrong decision
  2. The prototype can cost-effectively reduce the risk exposure
- There are net positive side effects
  3. The CP process does not consume too much calendar time
  4. The prototypes have added value for teambuilding or training
  5. The prototypes can be used as part of the product

# Applying ICM Principles and Practices to CP

- When, what, and how much to prototype?
  - Risk management principle: buying information to reduce risk
- *Whom to involve in CP?*
  - *Satisficing principle: all success-critical stakeholders*
- *How to sequence CP?*
  - *Incremental growth, iteration principles*
- How to plan for CP?
  - Concurrent engineering principle: more parallel effort
- What is needed at Milestone B besides prototypes?
  - Risk management principle: systemic analysis insights

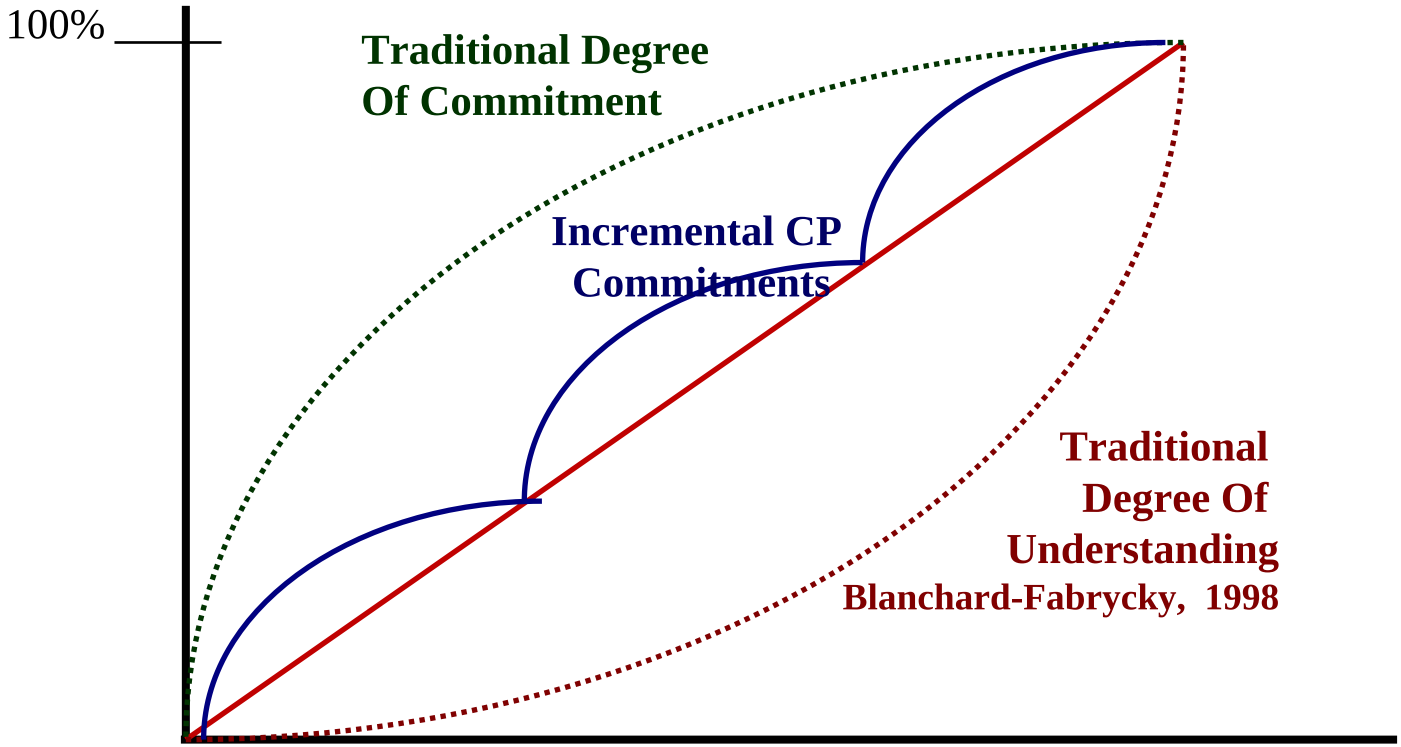
# Whom to Involve in CP?

– Satisficing principle: All success-critical stakeholders

- Success-critical: high risk of neglecting their interests
  - Acquirers
  - Developers
  - Users
  - Testers
  - Operators
  - Maintainers
  - Interoperators
  - Others
- Risk-driven level of involvement
  - Interoperators: initially high-level; increasing detail
- Need to have CRACK stakeholder participants
  - Committed, Representative, Authorized, Collaborative, Knowledgeable

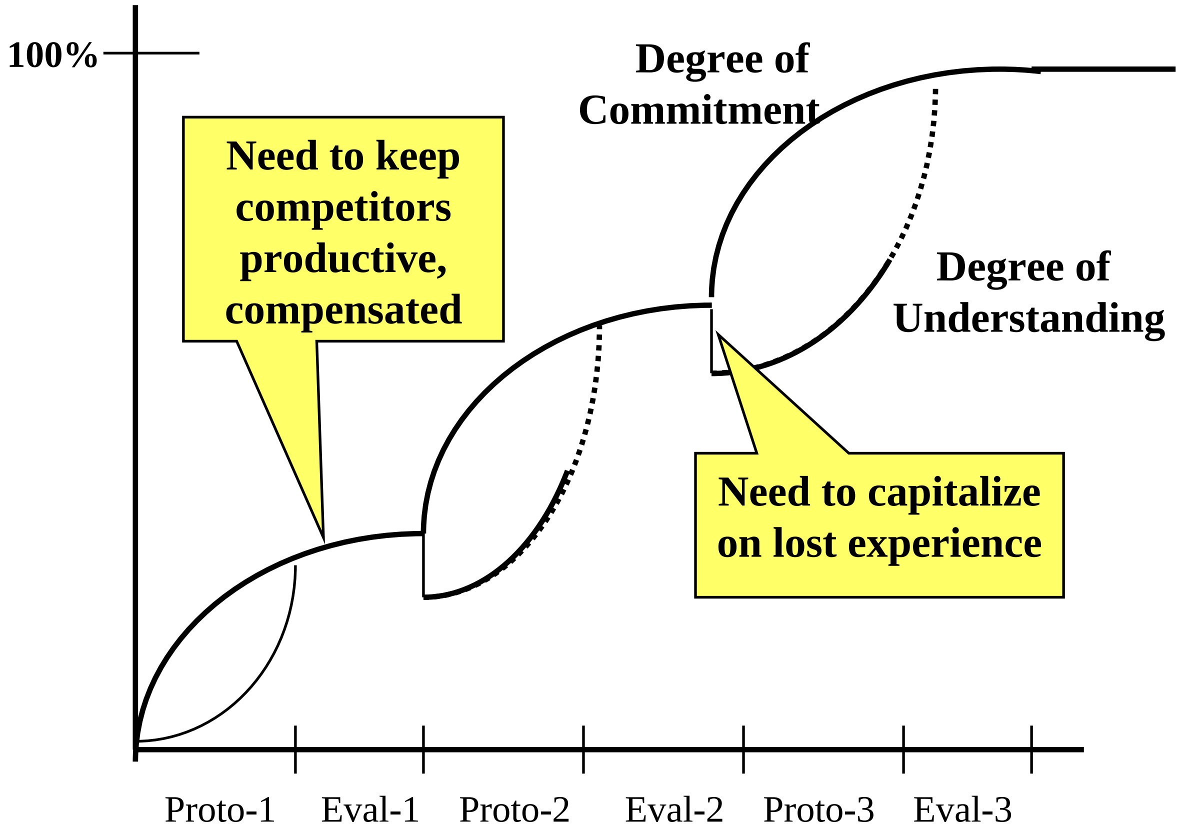
# How to Sequence CP?

– **Iterative cycles; incremental commitment principles**



# Actual CP Situation: Need to Conserve Momentum

- Need time to evaluate and rebaseline
- Eliminated competitors' experience lost



# Keeping Competitors Productive and Supported During Evaluations

## – Concurrent engineering principle

- **Provide support for a core group within each competitor organization**
  - Focused on supporting evaluation activities
  - Avoiding loss of tacit knowledge and momentum
- **Key evaluation support activities might include**
  - Supporting prototype exercises
  - Answering questions about critical success factors
- **Important to keep evaluation and selection period as short as possible**
  - Through extensive preparation activities (see next chart)

# Keeping Acquirers Productive and Supported During Prototyping

- Adjusting plans based on new information
- Preparing evaluation tools and testbeds
  - Criteria, scenarios, experts, stakeholders, detailed procedures
- Possibly assimilating downselected competitors
  - IV&V contracts as consolation prizes
- Identifying, involving success-critical stakeholders
- Reviewing interim progress
- Pursuing complementary acquisition initiatives
  - Operational concept definition, life cycle planning, external interface negotiation, mission cost-effectiveness analysis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# Applying ICM Principles and Practices to CP

- **When, what, and how much to prototype?**
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- **How to sequence CP?**
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- **How to plan for CP?**
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- ***What is needed at Milestone B besides prototypes?***
  - *Risk management principle: systemic analysis insights*

# Later CP Rounds Need Increasing Focus on Complementary Practices

## – By all success critical stakeholders

- Stakeholder roles, responsibilities, authority, accountability
- Capability priorities and sequencing of development increments
- Concurrent engineering of requirements, architecture, feasibility evidence
- Early preparation of development infrastructure (i.e., key parts of the architecture)
- Acquisition planning, contracting, management, staffing, test and evaluation


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# When to Stop CP

– Commitment and accountability principle: Off-ramps

- Inadequate technology base
  - Lack of evidence of scalability, security, accuracy, robustness, airworthiness, useful lifetime, …
  - Better to pursue as research, exploratory development
- Better alternative solutions emerge
  - Commercial, other government
- Key success-critical stakeholders decommit
  - Infrastructure providers, strategic partners, changed leadership

*Important to emphasize possibility of off-ramps….*


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# Acquiring Organization's ICM-Based CP Plan

- **Addresses issues discussed above**
  - Risk-driven prototyping rounds, concurrent definition and development, continuity of support, stakeholder involvement, off-ramps
- **Organized around key management questions**
  - Objectives (why?): concept feasibility, best system solution
  - Milestones and Schedules (what? when?): Number and timing of competitive rounds; entry and exit criteria, including off-ramps
  - Responsibilities (who? where?): Success-critical stakeholder roles and responsibilities for activities and artifacts
  - Approach (how?): Management approach or evaluation guidelines, technical approach or evaluation methods, facilities, tools, and concurrent engineering
  - Resources (how much?): Necessary resources for acquirers, competitors, evaluators, other stakeholders across full range of prototyping and evaluation rounds
  - Assumptions (whereas?): Conditions for exercise of off-ramps, rebaselining of priorities and criteria
- **Provides a stable framework for pursuing CP**

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# CP Conclusions

- CP most effective in reducing technical risk
  - If project is low-risk, may not need CP
    - May be worth it for teambuilding
- Other significant risks need resolution by Milestone B
  - Systemic Analysis DataBase (SADB) sources: management, acquisition, requirements, staffing, organizing, contracting
- CP requires significant, continuing preparation
  - Prototypes are just tip of iceberg
  - Need evaluation criteria, tools, testbeds, scenarios, staffing, procedures
- Need to sustain CP momentum across evaluation breaks
  - Useful competitor tasks to do; need funding support
- ICM provides effective framework for CP plan, execution
  - CP value propositions, milestone criteria, guiding principles
- CP will involve changes in cultures and institutions
  - Need continuous corporate assessment and improvement of CP-related principles, processes, and practices

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# List of Acronyms

| | |
|---|---|
| CD | Concept Development |
| CP | Competitive Prototyping |
| DCR | Development Commitment Review |
| DoD | Department of Defense |
| ECR | Exploration Commitment Review |
| EV | Expected Value |
| EVNI | Expected Value, No Information |
| EVPI | Expected Value, Perfect Information |
| FCR | Foundations Commitment Review |
| FED | Feasibility Evidence Description |
| GAO | Government Accounting Office |
| ICM | Incremental Commitment Model |
| KPP | Key Performance Parameter |
| MBASE | Model-Based Architecting and Software Engineering |
| OCR | Operations Commitment Review |
| P(FN) | Probability of False Negatives |
| P(FP) | Probability of False Positives |
| RE | Risk Exposure |
| RUP | Rational Unified Process |
| V&V | Verification and Validation |
| VB | Value of Bold approach |
| VBS | VB for success |
| VBF | VB for failure |
| VC | Value of Conservative approach |
| VCR | Valuation Commitment Review |


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# Competitive Prototyping Policy: John Young Memo

THE UNDER SECRETARY OF DEFENSE
3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION, TECHNOLOGY AND LOGISTICS

19 SEP 2007

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
COMMANDER, U.S. SPECIAL OPERATIONS COMMAND
DIRECTORS OF THE DEFENSE AGENCIES

SUBJECT: Prototyping and Competition

Many troubled programs share common traits – the programs were initiated with inadequate technology maturity and an elementary understanding of the critical program development path. Specifically, program decisions were based largely on paper proposals that provided inadequate knowledge of technical risk and a weak foundation for estimating development and procurement cost. The Department must rectify these situations.

Lessons of the past, and the recommendations of multiple reviews, including the Packard Commission report, emphasize the need for, and benefits of, quality prototyping. The Department needs to discover issues before the costly System Design and Development (SDD) phase. During SDD, large teams should be producing detailed manufacturing designs – not solving myriad technical issues. Government and industry teams must work together to demonstrate the key knowledge elements that can inform future development and budget decisions.

To implement this approach, the Military Services and Defense Agencies will formulate all pending and future programs with acquisition strategies and funding that provide for two or more competing teams producing prototypes through Milestone (MS) B. Competing teams producing prototypes of key system elements will reduce technical risk, validate designs, validate cost estimates, evaluate manufacturing processes, and refine requirements. In total, this approach will also reduce time to fielding.

Beyond these key merits, program strategies defined with multiple, competing prototypes provide a number of secondary benefits. First, these efforts exercise and develop government and industry management teams. Second, the prototyping efforts provide an opportunity to develop and enhance system engineering skills. Third, the programs provide a method to exercise and retain certain critical core engineering skills in the government and our industrial base. Fourth, prototype efforts can attract a new generation of young scientists and engineers to apply their technical talents to the needs of our Nation's Warfighters. Finally, these prototype efforts can inspire the imagination and creativity of a new generation of young students, encouraging them to pursue technical educations and careers.

Based on these considerations, all acquisition strategies requiring USD(AT&L) approval must be formulated to include competitive, technically mature prototyping through MS B. The Component Acquisitions Executives will review all existing programs and all programs in the initial stages of development for the potential to adopt this acquisition strategy. It is the policy of the Department of Defense that this acquisition strategy should be extended to all appropriate programs below ACAT I.

John J. Young, Jr.
Acting

cc:
Under Secretaries Of Defense
Component Acquisition Executives

2


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