Incremental Commitment Model & A Process Decision Table for Integrated Systems and Software Engineering

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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

The ICM: What It Is and Isn’t

• Risk-driven framework for tailoring system processes
  – Not a one-size-fits-all process
  – Focused on future process challenges
• 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 Used by 60-80% of CrossTalk Top-5 projects, 2002-2005
The Incremental Commitment Life Cycle Process: Overview

<table>
<thead>
<tr>
<th>Stage I: Definition</th>
<th>Stage II: Development and Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor Point</td>
<td>Anchor Point</td>
</tr>
<tr>
<td>Feasibility Evidence</td>
<td>milestone</td>
</tr>
</tbody>
</table>

Activities

- Concurrent risk and opportunity-driven growth
- Definition
- Evaluation of evidence
- Stakeholder review and commitment

Risk patterns determine life cycle process

Synchronize, stabilize concurrency via FEDs

**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 Anchor Point Milestone Content (1)
(Risk-driven level of detail for each element)

<table>
<thead>
<tr>
<th>Milestone Element</th>
<th>Foundations Commitment Review (FCR/MS-A) Package</th>
<th>Development Commitment Review (DCR/MS-B) Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of Operational</td>
<td>• System shared vision update</td>
<td>• Elaboration of system objectives and scope by increment</td>
</tr>
<tr>
<td>Concept</td>
<td>• Top-level system objectives and scope</td>
<td>• Elaboration of operational concept by increment</td>
</tr>
<tr>
<td></td>
<td>– System boundary; environment parameters and assumptions</td>
<td>– Including all mission-critical operational scenarios</td>
</tr>
<tr>
<td></td>
<td>• Top-level operational concepts</td>
<td>– Generally decreasing detail in later increments</td>
</tr>
<tr>
<td></td>
<td>– Production, deployment, operations and sustainment scenarios and parameters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Organizational life-cycle responsibilities (stakeholders)</td>
<td></td>
</tr>
<tr>
<td>System Prototype(s)</td>
<td>• Exercise key usage scenarios</td>
<td>• Exercise range of usage scenarios</td>
</tr>
<tr>
<td></td>
<td>• Resolve critical risks</td>
<td>• Resolve major outstanding risks</td>
</tr>
<tr>
<td></td>
<td>– E.g., quality attribute levels, technology maturity levels</td>
<td></td>
</tr>
<tr>
<td>Definition of System</td>
<td>• Top-level functions, interfaces, quality attribute levels, including</td>
<td>• Elaboration of functions, interfaces, quality attributes, and constraints by increment</td>
</tr>
<tr>
<td>Requirements</td>
<td>– Growth vectors and priorities</td>
<td>– Including all mission-critical off-nominal requirements</td>
</tr>
<tr>
<td></td>
<td>• Project and product constraints</td>
<td>– Generally decreasing detail in later increments</td>
</tr>
<tr>
<td></td>
<td>• Stakeholders’ concurrence on essentials</td>
<td>• Stakeholders’ concurrence on their priority concerns</td>
</tr>
<tr>
<td></td>
<td>– Including all mission-critical off-nominal requirements</td>
<td></td>
</tr>
</tbody>
</table>

ICM Anchor Point Milestone Content (2)
(Risk-driven level of detail for each element)

<table>
<thead>
<tr>
<th>Milestone Element</th>
<th>Foundations Commitment Review (FCR/MS-A) Package</th>
<th>Development Commitment Review (DCR/MS-B) Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of System</td>
<td>• Top-level definition of at least one feasible architecture</td>
<td>• Choice of architecture and elaboration by increment and component</td>
</tr>
<tr>
<td>Architecture</td>
<td>– Physical and logical elements and relationships</td>
<td>– Physical and logical components, connectors, configurations, constraints</td>
</tr>
<tr>
<td></td>
<td>• Choices of Non-Developmental Items (NDI)</td>
<td>– NDI choices</td>
</tr>
<tr>
<td></td>
<td>• Identification of infeasible architecture options</td>
<td>– Domain-architecture and architectural style choices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Architecture evolution parameters</td>
</tr>
<tr>
<td>Definition of Life-Cycle</td>
<td>• Identification of life-cycle stakeholders</td>
<td>• Elaboration of WWWWWHH* for Initial Operational Capability (IOC) by phase, function</td>
</tr>
<tr>
<td>Plan</td>
<td>– Users, customers, developers, testers, sustainers, interoperators,</td>
<td>– Partial elaboration, identification of key TBD’s for later increments</td>
</tr>
<tr>
<td></td>
<td>general public, others</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Identification of life-cycle process model</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Top-level phases, increments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Top-level WWWWWHH* by phase, function</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Production, deployment, operations, sustainment</td>
<td></td>
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</tbody>
</table>

ICM Anchor Point Milestone Content (3)
(Risk-driven level of detail for each element)

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<thead>
<tr>
<th>Milestone Element</th>
<th>Foundations Commitment Review (FCR/MS-A) Package</th>
<th>Development Commitment Review (DCR/MS-B) Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility Evidence Description (FED)</td>
<td>• Evidence of consistency, feasibility among elements above - Via physical and logical modeling, testbeds, prototyping, simulation, instrumentation, analysis, etc. - Mission cost-effectiveness analysis for requirements, feasible architectures - Identification of evidence shortfalls; risks - Stakeholders’ concurrence on essentials</td>
<td>• Evidence of consistency, feasibility among elements above - Identification of evidence shortfalls; risks - All major risks resolved or covered by risk management plan - Stakeholders’ concurrence on their priority concerns, commitment to development</td>
</tr>
</tbody>
</table>

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
Case 1: Use NDI

- Exploration phase identifies NDI opportunities
- NDI risk/opportunity analysis indicates risks acceptable
  - Product growth envelope fits within NDI capability
  - Compatible NDI and product evolution paths
  - Acceptable NDI volatility
    - Some open-source components highly volatile
  - Acceptable usability, dependability, interoperability
  - NDI available or affordable Example: Small accounting system
- Size/complexity: Low
- Anticipated change rate (% per month): Low
- Criticality: Low
- NDI support: Complete
- Organization and personnel capability: NDI-experienced
- Key Stage I activities: Acquire NDI
- Key Stage II activities: Use NDI
- Time/build: Driven by time to initialize/tailor NDI
- Time/increment: Driven by NDI upgrades
Case 2: Pure Agile Methods

- Exploration phase determines
  - Low product and project size and complexity
  - Fixing increment defects in next increment acceptable
  - Existing hardware and NDI support of growth envelope
  - Sufficient agile-capable personnel
  - Need to accommodate rapid change, emergent requirements, early user capability
- Example: E-services
- Size/complexity: Low
- Anticipated change rate (% per month): 1-30%
- Criticality: Low to medium
- NDI support: Good; in place
- Organization and personnel capability: Agile-ready, medium to high capability
- Key Stage I activities: Skip Valuation and Architecting phases
- Key Stage II activities: Scrum plus agile methods of choice
- Time/build: Daily
- Time/increment: 2-6 weeks

Case 3: Architected Agile

- Exploration phase determines
  - Need to accommodate fairly rapid change, emergent requirements, early user capability
  - Low risk of scalability up to 100 people
  - NDI support of growth envelope
  - Nucleus of highly agile-capable personnel
  - Moderate to high loss due to increment defects
- Example: Business data processing
- Size/complexity: Medium
- Anticipated change rate (% per month): 1-10%
- Criticality: Medium to high
- NDI support: Good, most in place
- Organization and personnel capability: Agile-ready, med-high capability
- Key Stage I activities: Combined Valuation and Architecting phase, complete NDI preparation
- Key Stage II activities: Architecture-based scrum of scrums
- Time/build: 2-4 weeks  Time/increment: 2-6 months
Case 4: Formal Methods

- Biggest risks: Software/hardware does not accurately implement required algorithm precision, security, safety mechanisms, or critical timing
- Example: Security kernel or safety-critical LSI chip
- Size/complexity: Low
- Anticipated change rate (% per month): 0.3%
- Criticality: Extra high
- NDI support: None
- Organization and personnel capability: Strong formal methods experience
- Key Stage I activities: Precise formal specification
- Key Stage II activities: Formally-based programming language; formal verification
- Time/build: 1-5 days
- Time/increment: 1-4 weeks

Case 5: Hardware Component with Embedded Software

- Biggest risks: Device recall, lawsuits, production line rework, hardware-software integration
  - DCR carried to Critical Design Review level
  - Concurrent hardware-software design
    - Criticality makes Agile too risky
  - Continuous hardware-software integration
    - Initially with simulated hardware
- Low risk of overrun
  - Low complexity, stable requirements and NDI
  - Little need for risk reserve
  - Likely single-supplier software
Case 5: Hardware Component with Embedded Software (continued)

- Example: Multi-sensor control device
- Size/complexity: Low
- Anticipated change rate (% per month): 0.3-1%
- Criticality: Medium to very high
- NDI support: Good, in place
- Organization and personnel capability: Experienced; medium to high capability
- Key Stage I activities: Concurrent hardware and software engineering; CDR-level ICM DCR
- Key Stage II activities: IOC Development, LRIP, FRP, concurrent version N+1 engineering
- Time/build: 1-5 days (software)
- Time/increment: Market-driven

Case 6: Indivisible IOC

- Biggest risk: Complexity, NDI uncertainties cause cost-schedule overrun
  - Similar strategies to case 5 for criticality (CDR, concurrent HW-SW design, continuous integration)
  - Add deferrable software features as risk reserve
    - Adopt conservative (90% sure) cost and schedule
    - Drop software features to meet cost and schedule
    - Strong award fee for features not dropped
  - Likely multiple-supplier software makes longer (multi-weekly) builds more necessary
Case 6: Indivisible IOC (continued)

- Example: Complete vehicle platform
- Size/complexity: Medium to high
- Anticipated change rate (% per month): 0.3-1%
- Criticality: High to very high
- NDI support: Some in place
- Organization and personnel capability: Experienced, medium to high capability
- Key Stage I activities: Determine minimum-IOC likely, conservative cost; Add deferrable software features as risk reserve
- Key Stage II activities: Drop deferrable features to meet conservative cost; Strong award fee for features not dropped
- Time/build: 2-6 weeks (software)
- Time/increment: 6-18 months (platform)

Case 7: NDI-Intensive

- Biggest risks: incompatible NDI; rapid change, business/mission criticality; low NDI assessment and integration experience; supply chain stakeholder incompatibilities
- Example: Supply chain management
- Size/complexity: Medium to high
- Anticipated change rate (% per month): 0.3-3%
- Criticality: Medium to very high
- NDI support: NDI-driven architecture
- Organization and personnel capability: NDI-experienced; medium to high capability
- Key Stage I activities: Thorough NDI-suite life cycle cost-benefit analysis, selection, concurrent requirements and architecture definition
- Key Stage II activities: Pro-active NDI evolution influencing, NDI upgrade synchronization
- Time/build: 1-4 weeks (software)
- Time/increment: 6-18 months (systems)
Case 8: Hybrid Agile/Plan-Driven System

- Biggest risks: large scale, high complexity, rapid change, mixed high/low criticality, partial NDI support, mixed personnel capability
- Example: C4ISR system
- Size/complexity: Medium to very high
- Anticipated change rate (% per month): Mixed parts; 1-10%
- Criticality: Mixed parts; medium to very high
- NDI support: Mixed parts
- Organization and personnel capability: Mixed parts
- Key Stage I activities: Full ICM; encapsulated agile in high changed; low-medium criticality parts (often HMI, external interfaces)
- Key Stage II activities: Full ICM, three-team incremental development, concurrent V&V, next-increment rebaselining
- Time/build: 1-2 months
- Time/increment: 9-18 months

Case 9: Multi-Owner System of Systems

- Biggest risks: all those of Case 8 plus
  - Need to synchronize, integrate separately-managed, independently-evolving systems
  - Extremely large-scale; deep supplier hierarchies
  - Rapid adaptation to change extremely difficult
- Example: Net-centric military operations or global supply chain management
- Size/complexity: Very high
- Anticipated change rate (% per month): Mixed parts; 1-10%
- Criticality: Very high
- NDI support: Many NDIs; some in place
- Organization and personnel capability: Related experience, medium to high
- Key Stage I activities: Full ICM; extensive multi-owner teambuilding, negotiation
- Key Stage II activities: Full ICM; large ongoing system/software engineering effort
- Time/build: 2-4 months Time/increment: 18-24 months
Case 10: Family of Systems

- Biggest risks: all those of Case 8 plus
  - Need to synchronize, integrate separately-managed, independently-evolving systems
  - Extremely large-scale; deep supplier hierarchies
  - Rapid adaptation to change extremely difficult
- Example: Medical device product line
- Size/complexity: Medium to very high
- Anticipated change rate (% per month): 1-3%
- Criticality: Medium to very high
- NDI support: Some in place
- Organization and personnel capability: Related experience, medium to high capability
- Key Stage I activities: Full ICM; full stakeholder participation in product line scoping; strong business case
- Key Stage II activities: Full ICM; extra resources for first system, version control, multi-stakeholder support
- Time/build: 1-2 months Time/increment: 9-18 months

Frequently Asked Question

- Q: Having all that ICM generality and then using the decision table to come back to a simple model seems like an overkill.
  - If my risk patterns are stable, can’t I just use the special case indicated by the decision table?

- A: Yes, you can and should – as long as your risk patterns stay stable. But as you encounter change, the ICM helps you adapt to it.
  - And it helps you collaborate with other organizations that may use different special cases.
Conclusions

• “One-size-fits-all” process guidelines and contracts do not fit all project situations
  – And are very risky for some situations
• The ICM decision table enables projects to find the right fit of process to situation
• Most situations are covered by a small number of process drivers
  – Size and complexity
  – Rate of requirements change
  – Product criticality
  – Available Non-Developmental Item (NDI) support
  – Relevant organizational and personnel capability
• The process drivers are often determinable in early stages
  – E.g., the ICM Exploration phase
  – Or your previous project’s process if the drivers haven’t changed
• ICM Details: http://csse.usc.edu/csse/research/ICM/index.html