Future Challenges for Systems and Software Cost Estimation and Measurement

Barry Boehm, USC-CSSE
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Summary

• Current and future trends create challenges for DoD systems and software data collection and analysis
  – Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS and services, high assurance with agility
  – DoD initiatives: DoDI 5000.02, evolutionary acquisition, competitive prototyping, time-certain milestones

• Updated software data definitions and estimation methods could help DoD systems management
  – Examples: incremental and evolutionary development; COTS and services; net-centric systems of systems
  – Further effort and coordination needed to converge on these
  – Being addressed in Brad Clark workshop this afternoon
Current and Future DoD Challenges

- Emergent requirements
  - Cannot prespecify requirements, cost, schedule, EVMS
  - Need to estimate and track early concurrent engineering

- Rapid change
  - Long acquisition cycles breed obsolescence
  - DoDI 5000.02 emphasis on evolutionary acquisition

- Net-centric systems of systems
  - Incomplete visibility and control of elements

- Model, COTS, service-based, Brownfield systems
  - New phenomenology, counting rules

- Always-on, never-fail systems
  - Need to balance agility and high assurance
The Broadening Early Cone of Uncertainty (CU)

- Need greater investments in narrowing CU
  - Mission, investment, legacy analysis
  - Competitive prototyping
  - Concurrent engineering
  - Associated estimation methods and management metrics

- Larger systems will often have subsystems with narrower CU’s
COSYSMO Operational Concept

# Requirements
# Interfaces
# Scenarios
# Algorithms
Volatility Factor

Size Drivers
Effort Multipliers

COSYSMO

Effort

- Application factors
  - 8 factors
- Team factors
  - 6 factors
- Schedule driver

Calibration

WBS guided by ISO/IEC 15288

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## TOC

<table>
<thead>
<tr>
<th>COSYSMO Application Factor Description</th>
<th>Identifier</th>
<th>Current Prod Range</th>
<th>Suggested Prod Range</th>
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Productivity Range (PR) is the Highest Number / Lowest Number and is an indication of the "Relative Degree of Influence" of this parameter on SE effort as currently. The "Suggested" column has no immediate impact in the COSYSMO SE Costing Mode. However, for the COSYSMO SE Data Collection Mode, it serves as a means of collecting your inputs as to what you think the "Relative Degree of Influence" of this parameter should be based upon your overall experience (not specific to the past program being characterized). If you agree with the "Current" number, do nothing. If you disagree, simply overwrite the current number with a new number n (n>1.0) in the appropriate cell.

Select the Rating from the pull-down that best represents the Rating program being estimated in the Mode or in the SE Data Collection Mode. Rating that best characterizes the program for which you are providing the rating.
COSYSMO Change Impact Analysis – I
– Added SysE Effort for Going to 3 Versions

- **Size:** Number, complexity, volatility, reuse of system requirements, interfaces, algorithms, scenarios (elements)
  - 1→3 Versions: add 3-6% per increment for number of elements
    add 2-4% per increment for volatility
  - Exercise Prep.: add 3-6% per increment for number of elements
    add 3-6% per increment for volatility

- **Most significant cost drivers (effort multipliers)**
  - Migration complexity: 1.10 – 1.20 (versions)
  - Multisite coordination: 1.10 – 1.20 (versions, exercise prep.)
  - Tool support: 0.75 – 0.87 (due to exercise prep.)
  - Architecture complexity: 1.05 – 1.10 (multiple baselines)
  - Requirements understanding: 1.05 – 1.10 for increments 1,2;
    1.0 for increment 3;   .9-.95 for increment 4
# COSYSMO Change Impact Analysis – II

– Added SysE Effort for Going to 3 Versions

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COSYSMO Requirements Counting Challenge

• Estimates made in early stages
  – Relatively few high-level design-to requirements

• Calibration performed on completed projects
  – Relatively many low-level test-to requirements

• Need to know expansion factors between levels
  – Best model: Cockburn definition levels
    • Cloud, kite, sea level, fish, clam

• Expansion factors vary by application area, size
  – One large company: Magic Number 7
  – Small e-services projects: more like 3:1, fewer lower levels

• Survey form available to capture your experience
Next-Generation Systems Challenges

- **Emergent requirements**
  - Example: Virtual global collaboration support systems
  - Need to manage early concurrent engineering

- **Rapid change**
  - In competitive threats, technology, organizations, environment

- **Net-centric systems of systems**
  - Incomplete visibility and control of elements

- **Model, COTS, service-based, Brownfield systems**
  - New phenomenology, counting rules

- **Always-on, never-fail systems**
  - Need to balance agility and high assurance
Rapid Change Creates a Late Cone of Uncertainty
– Need evolutionary/incremental vs. one-shot development

Uncertainties in competition, technology, organizations, mission priorities

Phases and Milestones
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Evolutionary Acquisition per New DoDI 5000.02
No clean boundary between R&D and O&M
Incremental Development Productivity Decline (IDPD)

- **Example: Site Defense BMD Software**
  - 5 builds, 7 years, $100M; operational and support software
  - Build 1 productivity over 300 LOC/person month
  - Build 5 productivity under 150 LOC/PM
    - Including Build 1-4 breakage, integration, rework
    - 318% change in requirements across all builds
    - IDPD factor = 20% productivity decrease per build
  - Similar trends in later unprecedented systems
  - Not unique to DoD: key source of Windows Vista delays

- **Maintenance of full non-COTS SLOC, not ESLOC**
  - Build 1: 200 KSLOC new; 200K reused@20% = 240K ESLOC
  - Build 2: 400 KSLOC of Build 1 software to maintain, integrate
IDPD Cost Drivers: Conservative 4-Increment Example

• Some savings: more experienced personnel (5-20%)
  • Depending on personnel turnover rates
• Some increases: code base growth, diseconomies of scale, requirements volatility, user requests
  • Breakage, maintenance of full code base (20-40%)
  • Diseconomies of scale in development, integration (10-25%)
  • Requirements volatility; user requests (10-25%)
• Best case: 20% more effort (IDPD=6%)
• Worst case: 85% (IDPD=23%)
Effects of IDPD on Number of Increments

- Model relating productivity decline to number of builds needed to reach 8M SLOC Full Operational Capability
- Assumes Build 1 production of 2M SLOC @ 100 SLOC/PM
  - 20000 PM/ 24 mo. = 833 developers
  - Constant staff size for all builds
- Analysis varies the productivity decline per build
  - Extremely important to determine the incremental development productivity decline (IDPD) factor per build

![Graph showing the effects of IDPD on number of increments](graph.png)
Incremental Development Data Challenges

• Breakage effects on previous increments
  – Modified, added, deleted SLOC: need Code Count with diff tool

• Accounting for breakage effort
  – Charged to current increment or I&T budget (IDPD)
    • IDPD effects may differ by type of software
  – “Breakage ESLOC” added to next increment
  – Hard to track phase and activity distributions
    • Hard to spread initial requirements and architecture effort

• Size and effort reporting
  – Often reported cumulatively
  – Subtracting previous increment size may miss deleted code

• Time-certain development
  – Which features completed? (Fully? Partly? Deferred?)
“Equivalent SLOC” Paradoxes

- Not a measure of software size
- Not a measure of software effort
- Not a measure of delivered software capability
- A quantity derived from software component sizes and reuse factors that helps estimate effort
- Once a product or increment is developed, its ESLOC loses its identity
  - Its size expands into full SLOC
  - Can apply reuse factors to this to determine an ESLOC quantity for the next increment
    - But this has no relation to the product’s size
Current and Future DoD Challenges

• Emergent requirements
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Net-Centric Systems of Systems Challenges

• Need for rapid adaptation to change
  – See first, understand first, act first, finish decisively

• Built-in authority-responsibility mismatches
  – Increasing as authority decreases through Directed, Acknowledged, Collaborative, and Virtual SoS classes

• Severe diseconomies of scale
  – Weak early architecture and risk resolution
  – Need thorough flowdown/up of estimates, actuals
  – More complex integration and test preparation, execution

• More software intensive
  – Best to use parallel software WBS

• Many different classes of system elements
  – One-size-fits-all cost models a poor fit
Added Cost of Weak Architecting

Calibration of COCOMO II Architecture and Risk Resolution factor to 161 project data points

% Added Cost, Very Low vs. Very High RESL Rating

Software Product Size (KSLOC)
Model, COTS, Service-Based, Brownfield Systems

New phenomenology, counting rules

- Product generation from model directives
  - Treat as very high level language: count directives

- Sizing COTS and services use needs improvement
  - Unrealistic to use COTS, services SLOC for sizing
  - Alternatives: function point elements, amount of glue code, activity-based assessment costing, tailoring parameters

- Brownfield legacy constraints, re-engineering
  - Re-engineer legacy code to fit new architecture
  - Apply reuse model for re-engineering

- A common framework for reuse, incremental development, maintenance, legacy re-engineering?
  - All involve reusing, modifying, deleting existing software
Achieving Agility and High Assurance - I

Using timeboxed or time-certain development
Precise costing unnecessary; feature set as dependent variable
Achieving Agility and High Assurance -II

Unforeseeable Change (Adapt)

Rapid Change

Foreseeable Change (Plan)

Short Development Increments

Increment N Baseline

Stable Development Increments

High Assurance

Current V&V Resources

Continuous V&V

Verification and Validation (V&V) of Increment N

Artifacts

Concerns

Future V&V Resources

Future Increment Baselines

Increment N Transition/Operations and Maintenance

Agile Rebaselining for Future Increments

Deferrals
Related Additional Measurement Challenges

• Tracking progress of rebaselining, V&V teams
  – No global plans; individual changes or software drops
  – Earlier test preparation: surrogates, scenarios, testbeds

• Tracking content of time-certain increments
  – Deferred or partial capabilities; effects across system

• Trend analysis of emerging risks
  – INCOSE Leading Indicators; SERC Effectiveness Measures

• Contributions to systems effectiveness
  – Measures of Effectiveness models, parameters

• Systems of systems progress, risk, change tracking
  – Consistent measurement flow-up, flow-down, flow-across
Software data definition topics for discussion

In Brad Clark workshop this afternoon

• Ways to treat data elements
  – COTS, other OTS (open source; services; GOTS; reuse; legacy code)
  – Other size units (function points object points, use case points, etc.)
  – Generated code: counting generator directives
  – Requirements volatility
  – Rolling up CSCIs into systems and systems of systems
  – Cost model inputs and outputs (e.g., submitting estimate files)

• Scope issues
  – Cost drivers, Scale factors
  – Reuse parameters: Software Understanding , Programmer Unfamiliarity
  – Phases included: hardware-software integration; systems of systems integration, transition, maintenance
  – WBS elements and labor categories included
  – Parallel software WBS

• How to involve various stakeholders
  – Government, industry, commercial cost estimation organizations
Summary

• Current and future trends create challenges for DoD systems and software data collection and analysis
  – Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS and services, high assurance with agility
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• Updated software data definitions and estimation methods could help DoD systems management
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References


Backup Charts
How Much Architecting is Enough?
- Larger projects need more

Sweet Spot Drivers:
Rapid Change: leftward
High Assurance: rightward
TRW/COCOMO II Experience Factory: IV

System objectives: fcn’y, perf., quality

Corporate parameters: tools, processes, reuse

Evaluate Corporate SW Improvement Strategies

Recalibrate COCOMO II

Accumulate COCOMO II calibration data

Rescope

COCOMO II

Execute project to next Milestone

Revise Milestones, Plans, Resources

Cost, Sched, Risks

Ok? Yes

Yes

Cost, Sched, Risks

Ok? No

Yes

Milestone planning resources

Ok? No

Milestone expectations

Yes

Revised Expectations

End

Done?

No

M/S Results

Yes

Improved Corporate Parameters

Corrected Corporate Quality drivers

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Choosing and Costing
Incremental Development Forms

<table>
<thead>
<tr>
<th>Type</th>
<th>Examples</th>
<th>Pros</th>
<th>Cons</th>
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<td>Evolutionary Sequential</td>
<td>Small: Agile Large: Evolutionary Development</td>
<td>Adaptability to change</td>
<td>Easiest-first; late, costly breakage</td>
<td>Small: Planning-poker-type Large: Parametric with IDPD</td>
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<td>Prespecified Sequential</td>
<td>Platform base plus PPPIs</td>
<td>Prespecifiable full-capability requirements</td>
<td>Emergent requirements or rapid change</td>
<td>COINCOMO with no increment overlap</td>
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<td>Modular product line</td>
<td>Cross-increment breakage</td>
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<td>Rebaselining Evolutionary</td>
<td>Mainstream product lines; Systems of systems</td>
<td>High assurance with rapid change</td>
<td>Highly coupled systems with very rapid change</td>
<td>COINCOMO, IDPD for development; COSYSMO for rebaselining</td>
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IDPD: Incremental Development Productivity Decline, due to earlier increments breakage, increasing code base to integrate
PPPIs: Pre-Planned Product Improvements
COINCOMO: COCOMO Incremental Development Model (COCOMO II book, Appendix B)

All Cost Estimation approaches also include expert-judgment cross-check.
Compositional approaches: Directed systems of systems

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<td>Assess sources of change; Negotiate rebaselined LCA2 package at all levels</td>
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### Comparison of Cost Model Parameters

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SoSE Core Element Mapping to COSOSIMO Sub-models

**COSOSIMO**

- Planning, Requirements Management, and Architecting (PRA)
- Source Selection and Supplier Oversight (SO)
- SoS Integration and Testing (I&T)

**Translating capability objectives**

- Understanding systems & relationships (includes plans)
- Developing, evolving and maintaining SoS design/arch
- Addressing new requirements & options
- Orchestrating upgrades to SoS
- Assessing (actual) performance to capability objectives
- Monitoring & assessing changes
- Orchestrating upgrades to SoS
- Monitoring & assessing changes