Current and Future Challenges for Systems and Software Cost Estimation

Barry Boehm, USC-CSSE

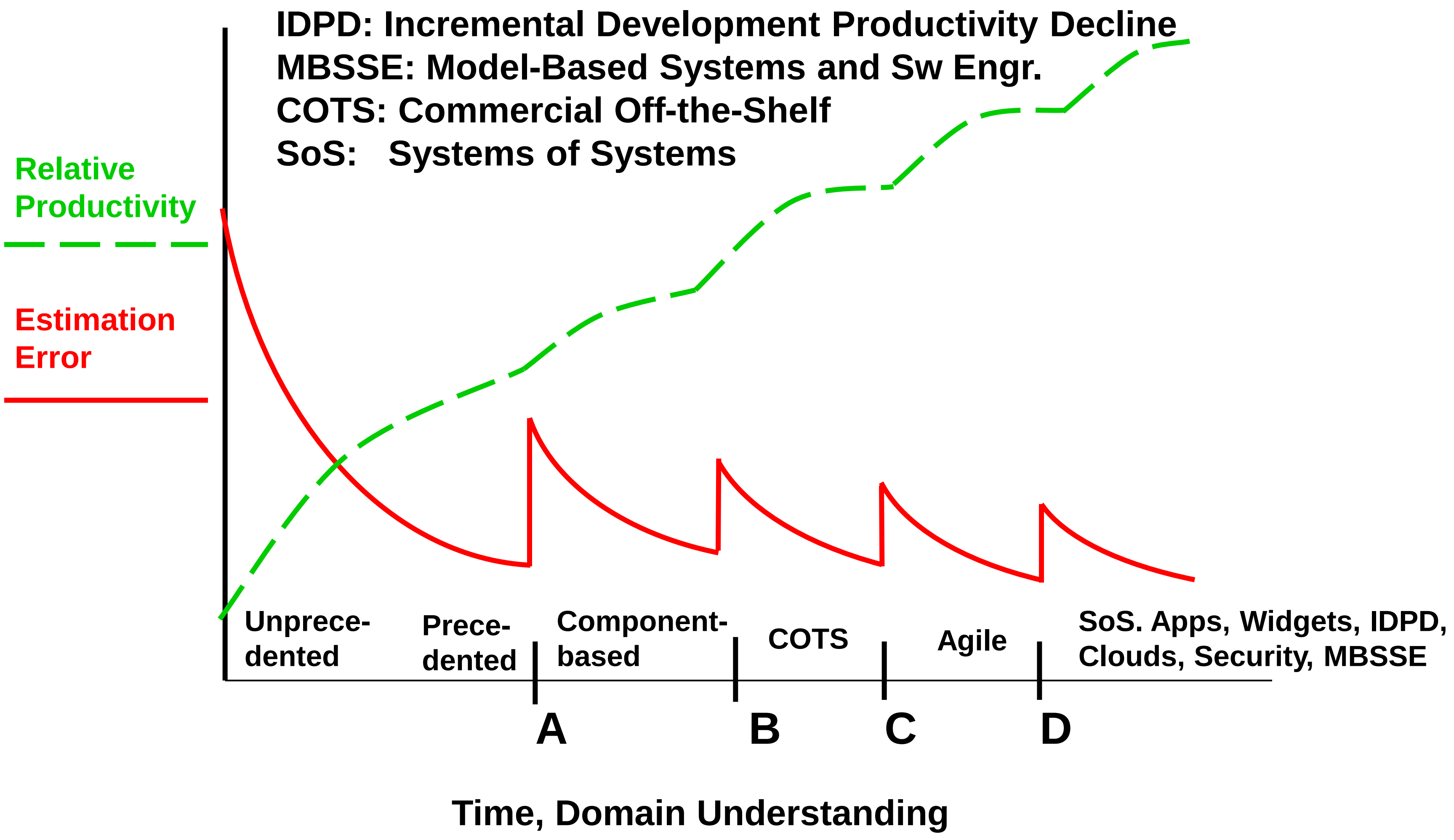
29th COCOMO-SSCM Forum

October 21, 2014

Summary

- Current and future trends create challenges for systems and software cost estimation
  - Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS, clouds, apps, widgets, high assurance with agility, multi-mission systems
- USC, NPS/AFIT, DoD Systems Engineering Research Center researching ways to address challenges
  - Beginning with space systems (COSATMO models)
  - Extendable to other DoD domains
- Forum includes related COCOMO-family workshops
  - Wednesday AM: COSYSMO 3.0
  - Thursday AM: COCOMO III

Software Estimation: The Receding Horizon



Current and Future Estimation Challenges

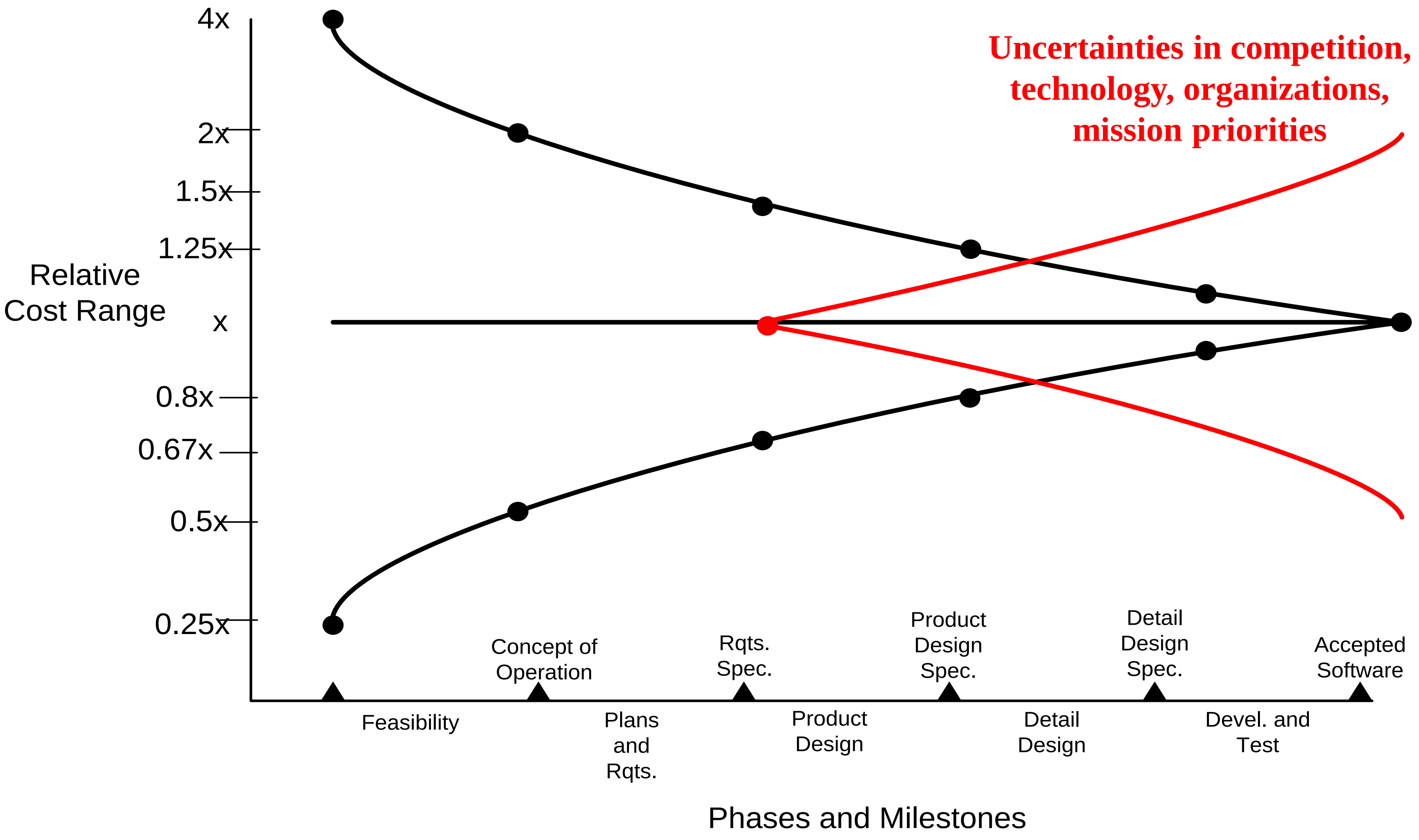
- **Emergent requirements**
  - **Cannot prespecify requirements, cost, schedule, EVMS**
  - **Need to estimate and track early concurrent engineering**
- **Rapid change**
  - **Long acquisition cycles breed obsolescence**
  - **Need better models for incremental development**
- **Net-centric systems of systems**
  - **Incomplete visibility and control of elements**
- **Model, COTS, service-based, Brownfield systems**
  - **New phenomenology, counting rules**
- **Major concerns with affordability**
  - **US DoD: Better Buying Power 3.0**

US DoD: Better Buying Power 3.0

Current draft about to become DoD policy

- Achieve affordable programs
- Achieve dominant capabilities while controlling lifecycle costs
- Incentivize productivity in industry and government
- Incentivize innovation in industry and government
- Eliminate unproductive processes and bureaucracy
- Promote effective competition
- Improve tradecraft in acquisition of services
- Improve the professionalism of the total acquisition workforce

Rapid Change Creates a Late Cone of Uncertainty
– Need evolutionary/incremental vs. one-shot development

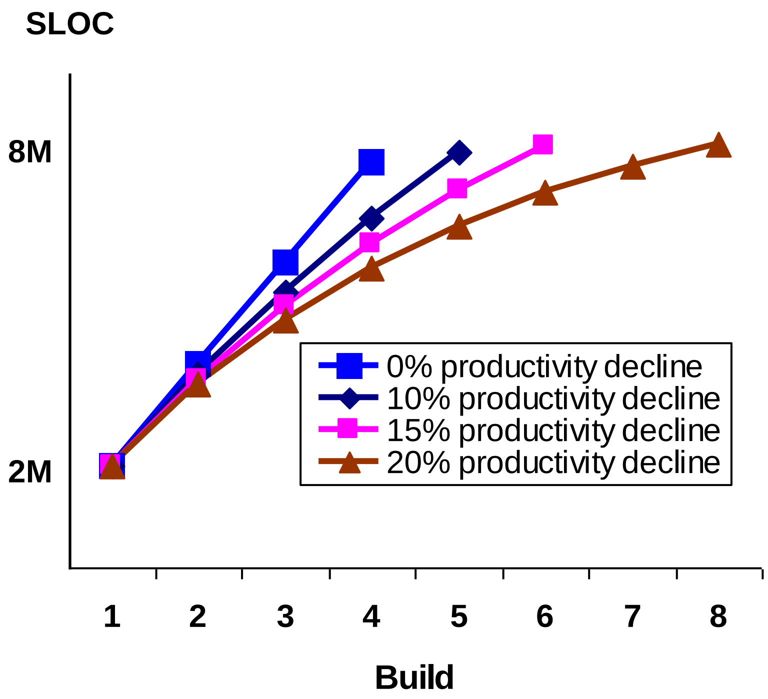


Incremental Development Productivity Decline (IDPD)

- 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

Effects of IDPD on Number of Increments

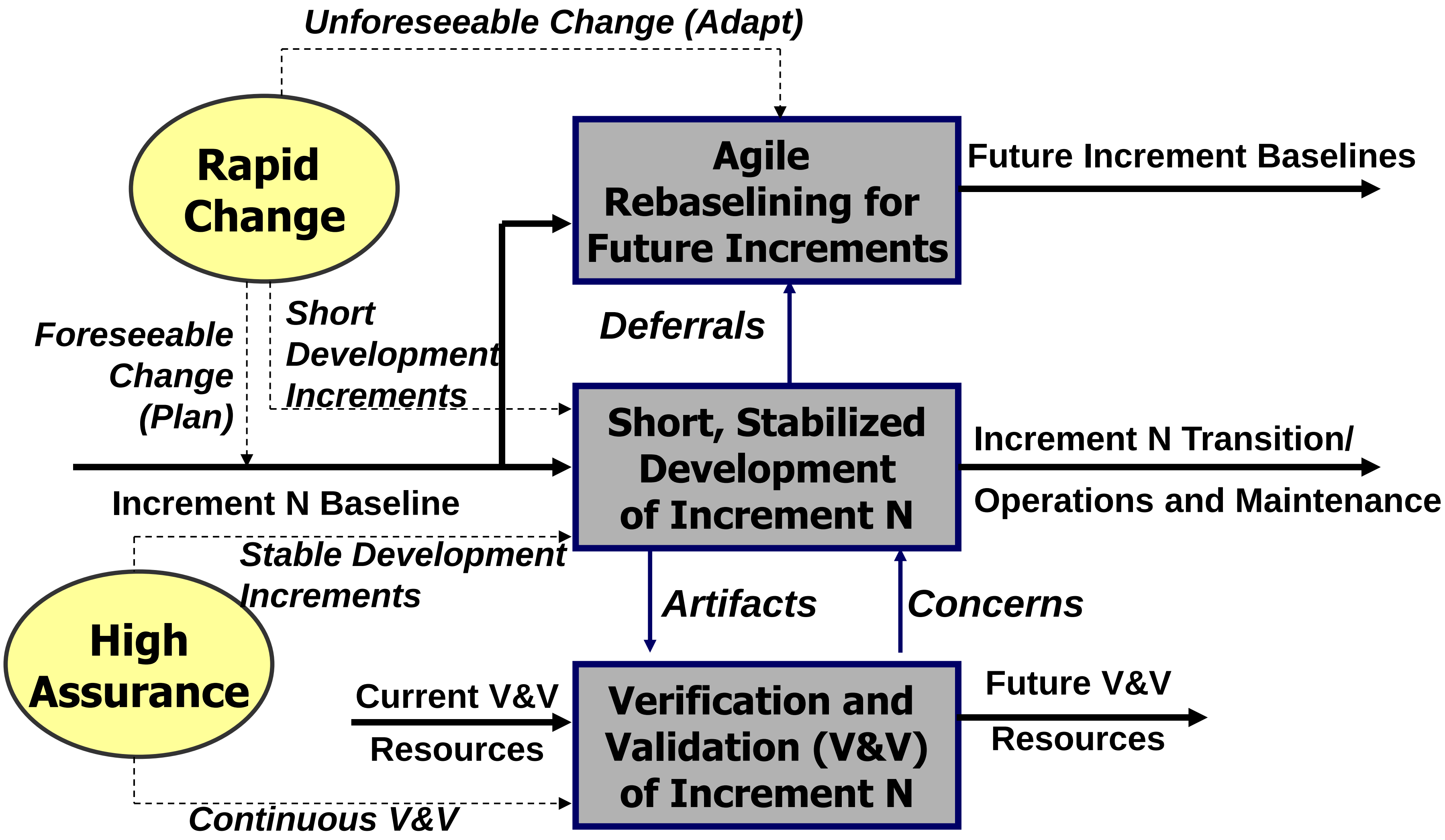
- **Model relating productivity decline to number of builds needed to reach 8M SLOC Full Operational Capability**
- **Assumes Build 1 production of 2M SLOC @ 100 SLOC/PM**
  - **20000 PM/ 24 mo. = 833 developers**
  - **Constant staff size for all builds**
- **Analysis varies the productivity decline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



Multi-Mission Systems Costing

- Product Line Engineering
  - Identify multi-mission commonalities and variabilities
  - Identify fully, partially sharable commonalities
  - Develop plug-compatible interfaces for variabilities
- Product Line Costing (COPLIMO) Parameters
  - Fractions of system fully reusable, partially reusable and cost of developing them for reuse
  - Fraction of system variabilities and cost of development
  - System lifetime and rates of change
- Product Line Life Cycle Challenges
  - Layered services vs. functional hierarchy
  - Modularization around sources of change
  - Version control, COTS refresh, and change prioritization
  - Balancing agility, assurance, and affordability

Risk-Driven Scalable Spiral Model: Increment View


Unforeseeable Change (Adapt)
Rapid Change
Agile Rebaselining for Future Increments
Future Increment Baselines
Foreseeable Change (Plan)
Short Development Increments
Deferrals
Short, Stabilized Development of Increment N
Increment N Transition/
Operations and Maintenance
Increment N Baseline
Stable Development Increments
Artifacts
Concerns
High Assurance
Current V&V
Resources
Verification and Validation (V&V) of Increment N
Future V&V
Resources
Continuous V&V

Summary

- Current and future trends create challenges for ground system cost estimation
  - Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS, clouds, apps, widgets, high assurance with agility, multi-mission systems
- ➡ DoD Systems Engineering Research Center researching ways to address challenges
  - Beginning with space systems (COSATMO models)
  - Extendable to other DoD domains
- Workshop objectives
  - Understand, prioritize ground system cost estimation needs, opportunities
  - Identify sources of expertise, data

COSATMO Concept

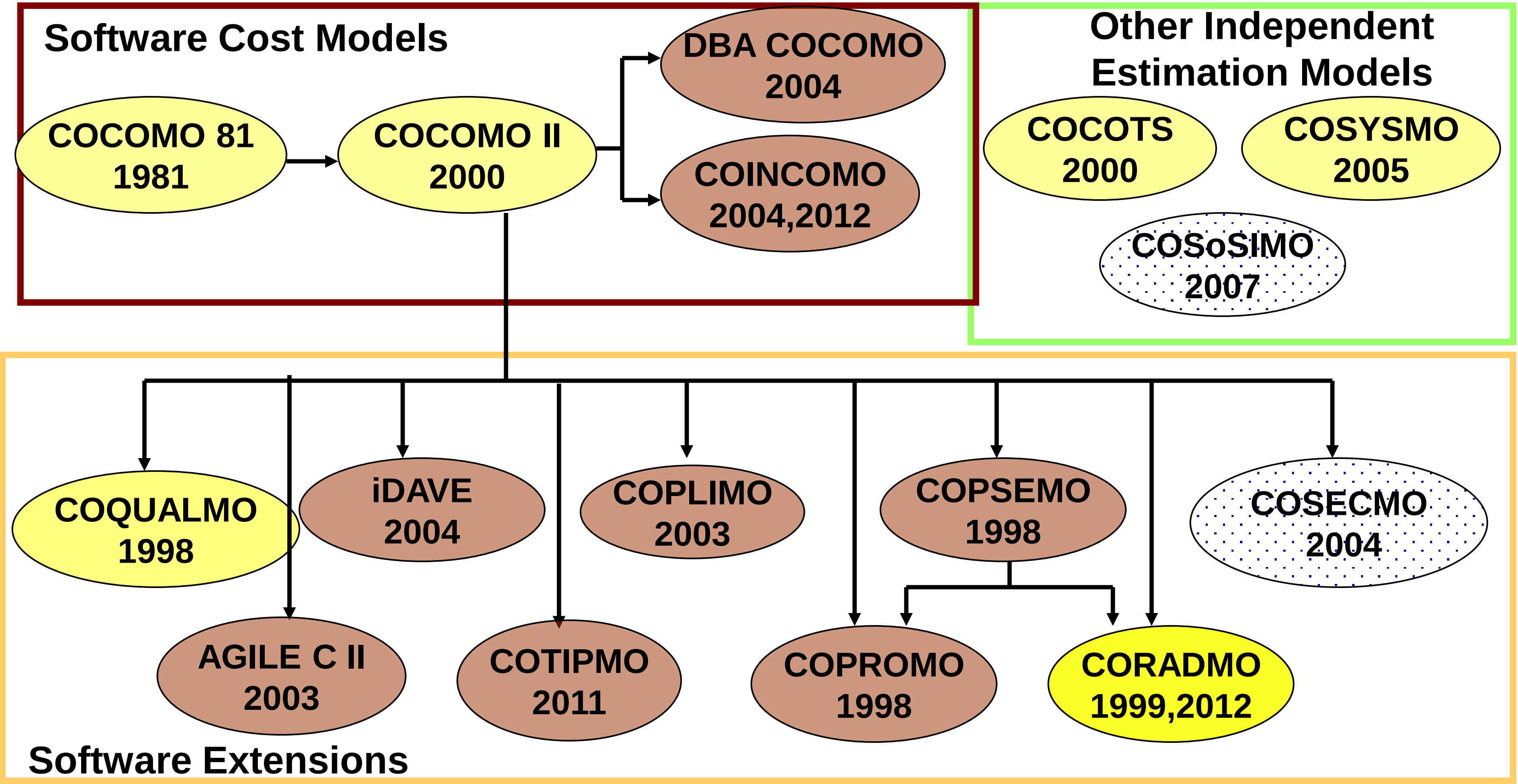
- Focused on current and future satellite systems
  - Accommodating rapid change, evolutionary development, Net-Centric SoSs, Families of systems, DI2E SWASe's
    - Software, Widgets, Assets, Services, etc.
  - Recognizes new draft DoDI 5000.02 process models
    - Hardware-intensive, DoD-unique SW-intensive, Incremental SW-intensive, Accelerated acquisition, 2 Hybrids (HW-, SW-dominant)
  - Supports affordability analyses (total cost of ownership):
    - Covers full life cycle: definition, development, production, operations, support, phaseout
    - Covers full system: satellite(s), ground systems, launch
    - Covers hardware, software, personnel costs
- Extensions to cover systems of systems, families of systems
- Several PhD dissertations involved (as with COSYSMO)
  - Incrementally developed based on priority, data availability

COSATMO Tentative Model

- Total satellite system cost =

  System engineering cost
  + Satellite software cost
  + Satellite vehicle hardware development and production cost
  + Launch cost
  + Initial ground software cost
  + Initial ground facility cost
  + Operation & support cost
- Model as sum of submodels relates to models in COCOMO family

COCOMO Family of Cost Models



Software Cost Models

COCOMO 81 1981

COCOMO II 2000

DBA COCOMO 2004

COINCOMO 2004,2012

Other Independent Estimation Models

COCOTS 2000

COSYSMO 2005

COSoSIMO 2007

Software Extensions

COQUALMO 1998

iDAVE 2004

COPLIMO 2003

COPSEMO 1998

COSECMO 2004

AGILE C II 2003

COTIPMO 2011

COPROMO 1998

CORADMO 1999,2012

Legend:

Model has been calibrated with historical project data and expert (Delphi) data 🟨

Model is derived from COCOMO II 🟫

Model has been calibrated with expert (Delphi) data ⁙

Dates indicate the time that the first paper was published for the model

COSATMO Submodel Starting Points

- System engineering: COSYSMO, perhaps with add-ons
- Satellite vehicle hardware development and production: Current Aerospace hardware cost model(s); exploring extensions of COSYSMO for hardware cost estimation
- Satellite vehicle, ground system software development: COCOMO II, COCOTS, perhaps with add-ons
- Launch model: similarity model, based on vehicle mass, size, orbit
- Ground system equipment, supplies: construction, unit-cost, services cost models
- Operation & support: labor-grade-based cost models, software maintenance models

Summary

- **Current and future trends create challenges for systems and software cost estimation**
  - **Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS, clouds, apps, widgets, high assurance with agility, multi-mission systems**
- **USC, NPS/AFIT, DoD Systems Engineering Research Center researching ways to address challenges**
  - **Beginning with space systems (COSATMO models)**
  - **Extendable to other DoD domains**
- **Forum includes related COCOMO-family workshops**
  - ➡ **Wednesday AM: COSYSMO 3.0**
  - **Thursday AM: COCOMO III**

COSYSMO 3.0 Context

- **COSYSMO 1.0 focused on basic-project SE costs**
  - **4 size drivers: #rqts, interfaces, scenarios, key algorithms**
  - **Weighted by complexity and added together**
  - **14 cost drivers: 8 technical, 6 personnel-related**
  - **Calibrated to 50+ project data points from 7 companies**
  - **Adopted by Galorath, Price Systems, Softstar Systems**
- **COSYSMO 2.0 added SE-with-reuse effects to 1.0**
  - **Calibrated to 40+ BAE Systems project data points**
- **COSYSMO-REVL added rqts-volatility effects to 1.0**
  - **Calibrated to 25 Boeing project data points**
- **COSYSMO 3.0 proposes to harmonize 2.0 and –REVL**
  - **And adding SE-for-reuse, SE-for-SoS interoperability effects**
  - **And revisiting COSYSMO 1.0 size and cost drivers**
  - **Also exploring COSYSMO for system development costing**

COSYSMO 3.0 Directions (Adapted from ARR slides [8])

Harmonize existing COSYSMO family models:

- **Several factors affecting the COSYSMO cost model have been shown to be valuable in increasing estimation accuracy (terminology from [5]):**
  - **Reuse (simple model--SEWR) [3]**
  - **Reuse (with SEFR) [1]**
  - **Requirements volatility (SERV) [4]**

  The rating scales for these could be integrated into a comprehensive COSYSMO model.

Enhancement planned for inclusion:

- **System-of-system considerations are hypothesized to affect system engineering costs:**
  - **Interoperability considerations [6]**

COSYSMO 3.0 Directions
Part 2

Enhancements under discussion:

- **Explore a model for total development cost based primarily on the COSYSMO parameters (Cole)**
- **Reduce the number of Effort Multipliers (Roedler)**

Harmonized COSYSMO 3.0 Top-Level Model

$$PM_{C3} = A_{C3} \times (Size_{C3})^{E_{C3}} \times \prod_{j=1}^{14+} EM_{C3,j}$$

Elements of the Harmonized COSYSMO 3.0 model:

- ***Calibration parameter A***
- **Interoperability**
- **Size model**
  - **eReq submodel**
  - **Partial development submodel**
- **Exponent (E) model**
  - **SF submodel**
  - **REVL submodel**
- **Effort multipliers EM**
  - **14 unchanged EMs**
  - **SEFR**
  - **Interoperability**
- **Multi-subproject model**

Harmonized COSYSMO 3.0 Interoperability Model

- Lane & Valerdi [6] propose that interoperability be considered a cost influence in the COSYSMO family
- Motivation: if a system is part of a system-of-systems, then that context is reflected in interoperability requirements on the system
- Two ways this influence could be manifested are proposed:
  - Method 1: Add a new effort multiplier
  - Method 2: Adjust the easy/medium/difficult rating scale for system interfaces (part of the Size model)
- Both Methods are shown in this presentation; presumably only one would be retained in COSYSMO 3.0.

Harmonized COSYSMO 3.0 Size Model

$$Size_{C3} = \sum_{Prods} eReq(Type(Prod), Difficulty(Prod)) \times$$

$$PartialDevFactor(Phase_{Start}(Prod), Phase_{End}(Prod))$$

- **Prod is one of the four system engineering products that determines size in COSYSMO family (per [2]):**
  - **System requirement**
  - **System interface**
  - **System algorithm**
  - **Operational scenario**
- **For simplicity in model explanation, each individual Prod is considered separately**
- **There are two submodels:**
  - **Equivalent nominal requirements (“eReq”)**
  - **Partial development**

Harmonized COSYSMO 3.0 Effort Multiplier Model (2/3)

- A new, 15th effort multiplier is “System Engineering for Reuse (SEFR)”
  - I.e., is the project developing intermediate and final system engineering results to be reused on later projects?
    - Reuse for product line is one example
  - Inspired by [1]
- Assumes there is an added cost for SEFR
- Starting point for rating scale (as suggested by Boehm) is COCOMO II RUSE:
  - Low: Not for reuse
  - Nominal: Reused across project
  - High: Reused across program
  - Very High: Reused across product line
  - Extra High: Reused across multiple product lines

Harmonized COSYSMO 3.0 Effort Multiplier Model (3/3)

Adjustment for interoperability (Method 1):

- **“Interoperability” might be a new, 16th effort multiplier**
- **Table 2 of [6] proposes this rating scale, depending on whether the project is for an existing system or a new system:**

Type of Development	**Level**				
	Very Low	**Low**	**Nominal**	**High**	**Very High**
Existing systems (based upon LISI levels)	Isolated	Connected	Functional standards employed	Domain standards employed	Enterprise standards employed
New system (s) (based upon LCIM conceptual levels)	System-specific data	Documented data	Aligned static data	Aligned dynamic data	Harmonized data

Summary

- Current and future trends create challenges for systems and software cost estimation
  - Mission challenges: emergent requirements, rapid change, net-centric systems of systems, COTS, clouds, apps, widgets, high assurance with agility, multi-mission systems
- USC, NPS/AFIT, DoD Systems Engineering Research Center researching ways to address challenges
  - Beginning with space systems (COSATMO models)
  - Extendable to other DoD domains
- Forum includes related COCOMO-family workshops
  - Wednesday AM: COSYSMO 3.0
  - ➡ Thursday AM: COCOMO III

Observations

- **COCOMO II challenged by different development strategies**
- **2000 calibration dataset is over 14 years old**
- **Productivity appears to be *increasing* over time**
- **Levels of reported process maturity increasing in Software Engineering data**
- **Productivity appears to decline with multiple incremental development**

COCOMO II Challenges

1995: one-size-fits-all model for 21st century software

1999: poor fit for schedule-optimized projects; CORADMO

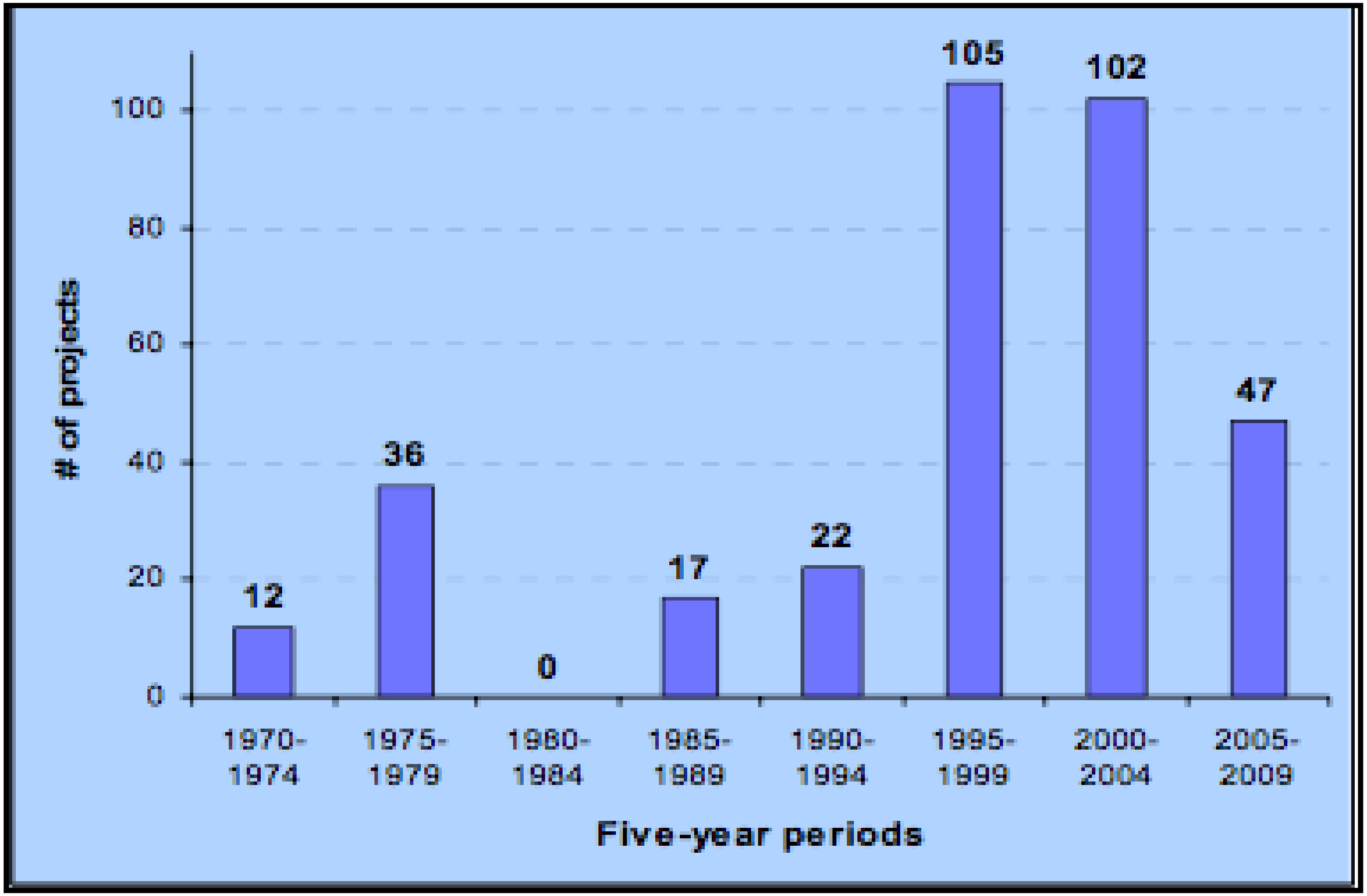
2000: poor fit for COTS-intensive projects: COCOTS

2003: need model for product line investment: COPLIMO

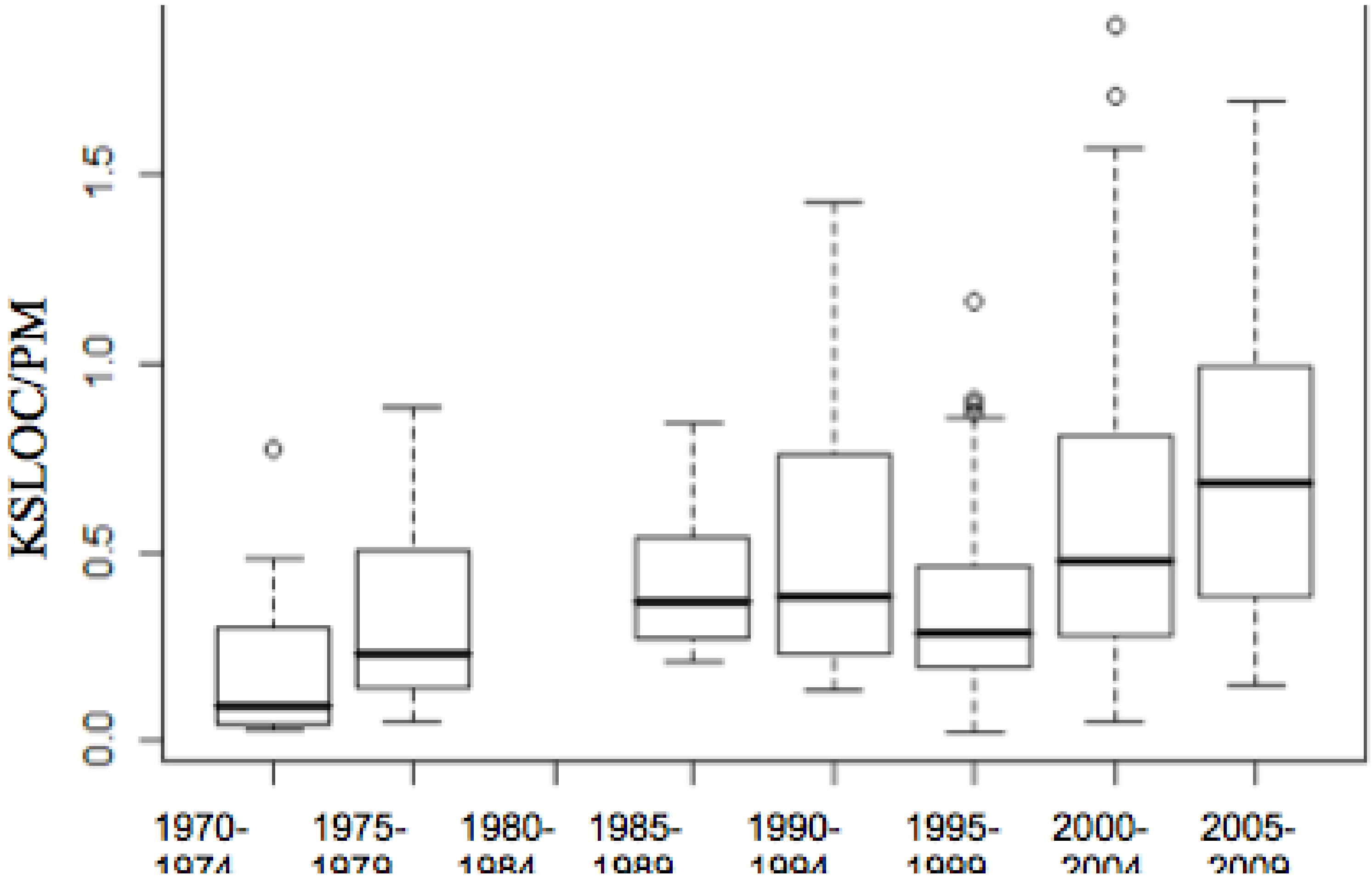
2003: poor fit for agile projects: Agile COCOMO II (partial)

2012: poor fit for incremental development: COINCOMO

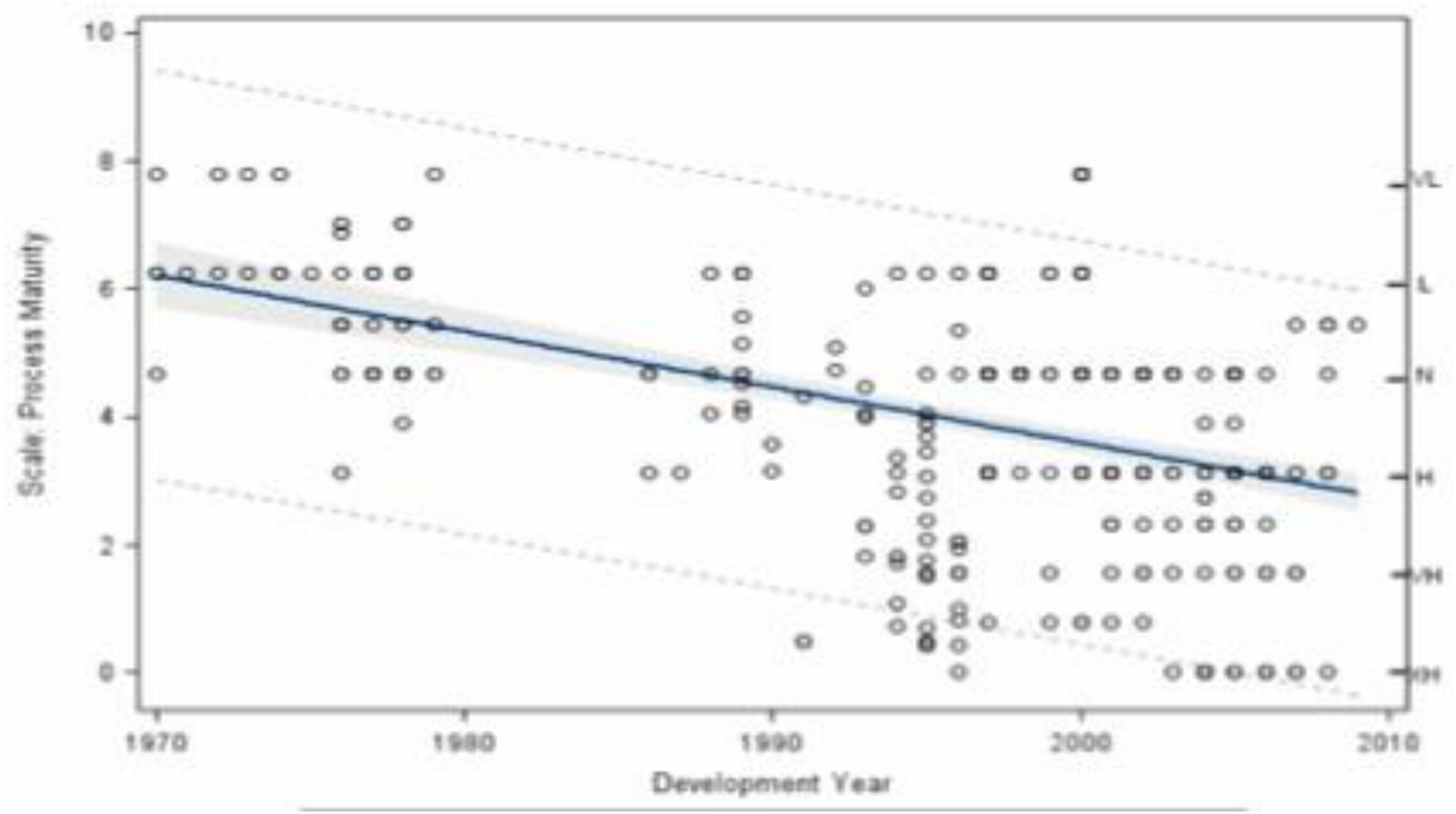
COCOMO II Data by 5-Year Periods



COCOMO II Data: Productivity Trends



COCOMO II Data: Process Maturity Trends



Workshop Topics

1. Consider incorporating Software Application Domains
2. Discuss additional model forms
3. Review current set of cost drivers

Super-Domains and AFCAA Productivity Types

Super Domain	Productivity Types
Real-Time (RT)	1 Sensor Control and Signal Processing
	2 Vehicle Control
	3 Vehicle Payload
	4 Real Time Embedded-Other
Engineering (ENG)	5 Mission Processing
	6 Executive
	7 Automation and Process Control
	8 Scientific Systems
	9 Telecommunications
Mission Support (MS)	10 Planning Systems
	11 Training
	12 Software Tools
	13 Test Software
Automated Information System (AIS)	14 Intelligence and Information Systems
	Software Services
	Software Applications

Additional Model Forms

- Keep COCOMO II models?
  - Application Composition
  - Early-Design
  - Post-Architecture
- Should COCOMO III be backwards compatibility to COCOMO 81 & COOCMO II?
- New parameters, e.g.,
  - to indicate the type of processes that are planned for the development e.g.: plan-driven, rapid development, architected agile, formal methods, COTS integration.

COCOMO II Cost Driver Review

- **New cost driver values based on post-2000 data points**
- **Review cost drivers for**
  - **Relevance?**
  - **Additions / deletions?**
- **Which cost drivers need a better rating selection system that reduces rating subjectivity**