The Key Roles of Maintainability in an Ontology for System Qualities

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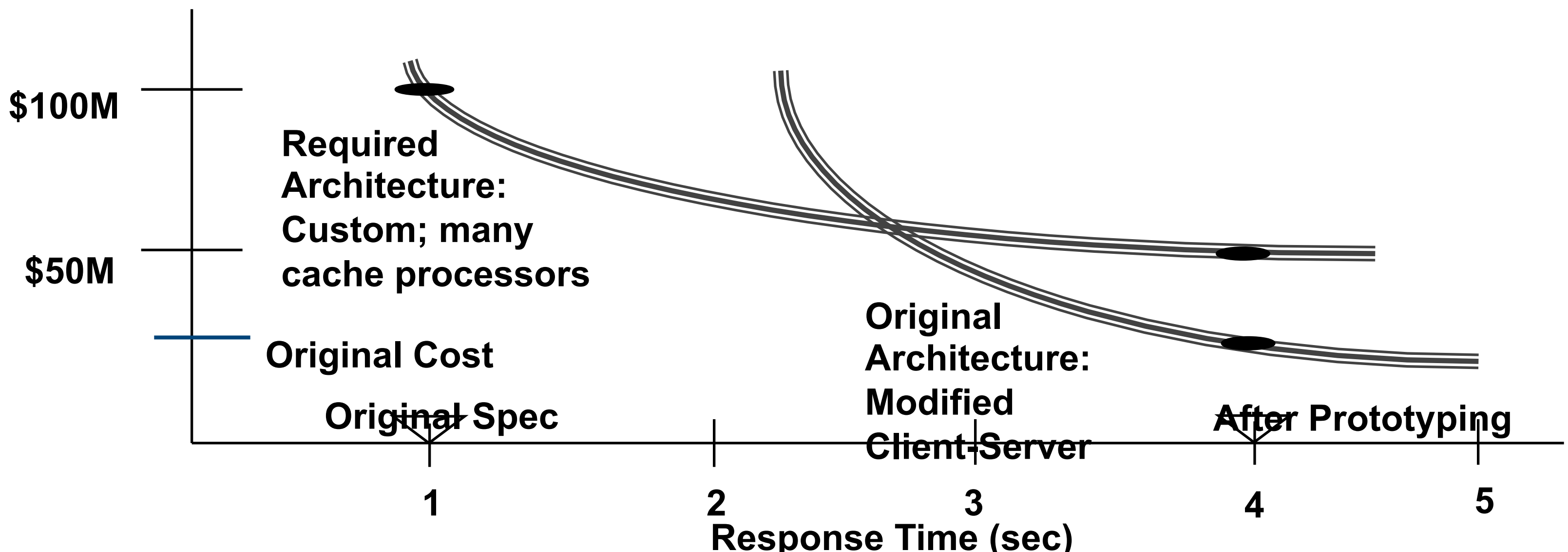
Outline

- Critical nature of system qualities (SQs)
  - Or non-functional requirements (NFRs); ilities
  - Major source of project overruns, failures
  - Significant source of stakeholder value conflicts
  - Poorly defined, understood
  - Underemphasized in project management
- Key roles of Maintainability in SQs ontology
  - Nature of an ontology; choice of IDEF5 structure
  - Stakeholder value-based, means-ends hierarchy
  - Synergies and Conflicts matrix and expansions
- Initial elaboration of Maintainability

Importance of SQ Tradeoffs

Major source of system overruns, Life cycle costs

- SQs have systemwide impact
  - System elements generally just have local impact
- SQs often exhibit asymptotic behavior
  - Watch out for the knee of the curve
- Best architecture is a discontinuous function of SQ level
  - "Build it quickly, tune or fix it later" highly risky
  - Large system example below



Example of SQ Value Conflicts: Security IPT

- **Single-agent key distribution; single data copy**
  - **Reliability: single points of failure**
- **Elaborate multilayer defense**
  - **Performance: 50% overhead; real-time deadline problems**
- **Elaborate authentication**
  - **Usability: delays, delegation problems; GUI complexity**
- **Everything at highest level**
  - **Modifiability: overly complex changes, recertification**

Proliferation of Definitions: Resilience

- **Wikipedia Resilience variants: Climate, Ecology, Energy Development, Engineering and Construction, Network, Organizational, Psychological, Soil**

- **Ecology and Society Organization Resilience variants: Original-ecological, Extended-ecological, Walker et al. list, Folke et al. list; Systemic-heuristic, Operational, Sociological, Ecological-economic, Social-ecological system, Metaphoric, Sustainabilty-related**

- **Variants in resilience outcomes**
  - **Returning to original state; Restoring or improving original state; Maintaining same relationships among state variables; Maintaining desired services; Maintaining an acceptable level of service; Retaining essentially the same function, structure, and feedbacks; Absorbing disturbances; Coping with disturbances; Self-organizing; Learning and adaptation; Creating lasting value**
  - **Source of serious cross-discipline collaboration problems**

Example of Current Practice

- "The system shall have a Mean Time Between Failures of 10,000 hours"
- What is a "failure?"
  - 10,000 hours on liveness
  - But several dropped or garbled messages per hour?
- What is the operational context?
  - Base operations? Field operations? Conflict operations?
- Most management practices focused on functions
  - Requirements, design reviews; traceability matrices; work breakdown structures; data item descriptions; earned value management
- What are the effects of or on other SQs?
  - Cost, schedule, performance, maintainability?

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Need for SQs Ontology

- **Oversimplified one-size-fits all definitions**
  - **ISO/IEC 25010, Reliability: the degree to which a system , product, or component performs specified functions under specified conditions for a specified period of time**
  - **OK if specifications are precise, but increasingly "specified conditions" are informal, sunny-day user stories.**
    - **Satisfying just these will pass "ISO/IEC Reliability," even if system fails on rainy-day user stories**
  - **Need to reflect that different stakeholders rely on different capabilities (functions, performance, flexibility, etc.) at different times and in different environments**
- **Proliferation of definitions, as with Resilience**
- **Weak understanding of inter-SQ relationships**
  - **Security Synergies and Conflicts with other qualities**

Current SERC SQs Ontology

- **Modified version of IDEF5 ontology framework**
  - Classes, Subclasses, and Individuals
  - Referents, States, Processes, and Relations
- **Top classes cover stakeholder value propositions**
  - Mission Effectiveness, Life Cycle Efficiency, Dependability, Changeability
- **Subclasses identify means for achieving higher-class ends**
  - Means-ends one-to-many for top classes
  - Ideally mutually exclusive and exhaustive, but some exceptions
  - Many-to-many for lower-level subclasses
- **Referents, States, Processes, Relations cover SQ variation**
  - Referents: Stakeholder-SQ value-variation (gas mileage vs. size, safety)
  - States: Internal (miles driven); External (off-road, bad weather)
  - Processes: Internal (cost vs. quality); External (haulage, wild driver)
  - Relations: Impact of other SQs (cost vs. weight vs. safety)

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Stakeholder value-based, means-ends hierarchy

- Mission operators and managers want improved Mission Effectiveness
  - Involves Physical Capability, Cyber Capability, Human Usability, Speed, Accuracy, Impact, Endurability, Maneuverability, Scalability, Versatility, Interoperability
- Mission investors and system owners want Life Cycle Efficiency
  - Involves Cost, Duration, Personnel, Scarce Quantities (capacity, weight, energy, …); Manufacturability, Maintainability
- All want system Dependability: cost-effective defect-freedom, availability, and safety and security for the communities that they serve
  - Involves Reliability, Availablilty, Maintainability, Survivability, Safety, Security, Robustness
- In an increasingly dynamic world, all want system Changeability: to be rapidly and cost-effectively changeable
  - Involves Maintainability (Modifiability, Repairability), Adaptability

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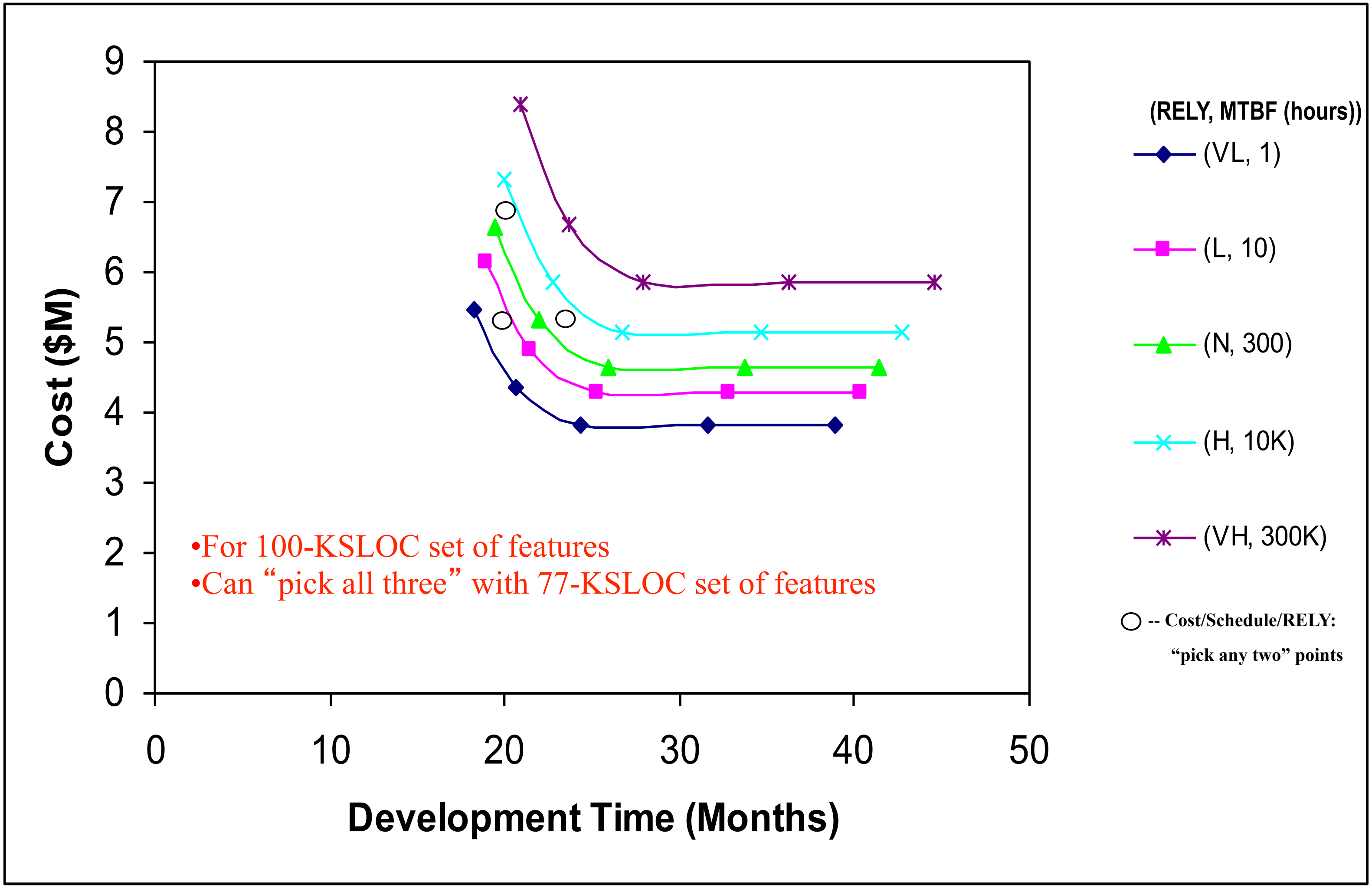
	Flexibility	Dependability	Mission Effectivenss	Resource Utilization	Physical Capability	Cyber Capability	Interoperability
Flexibility		Domain architecting within domain Modularity Self Adaptive Smart monitoring Spare Capacity Use software vs. hardware	Adaptability Many options Service oriented Spare capacity User programmability Versatility	Adaptability Agile methods Automated I/O validation Loose coupling for sustainability Product line architectures Staffing, Empowering	Adaptability Spare capacity	Adaptability Spare capacity	Adaptability Loose coupling Modularity Product line architectures Service-oriented connectors Use software vs. Hardware User programmability
Dependability	Accreditation Agile methods assurance Encryption Many options Multi-domain modifiability Multi-level security Self Adaptive defects User programmability		Accreditation FMEA Multi-level security Survivability Spare capacity	Automated aids Automated I/O validation Domain architecting within domain Product line architectures Staffing, Empowering **Total Ownership Cost** Value prioritizing	Fallbacks Lightweight agility Redundancy Spare capacity Value prioritizing	Fallbacks Redundancy Value prioritizing	Assertion Checking Domain architecting within domain Service oriented
Mission Effectivenss	Autonomy vs. Usability Modularity slowdowns Multi-domain architecture interoperability conflicts Versatility vs. Usability	Anti-tamper Armor vs. Weight Easiest-first development Redundancy Scalability Spare Capacity Usability vs. Security		Automated aids Domain architecting within domain Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain Staffing, Empowering
Resource Utilization	Agile Methods scalability Assertion checking overhead Fixed cost contracts Modularity Multi-domain architecture interoperability conflicts Spare capacity Tight coupling Use software vs. hardware	Accreditation **Acquisition Cost** Certification Easiest-first development Fallbacks Multi-domain architecture interoperability conflicts Redundancy Spare Capacity, tools costs Usability vs. Cost savings	Agile methods scalability Cost of automated aids Many options Multi-domain architecture interoperability conflicts Spare capacity Usability vs. Cost savings Versatility		Automated aids Domain architecting within domain Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain Rework cost savings Staffing, Empowering
Physical Capability	Multi-domain architecture interoperability conflicts Over-optimizing Tight coupling Use software vs. hardware	Lightweight agility Multi-domain architecture interoperability conflicts Over-optimizing	Multi-domain architecture interoperability conflicts Over-optimizing	Cost of automated aids Multi-domain architecture interoperability conflicts Over-optimizing		Automated aids Staffing, Empowering Value prioritizing	Automated aids Domain architecting within domain
Cyber Capability	Agile Methods scalability Multi-domain architecture interoperability conflicts Over-optimizing Tight coupling Use software vs. hardware	Multi-domain architecture interoperability conflicts Over-optimizing	Multi-domain architecture interoperability conflicts Over-optimizing	Cost of automated aids Multi-domain architecture interoperability conflicts Over-optimizing	Over-optimizing Physical architecture or cyber architecture		Automated aids Domain architecting within domain
Interoperability	Multi-domain architecture interoperability conflicts User-programmed interoperability	Encryption interoperability Multi-domain architecture interoperability conflicts	Multi-domain architecture interoperability conflicts	Assertion checking Cost, duration of added connectors	Over-optimizing Tight vs. Loose coupling	Reduced speed of Assertion checking Reduced speed of connectors, standards compliance Tight vs. Loose coupling	

COCOMO II-Based Tradeoff Analysis
Better, Cheaper, Faster: Pick Any Two?



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➡ **Initial elaboration of Maintainability**

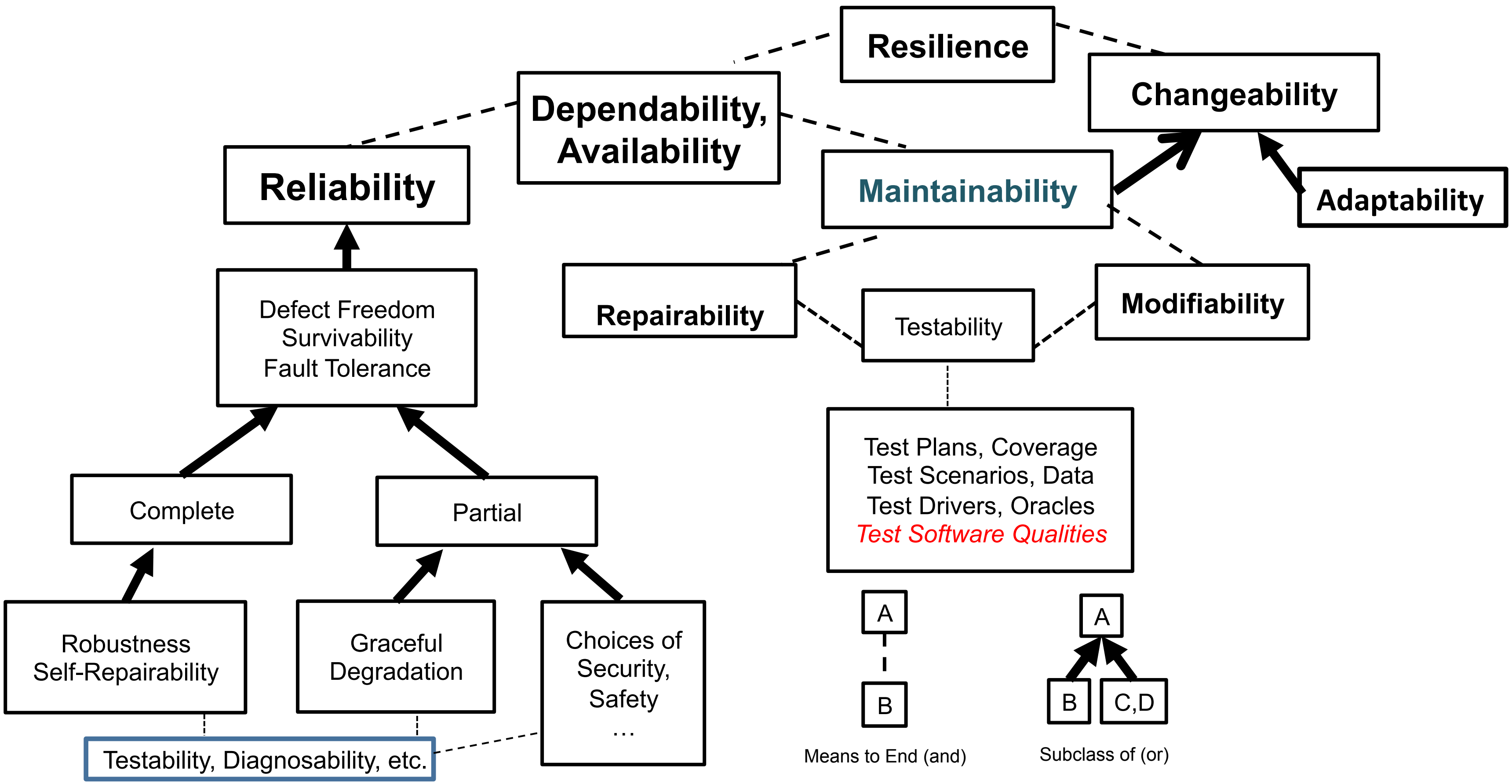
Problem and Opportunity (%O&M costs)

- US Government IT: ~75%; $59 Billion [GAO 2015]
- Hardware [Redman 2008]
  - 12% -- Missiles (average)
  - 60% -- Ships (average)
  - 78% -- Aircraft (F-16)
  - 84% -- Ground vehicles (Bradley)
- Software [Koskinen 2010]
  - 75-90% -- Business, Command-Control
  - 50-80% -- Complex platforms as above
  - 10-30% -- Simple embedded software
- Primary current emphasis minimizes acquisition costs

Maintainability Challenges and Responses

- Maintainability supports Life Cycle Efficiency, Dependability, and Changeability
  - Distinguish between Repairability and Modifiability
  - Elaborate each via means-ends relationships
- Multiple definitions of Changeability
  - Distinguish between Product Quality and Quality in Use (ISO/IEC 25010)
  - Provide mapping between Product Quality and Quality in Use viewpoints
- Changeability can be both external and internal
  - Distinguish between Maintainability and Adaptability
- Many definitions of Resilience
  - Define Resilience as a combination of Dependability and Changeability
- Variability of Dependability and Changeability values
  - Ontology addresses sources of variation
  - Referents (stakeholder values), States, Processes, Relations with other SQs
- Need to help stakeholders choose options, avoid pitfalls
  - Synergies and Conflicts, Opportunity Trees, Maintainability Readiness Levels
  - Quantitative Maintainability Assessment

Dependability, Changeability, and Resilience



Maintainability Opportunity Tree: Modifiability

- Anticipate Modifiability Needs
  - Evolution information
  - Trend analysis
  - Hotspot (change source) analysis
  - Modifier involvement
  - Address Potential Conflicts
- Design/Develop for Modifiability
  - Modularize around hotspots
  - Service-orientation; loose coupling
  - Spare capacity; product line engineering
  - Domain-specific architecture in domain
  - Enable user programmability
  - Address Potential Conflicts
- Improve Modification V&V
  - Prioritize, Schedule Modifications, V&V
  - Modification compatibility analysis
  - Regression test capabilities
  - Address Potential Conflicts

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Repairability Value: Cost of Downtime Survey

- ***Industry Sector Revenue/Hour***
- **Energy $2.8 million**
- **Telecommunications $2.0 million**
- **Manufacturing $1.6 million**
- **Financial Institutions $1.4 million**
- **Information Technology $1.3 million**
- **Insurance $1.2 million**
- **Retail $1.1 million**
- **Pharmaceuticals $1.0 million**
- **Banking $996,000**
- *Source: IT Performance Engineering & Measurement Strategies: Quantifying Performance Loss, Meta Group, October 2000.*

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SIS Maintainability Readiness Levels

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	**OpCon, Contracting: Missions, Scenarios, Resources, Incentives**	**Personnel Capabilities and Participation**	**Enabling Methods, Processes, and Tools (MPTs)**
9	5 years of successful maintenance operations,including outcome-based incentives, adaptation to new technologies, missions, and stakeholders	In addition, creating incentives for continuing effective maintainability. performance on long-duration projects	Evidence of improvements in innovative O&M MPTs based on ongoing O&M experience
8	One year of successful maintenance operations, including outcome-based incentives, refinements of OpCon.	Stimulating and applying People CMM Level 5 maintainability practices in continuous improvement and innovation in such technology areas as smart systems, use of multicore processors, and 3-D printing	Evidence of MPT improvements based on ongoing refinement, and extensions of ongoing evaluation, initial O&M MPTs.
7	System passes Maintainability Readiness Review with evidence of viable OpCon, Contracting, Logistics, Resources, Incentives, personnel capabilities, enabling MPTs	Achieving advanced People CMM Level 4 maintainability capabilities such as empowered work groups, mentoring, quantitative performance management and competency-based assets, particularly across key domains.	Advanced, integrated, tested, and exercised full-LC MBS&SE MPTs and Maintainability-other-SQ tradespace analysis
6	Mostly-elaborated maintainability OpCon. with roles, responsibilities, workflows, logistics management plans with budgets, schedules, resources, staffing, infrastructure and enabling MPT choices, V&V and review procedures.	Achieving basic People CMM levels 2 and 3 maintainability practices such as maintainability work environment, competency and career development, and performance management especially in such key areas such as V&V, identification & reduction of technical debt.	Advanced, integrated, tested full-LC Model-Based Software & Systems (MBS&SE) MPTs and Maintainability-other-SQ tradespace analysis tools identified for use, and being individually used and integrated.
5	Convergence, involvement of main maintainability success-critical stakeholders. Some maintainability use cases defined. Rough maintainability OpCon, other success-critical stakeholders, staffing, resource estimates. Preparation for NDI and outsource selections.	In addition, independent maintainability experts participate in project evidence-based decision reviews, identify potential maintainability conflicts with other SQs	Advanced full-lifecycle (full-LC) O&M MPTs and SW/SE MPTs identified for use. Basic MPTs for tradespace analysis among maintainability & other SQs, including TCO being used.
4	Artifacts focused on missions. Primary maintenance options determined, Early involvement of maintainability success-critical stakeholders in elaborating and evaluating maintenance options.	Critical mass of maintainability SysEs with mission SysE capability, coverage of full M-SysE.skills areas, representation of maintainability success-critical-stakeholder organizations.	Advanced O&M MPT capabilities identified for use: Model-Based SW/SE, TCO analysis support. Basic O&M MPT capabilities for modification, repair and V&V: some initial use.
3	Elaboration of mission OpCon, Arch views, lifecycle cost estimation. Key mission, O&M, success-critical stakeholders (SCSHs) identified, some maintainability options explored.	O&M success-critical stakeholders's provide critical mass of maintainability-capable Sys. engrs. Identification of additional. M-critical success-critical stakeholders.	Basic O&M MPT capabilities identified for use, particularly for OpCon, Arch, and Total cost of ownership (TCO) analysis: some initial use.
2	Mission evolution directions and maintainability implications explored. Some mission use cases defined, some O&M options explored.	Highly maintainability-capable SysEs included in Early SysE team.	Initial exploration of O&M MPT options
1	Focus on mission opportunities, needs. Maintainability not yet considered	Awareness of needs for early expertise for maintainability. concurrent engr'g, O&M integration, Life Cycle cost estimation	Focus on O&M MPT options considered

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SIS Maintainability Readiness Levels 5-7

Software-Intensive Systems Maintainability Readiness Levels			
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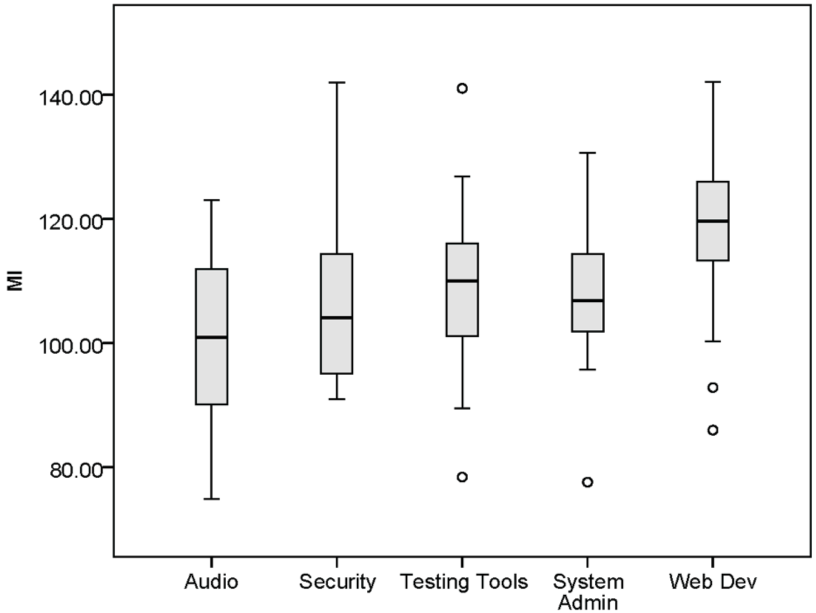
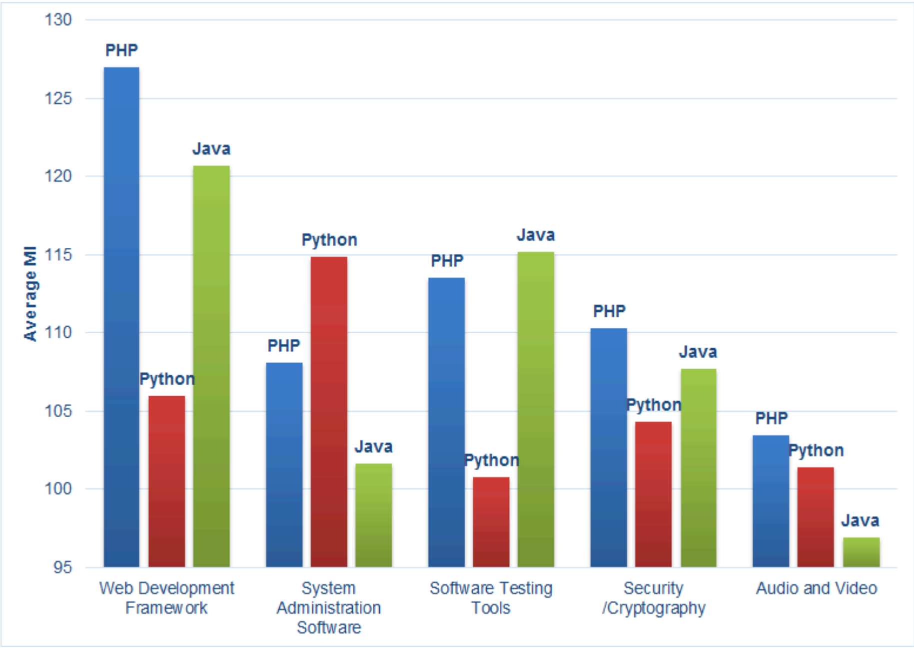
Initial Quantitative Maintainability Assessment:
Evaluate SW Maintainability Index on Open Source Projects

- Evaluate MI across 97 open source projects
  - 3 programming languages: Java, PHP, Python
  - 5 domains: Web development framework, System administration, Test tools, Security/Encryption, Audio-Video
- Test MI invariance across languages, domains
- Evaluate completeness of MI vs. other sources
  - COCOMO II Software Understandability factors
    - Structuredness (cohesion, coupling)
    - Self-descriptiveness (documentation quality)
    - Application clarity (software reflects application content)
  - Other maintainability enablers (architecture, V&V support)
    - Repairability: Diagnosability, Accessibility, Testability, Tool support
    - Search for similar defects; root cause analysis

MI Variation among domains





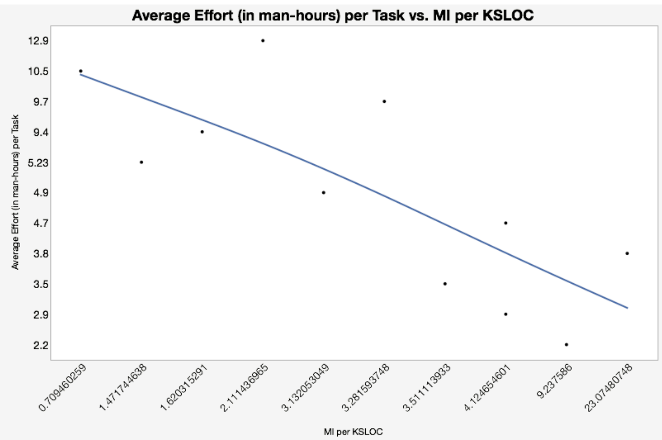
- Web Development Framework has shown the highest medians and the highest maximum value.
- Audio and Video has both the lowest maximum value and the lowest median value

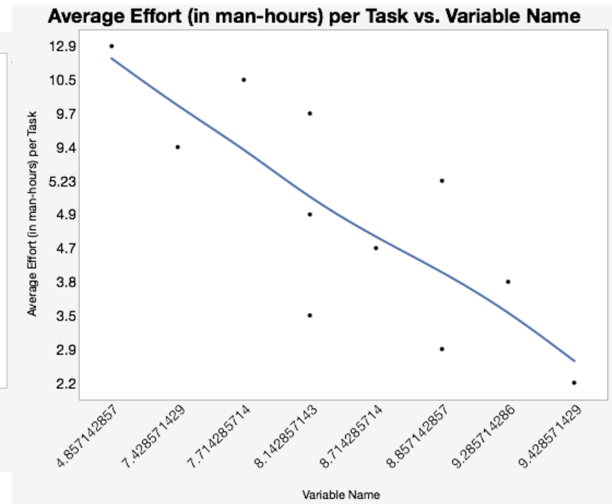
- **PHP** may be a good option for projects that desires higher maintainability within Web Development Framework, Security/Cryptography and Audio and Video domain,
- **Python** may be a good option for System Administrative Software
- **Java** may be a good option for Software Testing Tools.

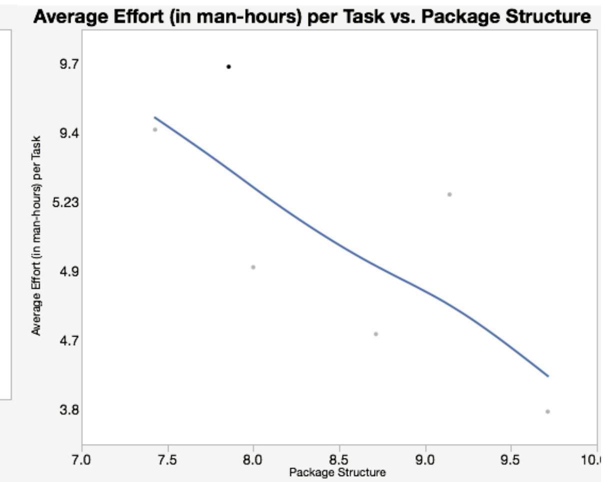
Evaluation of COCOMO II factors

- Evaluate COCOMO II Software Understandability factors across 11 Open Source projects
  - 6 Java projects and 5 PHP projects from Sourceforge; project sizes (in SLOC) range from 5K ~ 15K
  - Factors:
    - Code structure (e.g. coupling, cohesion, variable/class/package names, comment quality, etc.)
    - Documentation quality
    - Community quality (e.g. forum/mailing list activity, response time from core team, etc.)
  - Tasks:
    - Fixing existing bugs
    - Implementing new feature requests
  - Graduate students record effort in man-hours to complete assigned tasks and answer a pre-designed questionnaire based on COCOMO II Software Understandability factors in ratings of 1 to 10.

Initial Results







- More efforts, less MI density
- Better variable names, less effort
- Clearer package structure, less effort (only for Java projects)
- Forum/mailing list response time and Documentation quality seem to have less impact on how much effort it takes to complete maintenance tasks

Conclusions

- System qualities (SQs) are success-critical
  - Major source of project overruns, failures
  - Significant source of stakeholder value conflicts
  - Poorly defined, understood
  - Underemphasized in project management
- SQs ontology clarifies nature of system qualities
  - Using value-based, means-ends hierarchy
  - Identifies variation types: referents, states, processes, relations
  - Relations enable SQ synergies and conflicts identification
- Initial exploratory maintainability data analyses suggest empirical studies of SQs an attractive field of study

Backup charts

Nature of an ontology; choice of IDEF5 structure

- An ontology for a collection of elements is a definition of what it means to be a member of the collection

- For "system qualities," this means that an SQ identifies an aspect of "how well" the system performs
  - The ontology also identifies the sources of variability in the value of "how well" the system performs
    - Functional requirements specify "what;" NFRs specify "how well"

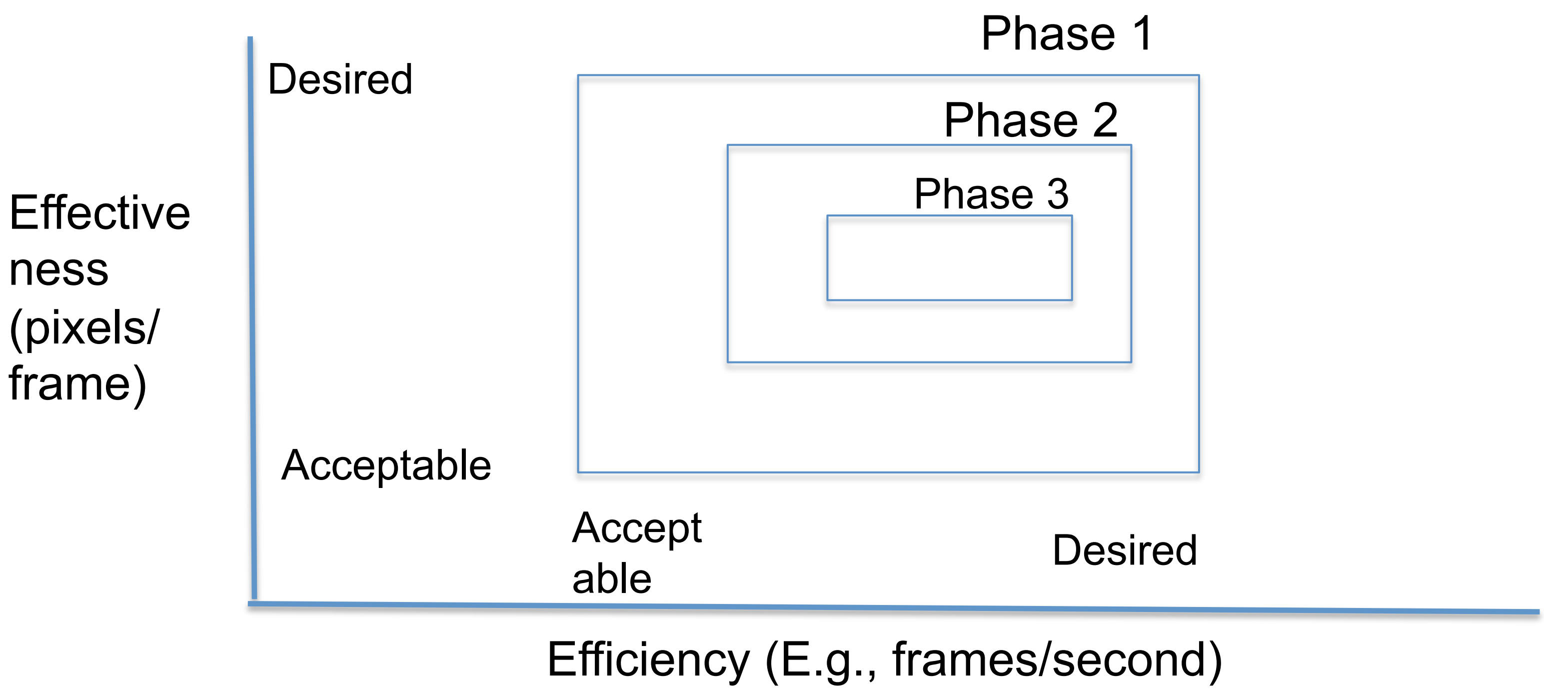
- After investigating several ontology frameworks, the IDEF5 framework appeared to best address the nature and sources of variability of system SQs
  - Good fit so far

Example: Reliability Revisited

- Reliability is the probability that the system will deliver stakeholder-satisfactory results for a given time period (generally an hour), given specified ranges of:
  - Stakeholders: desired and acceptable ranges of liveness, accuracy, response time, speed, capabilities, etc.
  - System internal and external states: integration test, acceptance test, field test, etc.; weather, terrain, DEFCON, takeoff/flight/landing, etc.
  - System internal and external processes: security thresholds, types of payload/cargo; workload volume, diversity
  - Effects of other SQs: synergies, conflicts

Set-Based SQs Definition Convergence

RPV Surveillance Example

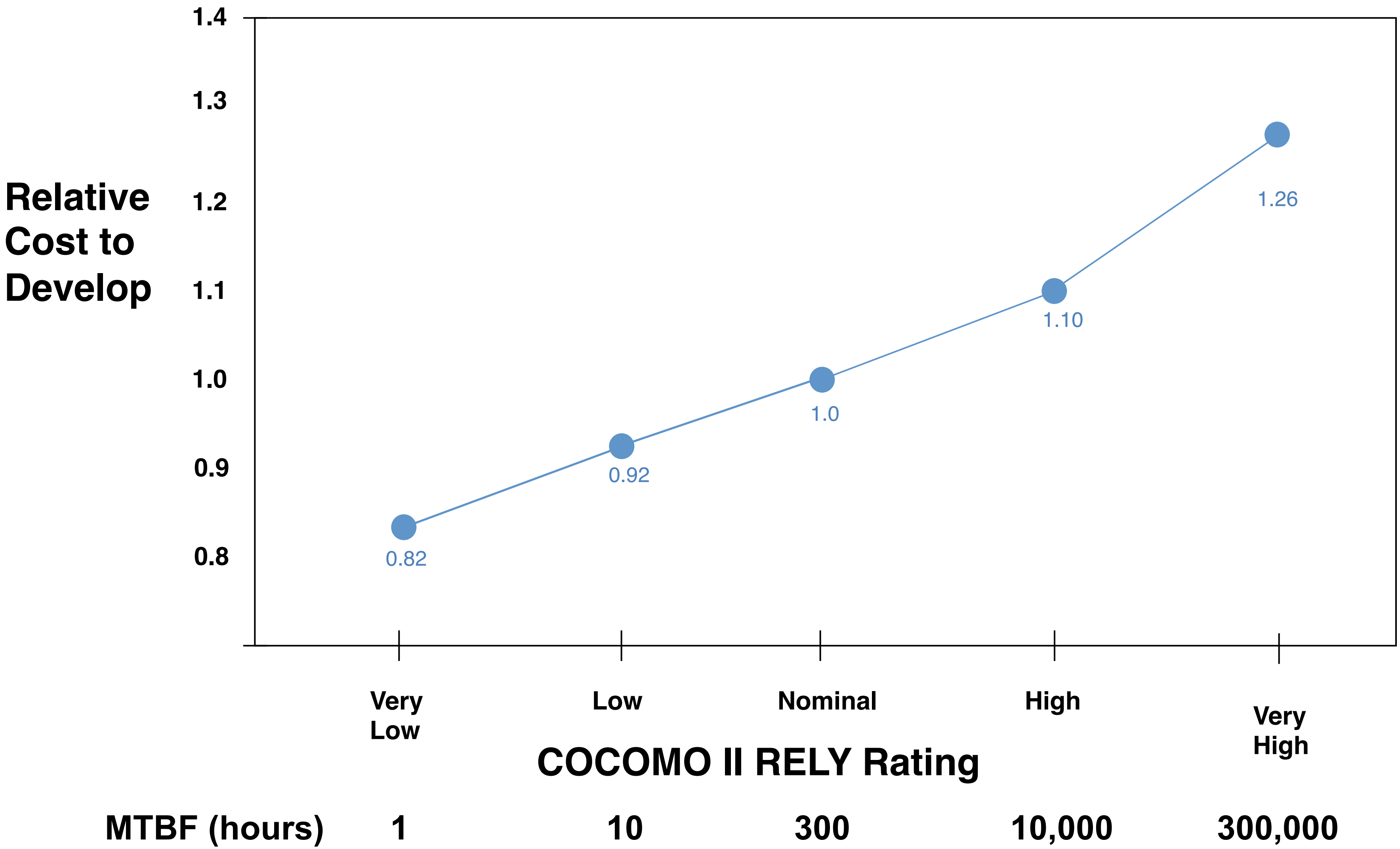


Phase 1. Rough ConOps, Rqts, Solution Understanding
Phase 2. Improved ConOps, Rqts, Solution Understanding
Phase 3. Good ConOps, Rqts, Solution Understanding

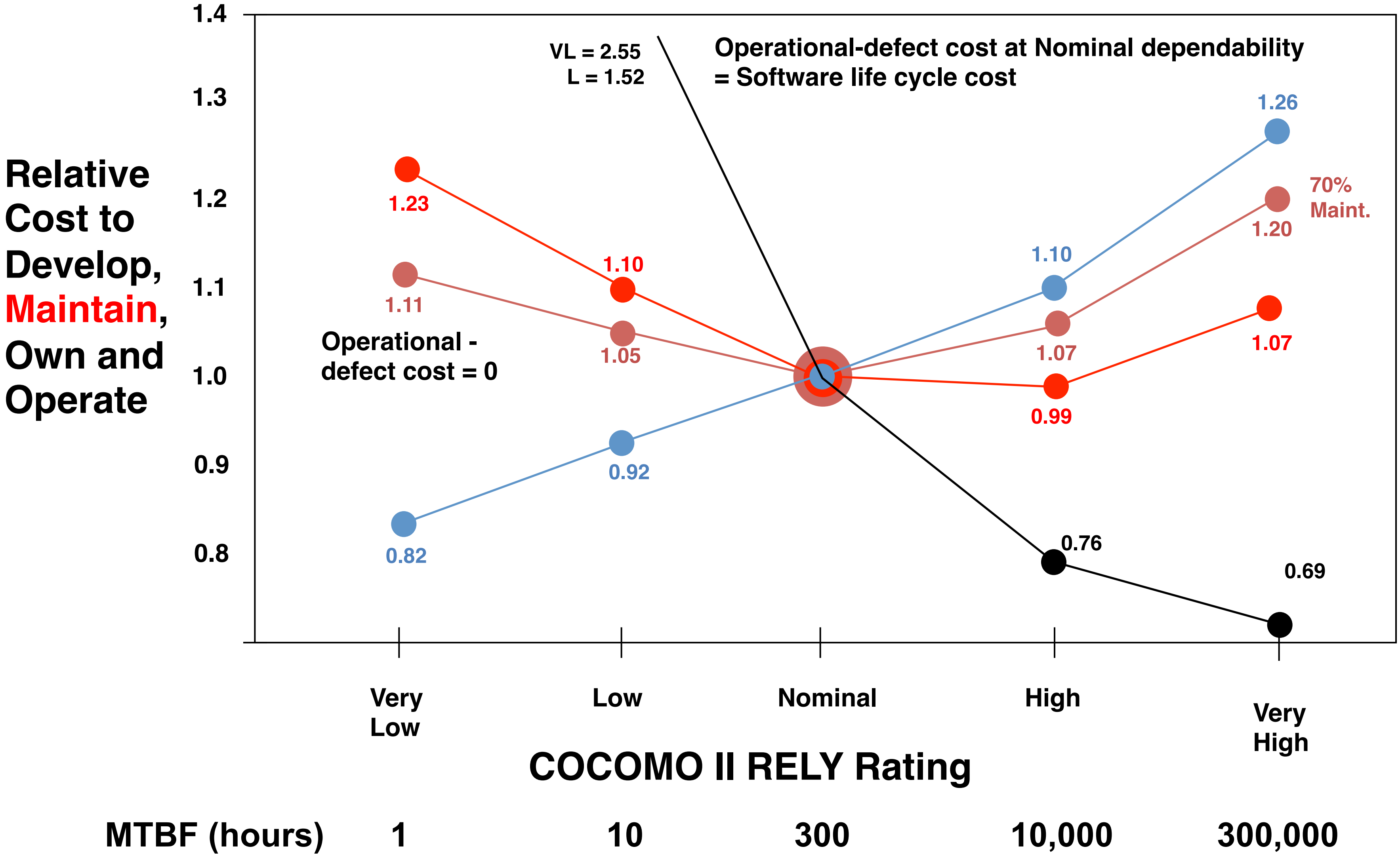
7x7 Synergies and Conflicts Matrix

- Mission Effectiveness expanded to 4 elements
  - Physical Capability, Cyber Capability, Interoperability, Other Mission Effectiveness (including Usability as Human Capability)
- Synergies and Conflicts among the 7 resulting elements identified in 7x7 matrix
  - Synergies above main diagonal, Conflicts below
- Work-in-progress tool will enable clicking on an entry and obtaining details about the synergy or conflict
  - Ideally quantitative; some examples next
- Still need synergies and conflicts within elements
  - Example 3x3 Dependability subset provided

Software Development Cost vs. Reliability



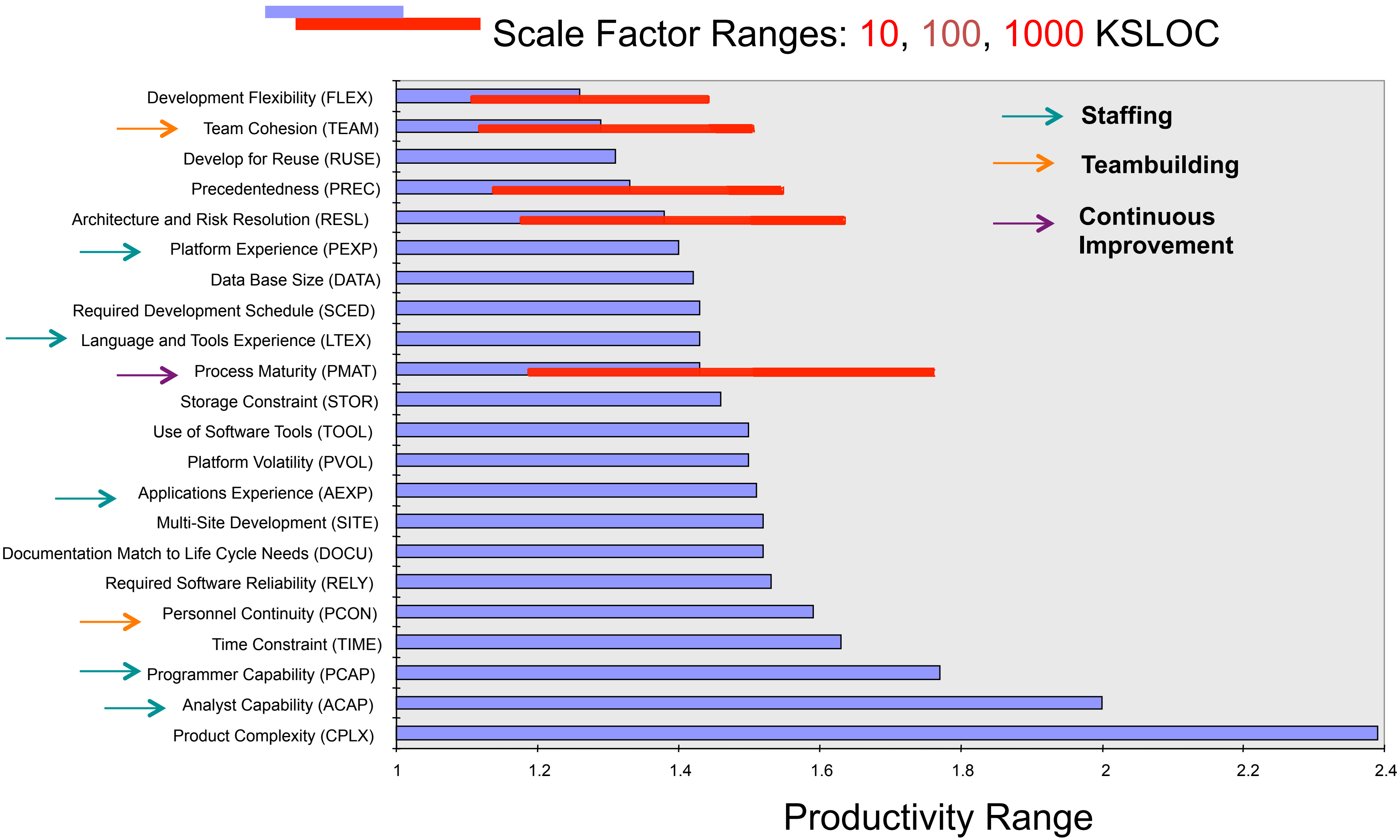
Software Ownership Cost vs. Reliability



Affordability and Tradespace Framework

- **Cost Improvements and Tradeoffs**
  - **Get the Best from People**
    - Staffing, Incentivizing, Teambuilding
    - Facilities, Support Services
    - Kaizen (continuous improvement)
  - **Make Tasks More Efficient**
    - Tools and Automation
    - Work and Oversight Streamlining
    - Collaboration Technology
  - **Eliminate Tasks**
    - Lean and Agile Methods
    - Task Automation
    - Model-Based Product Generation
  - **Eliminate Scrap, Rework**
    - Early Risk and Defect Elimination
    - Evidence-Based Decision Gates
    - Modularity Around Sources of Change
    - Incremental, Evolutionary Development
    - Value-Based, Agile Process Maturity
    - Risk-Based Prototyping
  - **Simplify Products (KISS)**
    - Value-Based Capability Prioritization
    - Satisficing vs. Optimizing Performance
  - **Reuse Components**
    - Domain Engineering and Architecture
    - Composable Components,Services, COTS
    - Legacy System Repurposing
  - **Reduce Operations, Support Costs**
    - Automate Operations Elements
    - Design for Maintainability, Evolvability
    - Streamline Supply Chain
    - Anticipate, Prepare for Change
  - **Value- and Architecture-Based Tradeoffs and Balancing**

Costing Insights: COCOMO II Productivity Ranges



Tradespace and Affordability Framework

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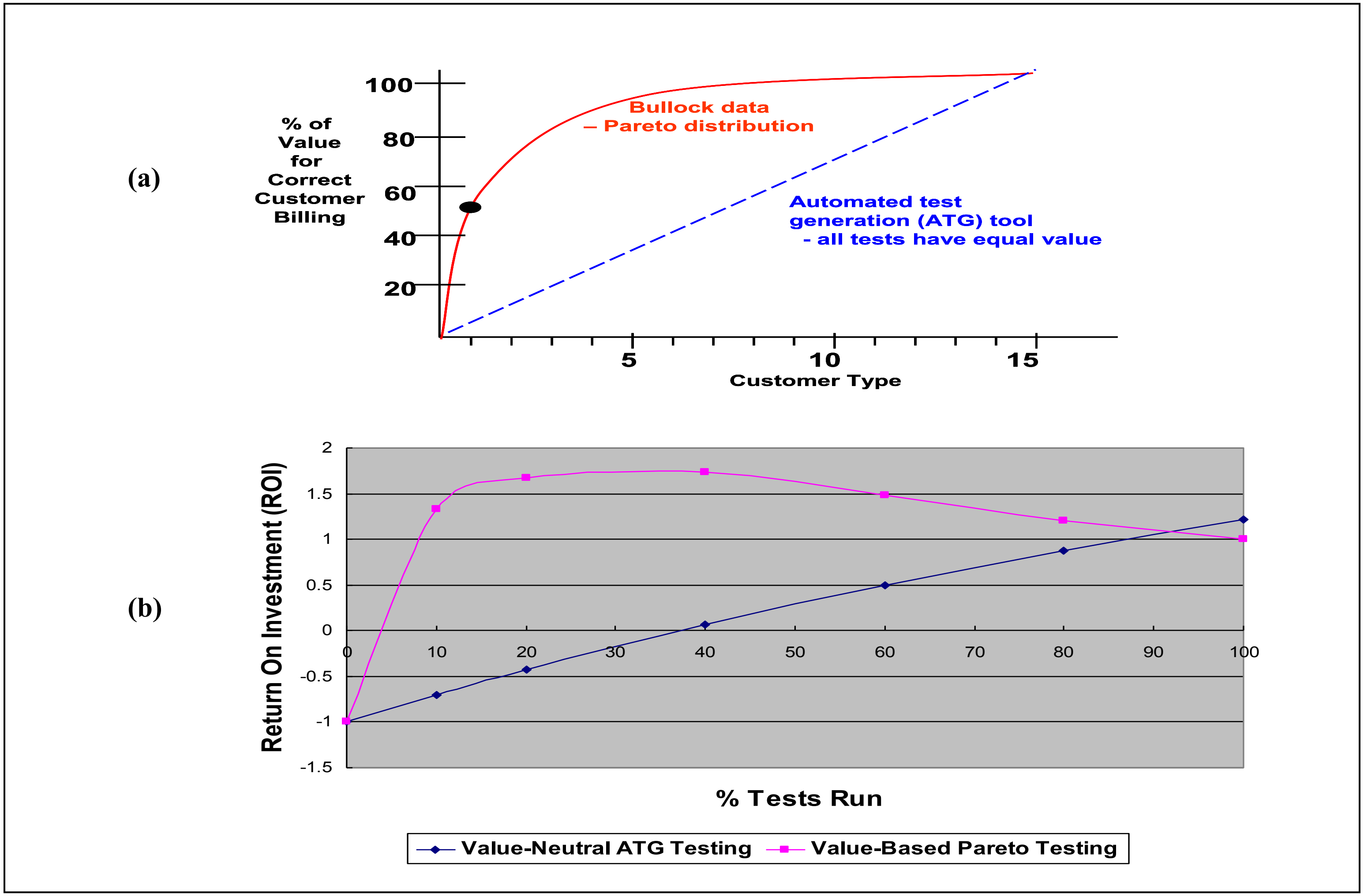
  - Design for Maintainability, Evolvability
  - Streamline Supply Chain
  - Anticipate, Prepare for Change
- **Value- and Architecture-Based Tradeoffs and Balancing**

Value-Based Testing: Empirical Data and ROI

— LiGuo Huang, ISESE 2005



Maintainability Opportunity Tree: Repairability

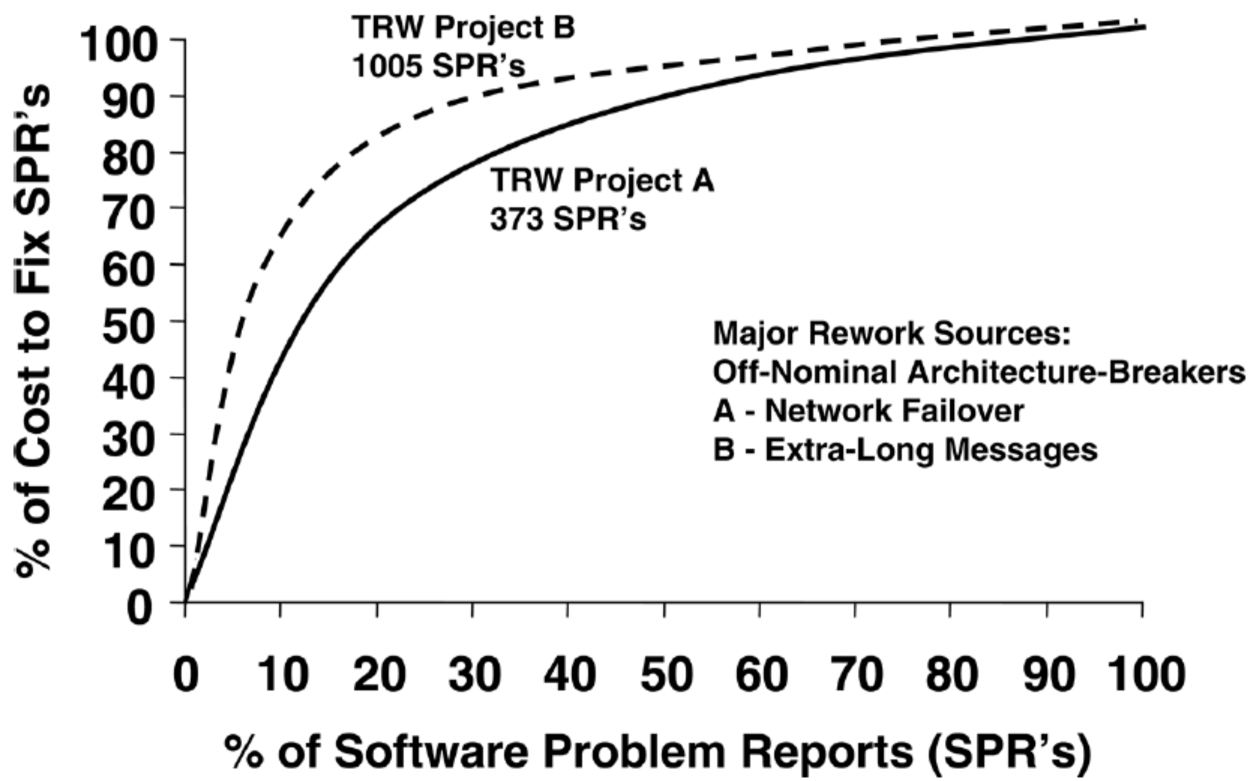
- Anticipate Repairability Needs
  - Repair facility requirements
  - Repair-type trend analysis
  - Repair skills analysis
  - Repair personnel involvement
  - Address Potential Conflicts
- Design/Develop for Repairability
  - Repair facility design, development
  - Replacement parts trend analysis
  - Replacement parts logistics development
  - Replacement accessibility deaign
  - Address Potential Conflicts
- Improve Repair Diagnosis
  - Smart system anomaly, trend analysis
  - Informative error messages
  - Multimedia diagnosis guides
  - Fault localization
  - Switchable spare components
  - Address Potential Conflicts
- Improve Repair, V&V Processes
  - Prioritize, Schedule Repairs, V&V
  - Repair compatibility analysis
  - Regression test capabilities
  - Address Potential Conflicts

Elaborating Modifiability Benefits - I

- Evolution Requirements
  - Keep, prioritize below-the-line IOC requirements
  - Use to determine modularization around sources of change, reduce ripple effects of changes
- Trend Analysis
  - Identify, prioritize responses to sources of change
    - Marketplace, competition, usage trends, mobility trends
  - Use to refine, evolve architecture
- Agile Methods, User Programmability
  - Enable rapid response to rapid change
- Hotspot Analysis
  - Gather data on most common sources of change
  - Use to modularize architecture, reduce ripple effects of changes

Use of Empirical Data in TOC Models: Pareto 80-20 Cost-to-fix Distribution

Contracts: Fixed cost and nominal-case requirements; 90 days to PDR



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Rework Sources Analysis: Projects A and B

- Change processing over 1 person-month = 152 person-hours

Category	Project A	Project B
Extra long messages		3404+626+443+328+244= 5045
Network failover	2050+470+360+160= 3040	
Hardware-software interface	620+200= 820	1629+513+289+232+166= 2832
Encryption algorithms		1247+368= 1615
Subcontractor interface	1100+760+200= 2060	
GUI revision	980+730+420+240+180 =2550	
Data compression algorithm		910
External applications interface	770+330+200+160= 1460	
COTS upgrades	540+380+190= 1110	741+302+221+197= 1461
Database restructure	690+480+310+210+170= 1860	
Routing algorithms		494+198= 692
Diagnostic aids	360	477+318+184= 979
TOTAL:	**13620**	**13531**

C4ISR Project C: Architecting for Change

USAF/ESC-TRW CCPDS-R Project*

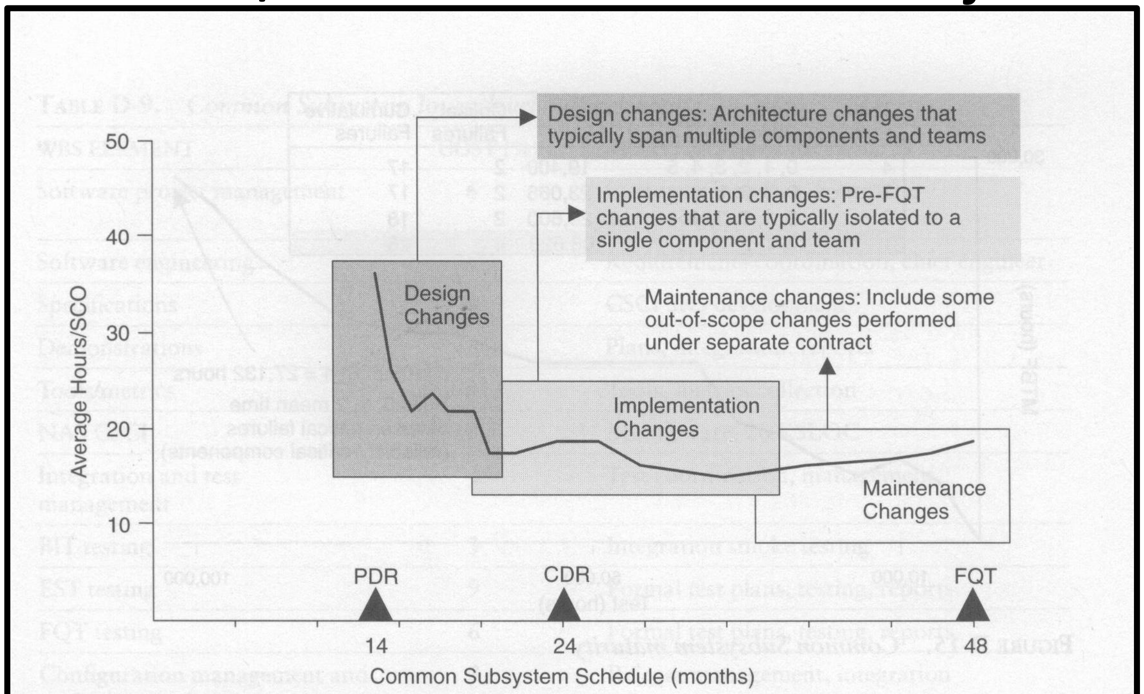


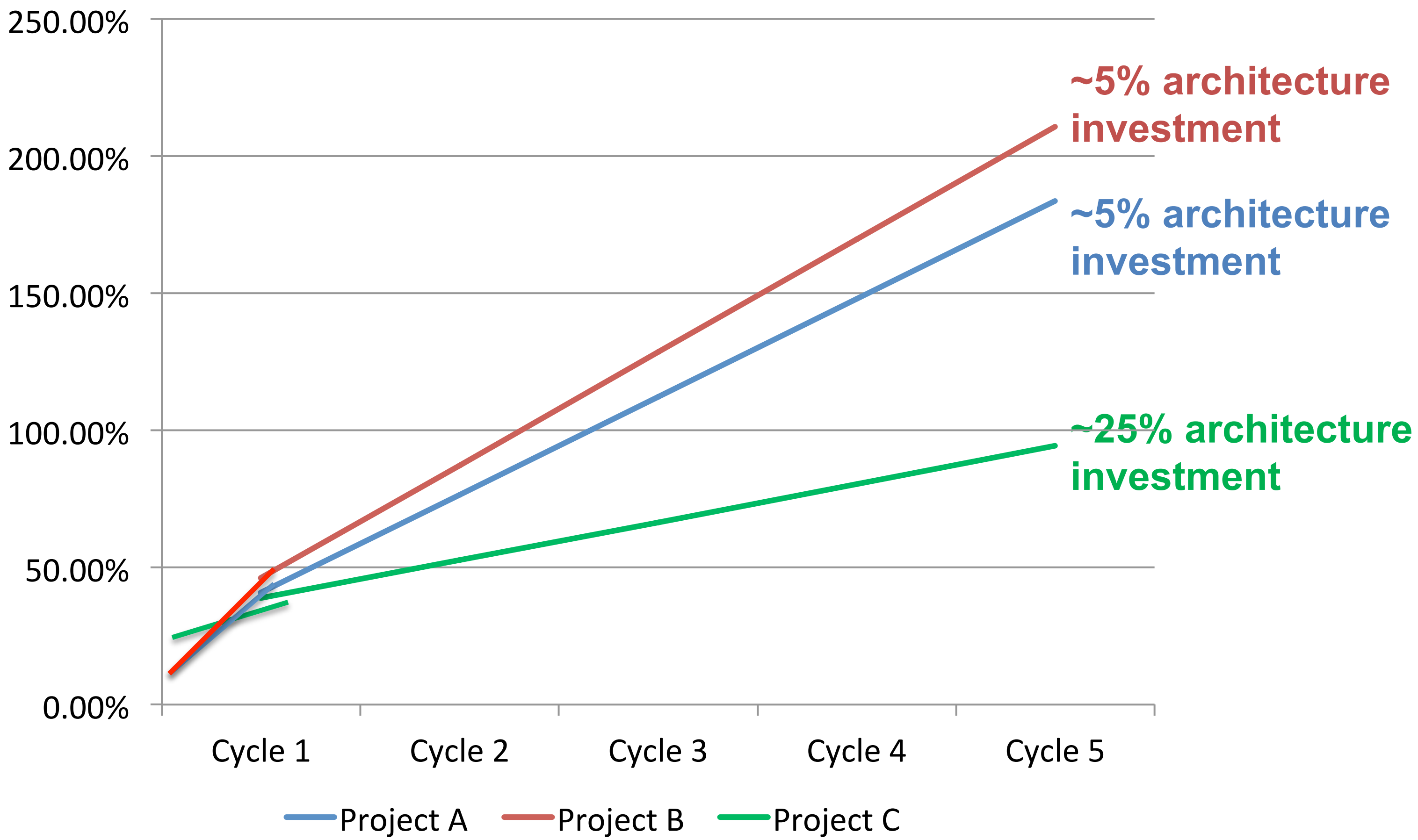
FIGURE D-14. *Common Subsystem adaptability*

When investments made in architecture, average time for change order becomes relatively stable over time…

* Walker Royce, *Software Project Management: A Unified Framework*. Addison-Wesley, 1998.

Relative* Total Ownership Cost (TOC)

For single system life cycle (TOC-SS)

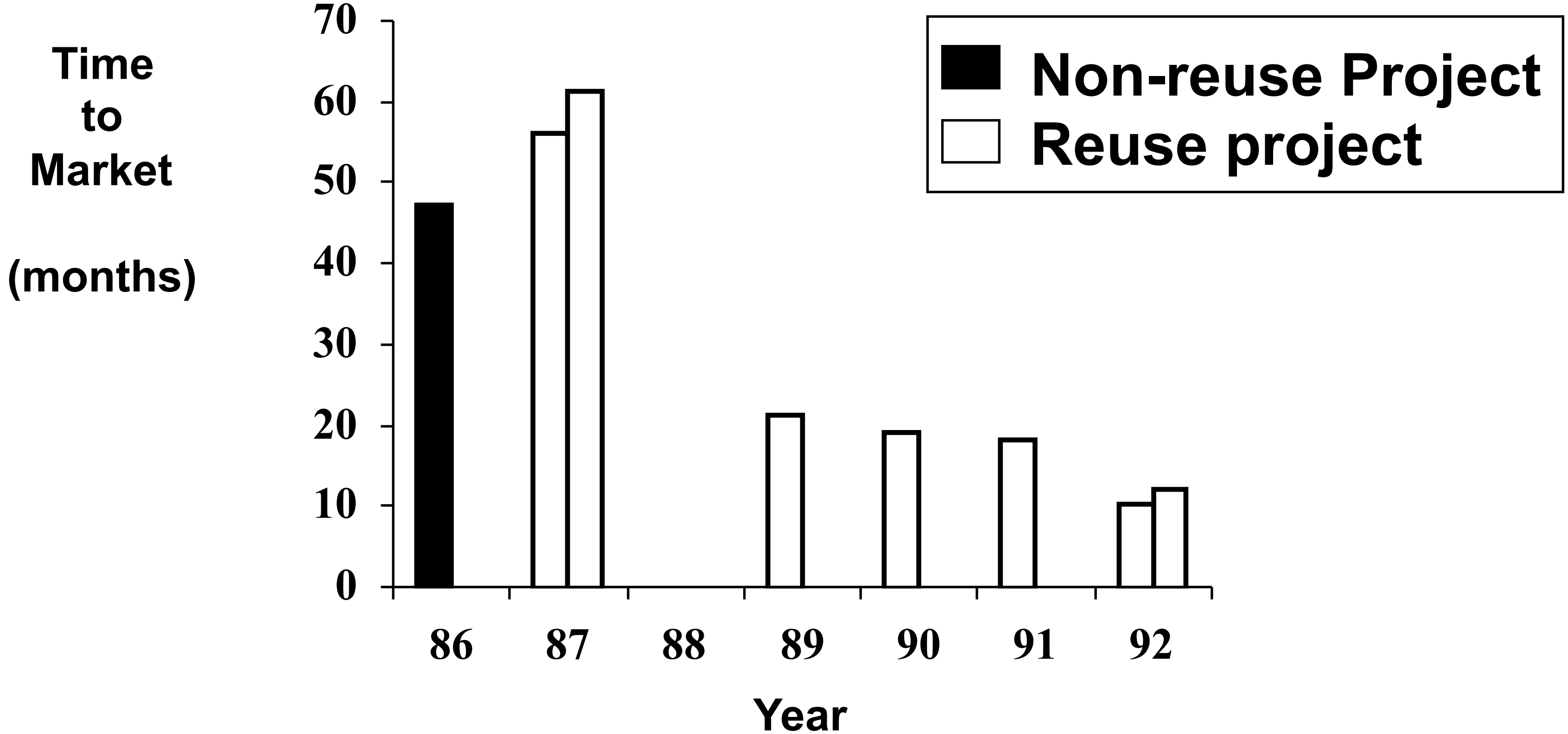


* Cumulative architecting and rework effort relative to initial development effort

Elaborating Modifiability Benefits – II
and Repairability Benefits

- Service-Oriented Architecture improves Interoperability
- Product-Line Engineering improves Total Ownership Cost (TOC)
  - Identify, modularize around product line Commonalities
  - Develop domain architecture, interfaces to Variabilities
  - Fewer components to modify, repair
- Improved Repairability improves Availability, TOC
  - Availability = MTBF / (MTBF + MTTR)
- Stakeholder Value-Based V&V improves Cost, Mission Effectiveness
  - Prioritizing inspection, test activities
  - Balancing level of inspection, test activities vs. rapid fielding

Reuse at HP's Queensferry Telecommunication Division



Widely Used Software Maintainability Index
Oman and Hagemeister, 1991

$$MIwoc_{(sourcefile)} = 171 - 5.2 * \ln HV - 0.23 * CC - 16.2 * \ln LLOC$$

$$MIwc_{(sourcefile)} = 50 * sin\sqrt{2.46 * CM}$$

$$MI_{(sourcefile)} = MIwoc_{(sourcefile)} + MIwc_{(sourcefile)}$$

$$MI = \frac{\sum MI_{(sourcefile)}}{Number\ of\ Source\ files}$$

Halstead Volume (HV)
Count of logical lines (LLOC)
Cyclomatic complexity (CC)
Percent of lines of comments (CM)

Open Source Software Data Analysis

Celia Chen, Lin Shi, Kam Srisopha

97 OSS projects, three languages, five domains, 1,899,700 LLOC in total.

Language	Average LLOC	Metrics Collection Tools
PHP	18643	Phpmetrics
Java	33871	CodePro, LocMetrics
Python	6644	Radon

Category	[1,1000]	[1000,5000]	[5001,10000]	>10,000
Web Development Framework	0	2	4	18
System Administration Software	6	4	3	5
Software Testing Tools	2	9	5	3
Security	7	6	4	1
Audio and Video	2	4	3	9

Domain	Number of Projects			Average LLOC
	Php	Java	Python	
Web Development Framework	8	8	8	45536
System Administration Software	6	6	6	12070
Software Testing Tools	6	6	7	12948
Security/Cryptography	6	6	6	4730
Audio and Video	6	6	6	14358

Results – Null Hypothesis 1
MI does not vary across PHP, Java and Python OSS projects

One-way ANOVA Results for language analysis

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
MIwoc	Between Groups	844.599	2	422.299	2.544	0.084
	Within Groups	15602.788	94	165.987		
	Total	16447.386	96			
MIwc	Between Groups	589.095	2	294.548	3.069	0.051
	Within Groups	9022.420	94	95.983		
	Total	9611.516	96			
MI	Between Groups	1044.871	2	522.435	2.614	0.079
	Within Groups	18783.525	94	199.825		
	Total	19828.395	96			

- **P-Value <0.1, but >0.05**
  - **Strongly suggestive rejection of null hypothesis for OSS projects**

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Results – Null Hypothesis 2
MI of PHP, Java and Python OSS projects does not vary by domain

One-way ANOVA for domains

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
MIwoc	Between Groups	1541.295	4	385.324	2.378	0.057
	Within Groups	14906.092	92	162.023		
	Total	16447.386	96			
MIwc	Between Groups	741.498	4	185.374	1.923	0.113
	Within Groups	8870.018	92	96.413		
	Total	9611.516	96			
MI	Between Groups	3221.732	4	805.433	4.462	0.002
	Within Groups	16606.663	92	180.507		
	Total	19828.395	96			

- Null hypothesis rejected with P-Value well below 0.05 (Definitive for OSS)

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SIS Maintainability Readiness Levels 1-3

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	OpCon, Contracting: Missions, Scenarios, Resources, Incentives	Personnel Capabilities and Participation	Enabling Methods, Processes, and Tools (MPTs)
3	Elaboration of mission OpCon, Arch views, lifecycle cost estimation. Key mission, O&M, success-critical stakeholders (SCSHs) identified, some maintainability options explored.	O&M success-critical stakeholders's provide critical mass of maintainability-capable Sys. engrs. Identification of additional. M-critical success-critical stakeholders.	Basic O&M MPT capabilities identified for use, particularly for OpCon, Arch, and Total cost of ownership (TCO) analysis: some initial use.
2	Mission evolution directions and maintainability implications explored. Some mission use cases defined, some O&M options explored.	Highly maintainability-capable SysEs included in Early SysE team.	Initial exploration of O&M MPT options
1	Focus on mission opportunities, needs. Maintainability not yet considered	Awareness of needs for early expertise for maintainability. concurrent engr'g, O&M integration, Life Cycle cost estimation	Focus on O&M MPT options considered

SIS Maintainability Readiness Levels 3-5

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	OpCon, Contracting: Missions, Scenarios, Resources, Incentives	Personnel Capabilities and Participation	Enabling Methods, Processes, and Tools (MPTs)
5	Convergence, involvement of main maintainability success-critical stakeholders. Some maintainability use cases defined. Rough maintainability OpCon, other success-critical stakeholders, staffing, resource estimates. Preparation for NDI and outsource selections.	In addition, independent maintainability experts participate in project evidence-based decision reviews, identify potential maintainability conflicts with other SQs	Advanced full-lifecycle (full-LC) O&M MPTs and SW/SE MPTs identified for use. Basic MPTs for tradespace analysis among maintainability & other SQs, including TCO being used.
4	Artifacts focused on missions. Primary maintenance options determined, Early involvement of maintainability success-critical stakeholders in elaborating and evaluating maintenance options.	Critical mass of maintainability SysEs with mission SysE capability, coverage of full M-SysE.skills areas, representation of maintainability success-critical-stakeholder organizations.	Advanced O&M MPT capabilities identified for use: Model-Based SW/SE, TCO analysis support. Basic O&M MPT capabilities for modification, repair and V&V: some initial use.
3	Elaboration of mission OpCon, Arch views, lifecycle cost estimation. Key mission, O&M, success-critical stakeholders (SCSHs) identified, some maintainability options explored.	O&M success-critical stakeholders's provide critical mass of maintainability-capable Sys. engrs. Identification of additional. M-critical success-critical stakeholders.	Basic O&M MPT capabilities identified for use, particularly for OpCon, Arch, and Total cost of ownership (TCO) analysis: some initial use.

SIS Maintainability Readiness Levels 5-7

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	OpCon, Contracting: Missions, Scenarios, Resources, Incentives	Personnel Capabilities and Participation	Enabling Methods, Processes, and Tools (MPTs)
7	System passes Maintainability Readiness Review with evidence of viable OpCon, Contracting, Logistics, Resources, Incentives, personnel capabilities, enabling MPTs	Achieving advanced People CMM Level 4 maintainability capabilities such as empowered work groups, mentoring, quantitative performance management and competency-based assets, particularly across key domains.	Advanced, integrated, tested, and exercised full-LC MBS&SE MPTs and Maintainability-other-SQ tradespace analysis
6	Mostly-elaborated maintainability OpCon. with roles, responsibilities, workflows, logistics management plans with budgets, schedules, resources, staffing, infrastructure and enabling MPT choices, V&V and review procedures.	Achieving basic People CMM levels 2 and 3 maintainability practices such as maintainability work environment, competency and career development, and performance management especially in such key areas such as V&V, identification & reduction of technical debt.	Advanced, integrated, tested full-LC Model-Based Software & Systems (MBS&SE) MPTs and Maintainability-other-SQ tradespace analysis tools identified for use, and being individually used and integrated.
5	Convergence, involvement of main maintainability success-critical stakeholders. Some maintainability use cases defined. Rough maintainability OpCon, other success-critical stakeholders, staffing, resource estimates. Preparation for NDI and outsource selections.	In addition, independent maintainability experts participate in project evidence-based decision reviews, identify potential maintainability conflicts with other SQs	Advanced full-lifecycle (full-LC) O&M MPTs and SW/SE MPTs identified for use. Basic MPTs for tradespace analysis among maintainability & other SQs, including TCO being used.

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SIS Maintainability Readiness Levels 7-9

Software-Intensive Systems Maintainability Readiness Levels			
SMR Level	OpCon, Contracting: Missions, Scenarios, Resources, Incentives	Personnel Capabilities and Participation	Enabling Methods, Processes, and Tools (MPTs)
9	5 years of successful maintenance operations, including outcome-based incentives, adaptation to new technologies, missions, and stakeholders	In addition, creating incentives for continuing effective maintainability. performance on long-duration projects	Evidence of improvements in innovative O&M MPTs based on ongoing O&M experience
8	One year of successful maintenance operations, including outcome-based incentives, refinements of OpCon.	Stimulating and applying People CMM Level 5 maintainability practices in continuous improvement and innovation in such technology areas as smart systems, use of multicore processors, and 3-D printing	Evidence of MPT improvements based on ongoing refinement, and extensions of ongoing evaluation, initial O&M MPTs.
7	System passes Maintainability Readiness Review with evidence of viable OpCon, Contracting, Logistics, Resources, Incentives, personnel capabilities, enabling MPTs	Achieving advanced People CMM Level 4 maintainability capabilities such as empowered work groups, mentoring, quantitative performance management and competency-based assets, particularly across key domains.	Advanced, integrated, tested, and exercised full-LC MBS&SE MPTs and Maintainability-other-SQ tradespace analysis

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SMRL Usage vs. Complexity, Criticality, Continuity

SMRL Level Vs. DoD Milestone	Simple, Non-Critical, Organic	Simple, Non-Critical, Transitioned	Intermediate	Highly Complex, Critical
MDD	1	1	2-3	3
MS A	2	3	4-5	5
MS B	3	4	6	6
IOC	5	6	7	7