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Ilities Tradespace and Affordability Analysis

Barry Boehm, USC

GSAW/INCOSE-LA/SPIN talk
Feb 26, 2014

Outline

- Context: DoD-Stevens-USC SERC Ilities Tradespace and Affordability Analysis Program (iTAP)
- Ilities Tradespace and Affordability Analysis
- Affordability and Cost Analysis
- Cost-Schedule Tradespace Analysis

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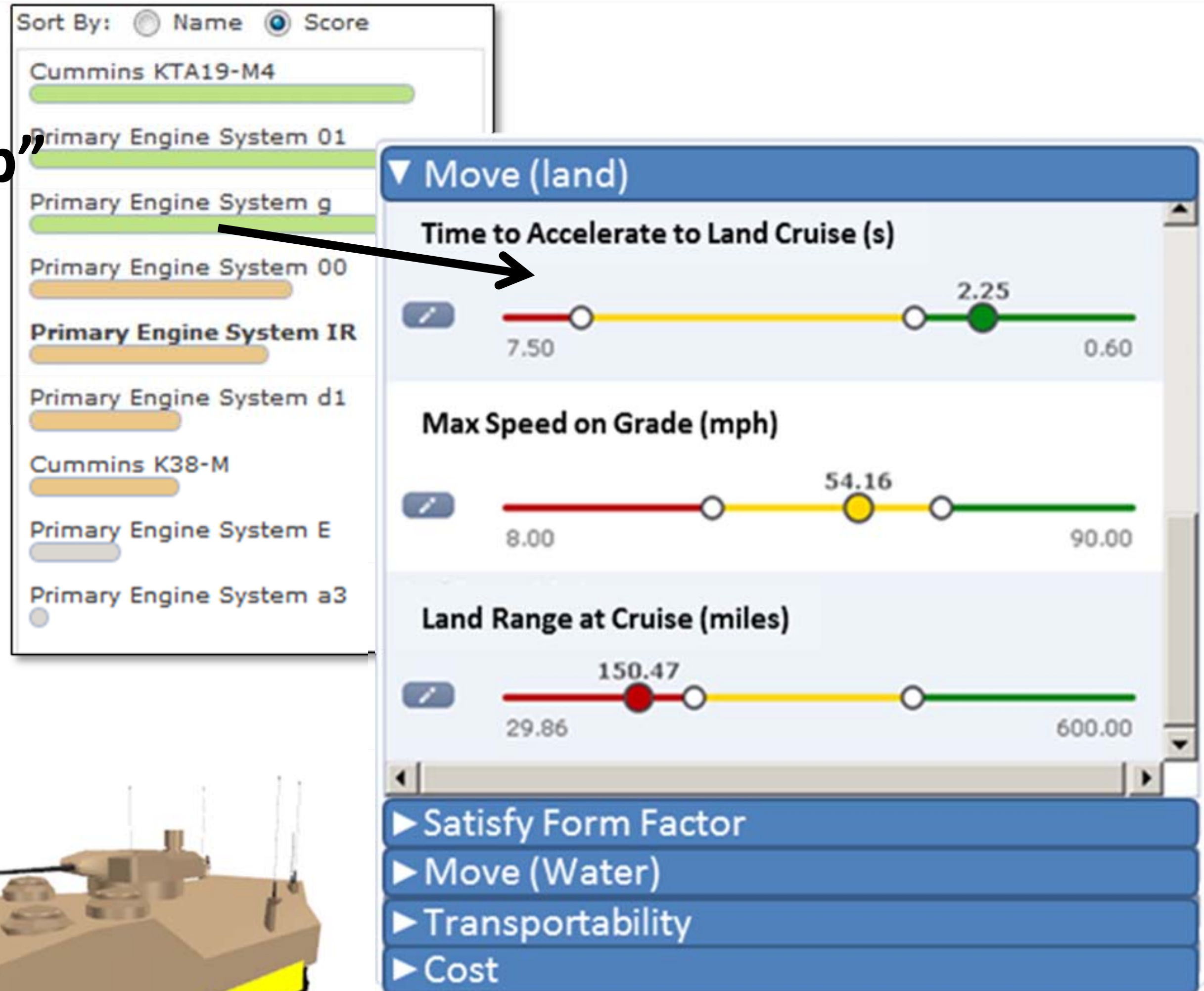
Context: SERC iTAP Initiative Elements

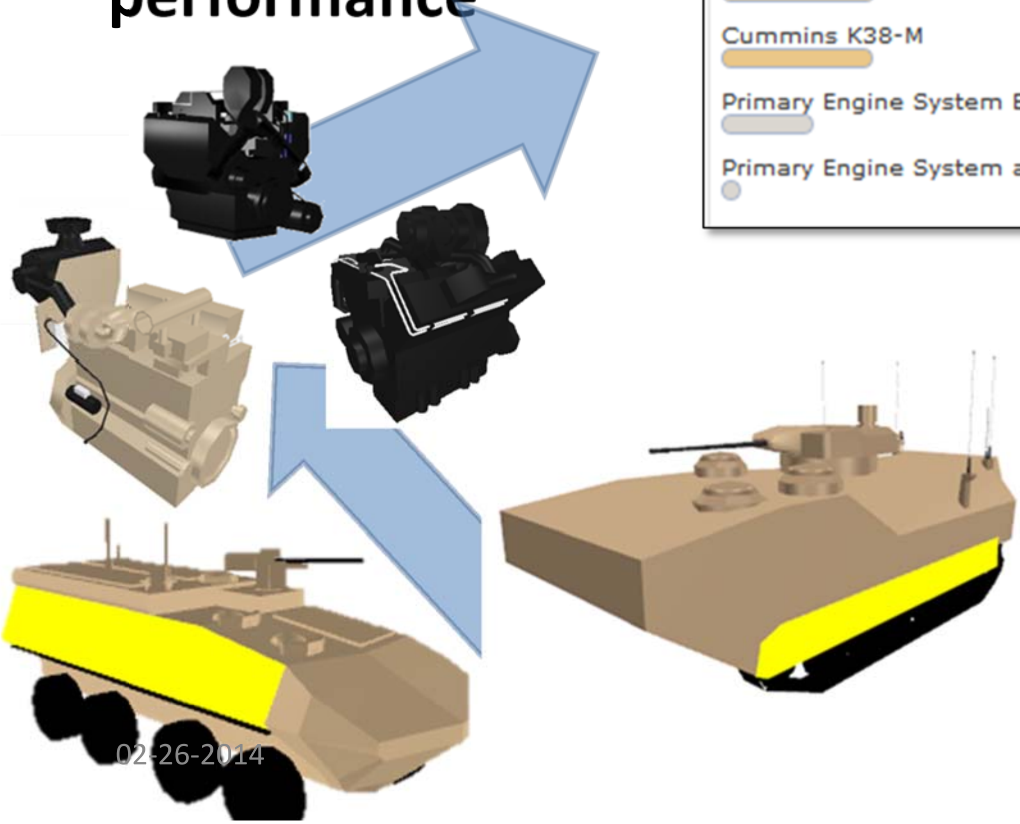
- Tradespace and affordability analysis foundations
  - More precise ility definitions and relationships
  - Stakeholder value-based, means-ends relationships
  - Ility strategy effects, synergies, conflicts
  - U. Virginia, MIT, USC
- Next-generation system cost-schedule estimation models
  - Initially for full-coverage space systems (COSATMO)
  - Extendable to other domains
  - USC, AFIT, GaTech, NPS
- Applied iTAP methods, processes, and tools (MPTs)
  - For concurrent cyber-physical-human systems
  - Experimental MPT piloting, evolution, improvement
  - Wayne State, AFIT, GaTech, NPS, Penn State, USC

GaTech – FACT Tradespace Tool

Being used by Marine Corps

- Configure vehicles from the “bottom up”
- Quickly assess impacts on performance

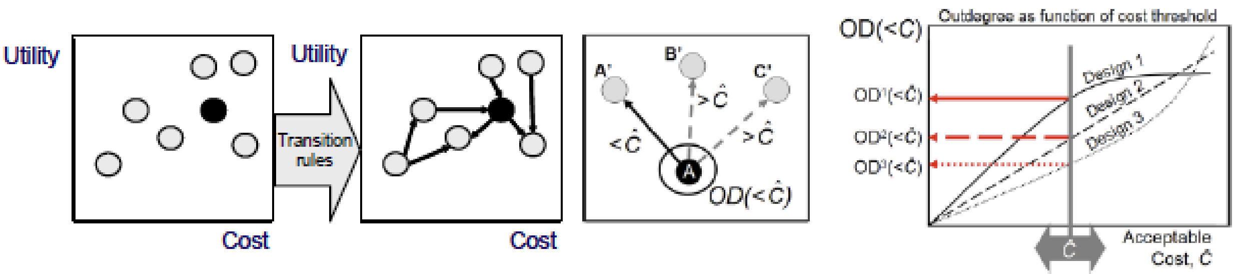




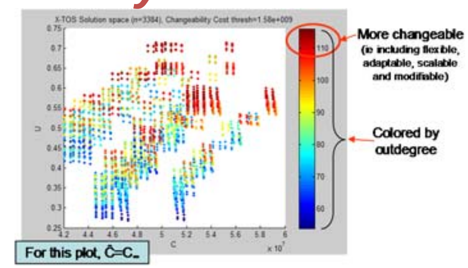
MIT: ilities in Tradespace Exploration

Based on SEAri research

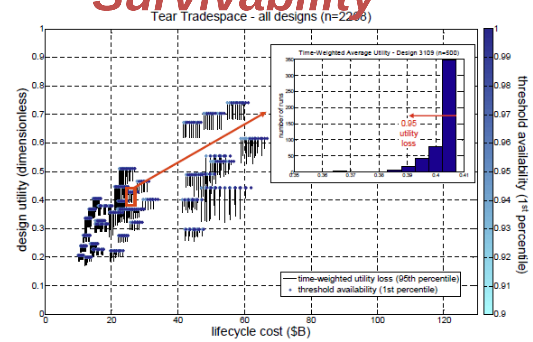
Enabling Construct: Tradespace Networks



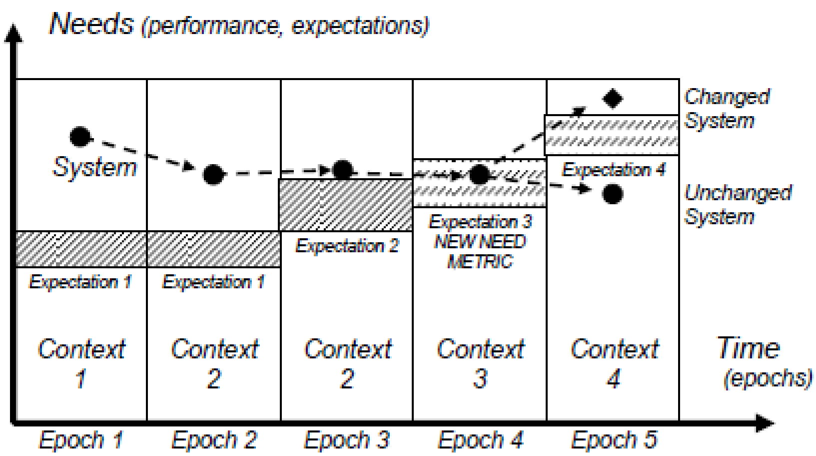
Changeability



Survivability

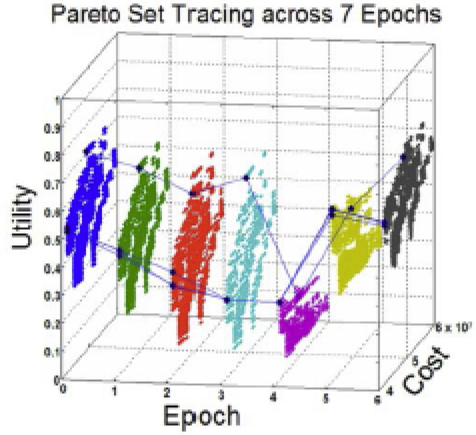


Enabling Construct: Epochs and Eras



Value Robustness

Pareto Set Tracing across 7 Epochs



Set of Metrics

Value Aspect	Acronym	Stands For	Definition
Robustness via "no change"	NPT	Normalized Pareto Trace	% epochs for which design is Pareto efficient in utility/cost
Robustness via "no change"	fNPT	Fuzzy Normalized Pareto Trace	Above, with margin from Pareto front allowed
Robustness via "change"	eNPT, efNPT	Effective (Fuzzy) Normalized Pareto Trace	Above, considering the design's end state after transitioning
"Value" gap	FPN	Fuzzy Pareto Number	% margin needed to include design in the fuzzy Pareto front
"Value" of a change	FPS	Fuzzy Pareto Shift	Difference in FPN before and after transition
"Value" of a change	ARI	Available Rank Increase	# of designs able to be passed in utility via best possible change
Degree of changeability	OD	Outdegree	# outgoing transition arcs from a design
Degree of changeability	FOD	Filtered Outdegree	Above, considering only arcs below a chosen cost threshold
Survivability	TWAUL	Time-weighted Average Utility Loss	Measure of central tendency of value losses over time for a design, as a result of experienced disturbances
Survivability	AT	Threshold Availability	% of lifetime for which design delivers utility above minimum acceptable levels before, during, and after a disturbance

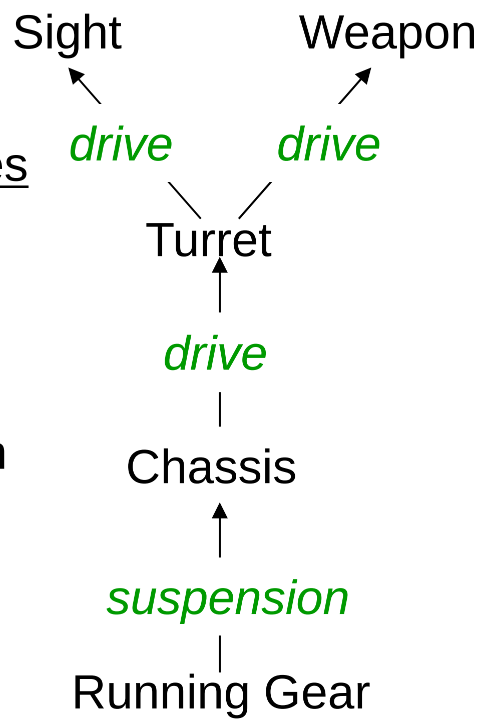
WSU: Versatility Factors and Physical Organization

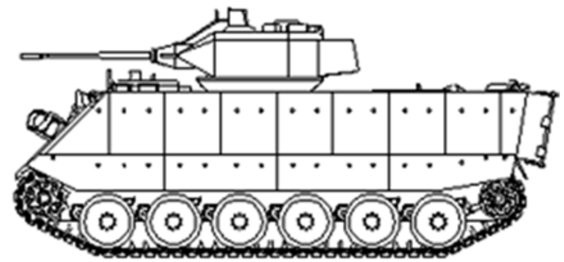
Components that Can be in Different Positions or Orientations

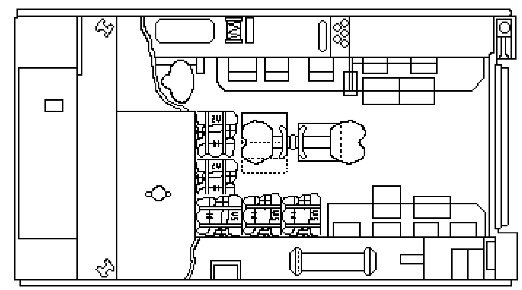
Isolated or Separated Compartments

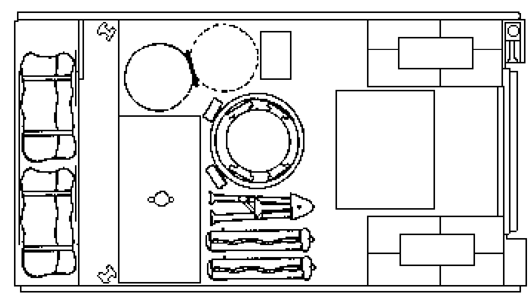
<u>Mass & Structure Properties</u>

- Mass
- Angular moments
- Imbalances*
- Load bearing wall strength
- Deck surface area
- Interior volumes**
- Interior surface areas**









*Angular moments of the CG about axes of rotation

** By crew station and compartment

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Outline

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- ➡ Ilities Tradespace and Affordability Analysis
- Affordability and Cost Analysis
- Cost-Schedule Tradespace Analysis

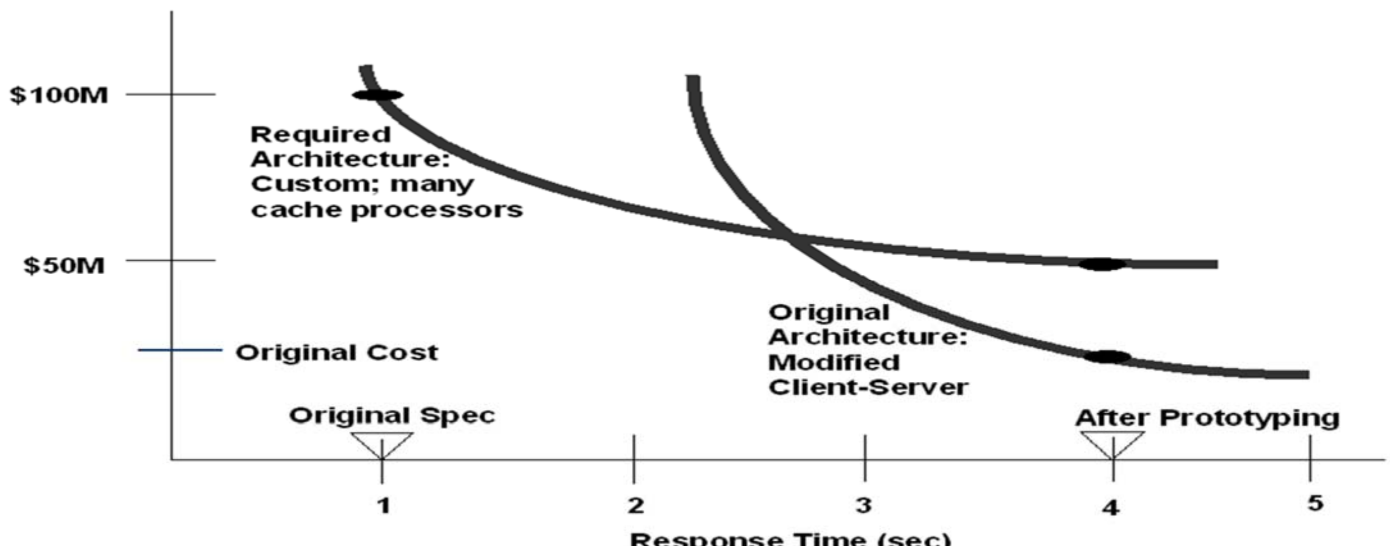
Ilities Tradespace and Affordability Analysis

- Critical nature of the ilities
  - Major source of project overruns, failures
  - Significant source of stakeholder value conflicts
  - Poorly defined, understood
  - Underemphasized in project management
- Challenges for cyber-physical-human systems
- SERC Foundations efforts
  - Stakeholder value-based, means-ends hierarchy
  - Formal analysis of ility definitions and relations
  - Architecture strategy synergies and conflicts

Importance of ility Tradeoffs

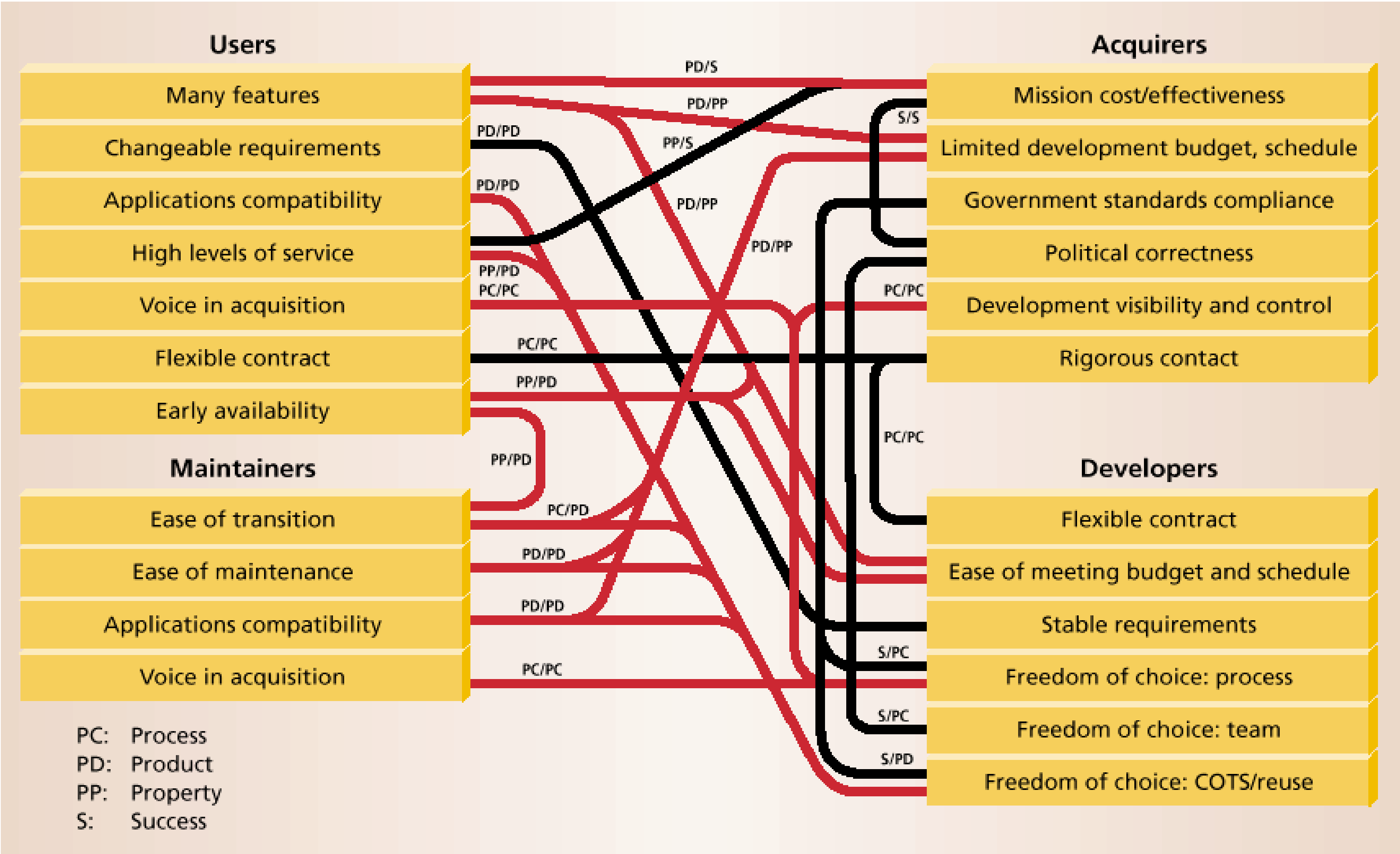
Major source of DoD system overruns

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



Role-Based Ilities Value Diversity

Bank of America Master Net



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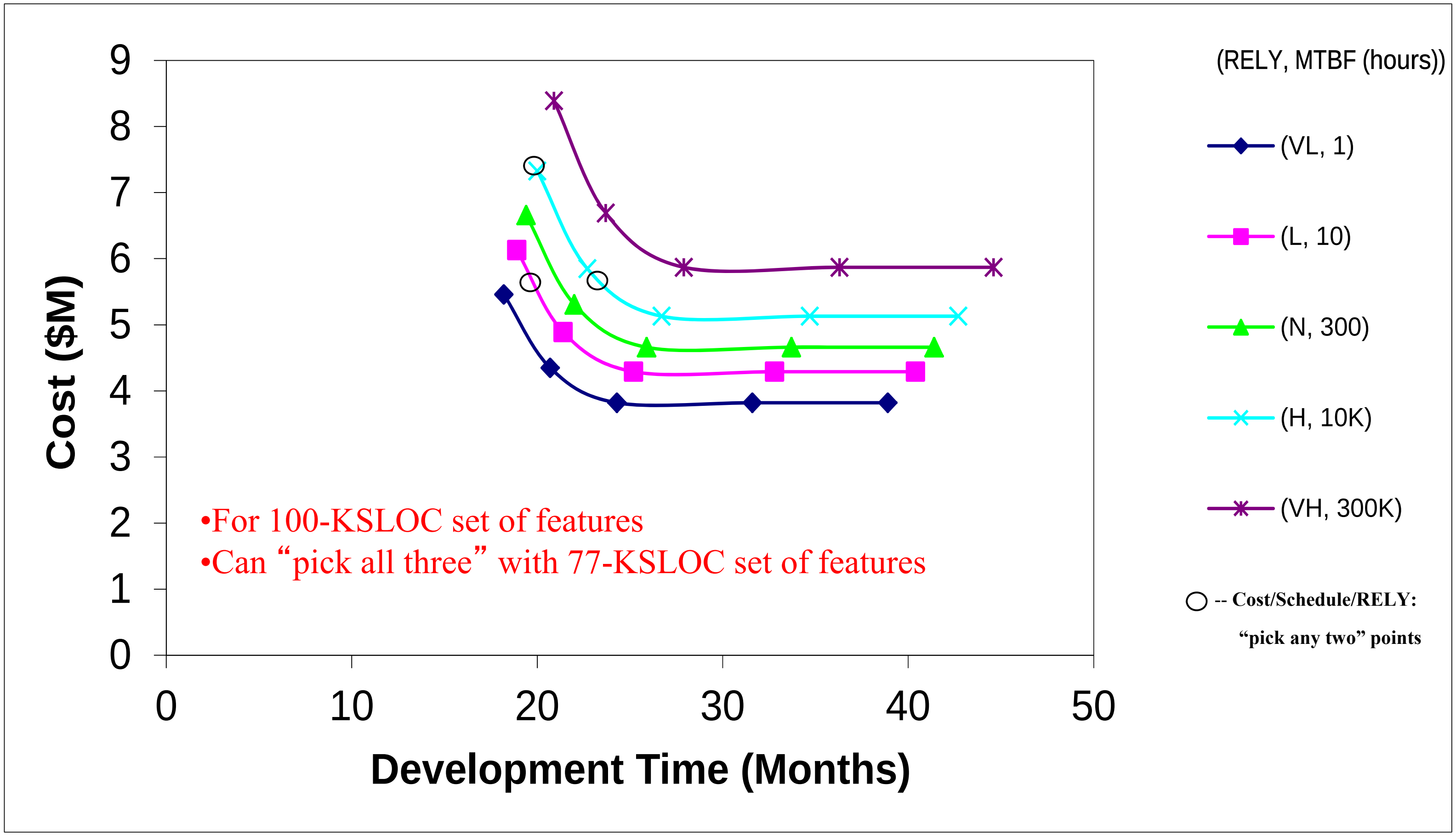
Example of Current Practice

- "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 on other –ilities?
  - Cost, schedule, performance, maintainability?

USC: COCOMO II-Based Tradeoff Analysis

Better, Cheaper, Faster: Pick Any Two?



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Importance of Cyber-Physical Systems

Major gap in tradespace analysis capabilities

- **Current ERS, DARPA tradespace research focused on physical system tradeoffs**
  - **Range, payload, size, weight, lethality, power and fuel consumption, communications bandwidth, etc.**
  - **Some focus on physical modularity, composability**

- **Current cyber tradespace research focused on software, computing, human factors tradeoffs**
  - **security, safety, interoperability, usability, flexibility, adaptability, dependability, response time, throughput, etc.**

- **Gaps in capabilities for co-design of hardware, software, and human factors; integration of tradespace analyses**

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Prioritized JCIDS ilities

User View by Combatant Commands: Top priority first

- Intelligence, Surveillance, and Reconnaissance
  - Comprehensive Persistent Survivable Integrated Timely Credible Adaptable Innovative
- Command and Control (note emphasis on Usability aspects)
  - Interoperability Understanding Timeliness Accessibility Simplicity Completeness Agility Accuracy Relevance Robustness Operational Trust
- Logistics: Supply
  - Responsiveness Sustainability Flexibility Survivability Attainability Economy Simplicity
- Logistics: Maintenance
  - Sustainability Responsiveness Attainability Flexibility Economy Survivability Simplicity
- Net-Centric: Information Transport
  - Accessible Capacity Accurate Timely Throughput Expeditionary Latency

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SERC Value-Based ilities Hierarchy

Based on ISO/IEC 9126, 25030; JCIDS; previous SERC research

- **Individual ilities**
  - **Mission Effectiveness**: Speed, Physical Capability, Cyber Capability, Usability, Accuracy, Impact, Endurability, Maneuverability, Scalability, Versatility
  - **Resource Utilization:** Cost, Duration, Personnel, Scarce Quantities (capacity, weight, energy, …); Manufacturability, Sustainability
  - **Protection:** Security, Safety
  - **Robustness:** Reliability, Availablilty, Maintainability, Survivability
  - **Flexibility:** Modifiability, Tailorability, Adaptability
  - **Composability:** Interoperability, Openness, Service-Orientation

- **Composite ilities**
  - **Comprehensiveness/Suitability:** all of the above
  - **Dependability:** Mission Effectiveness, Protection, Robustness
  - **Resilience:** Protection, Robustness, Flexibility
  - **Affordability:** Mission Effectiveness, Resource Utilization

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Means-Ends Framework: Affordability

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

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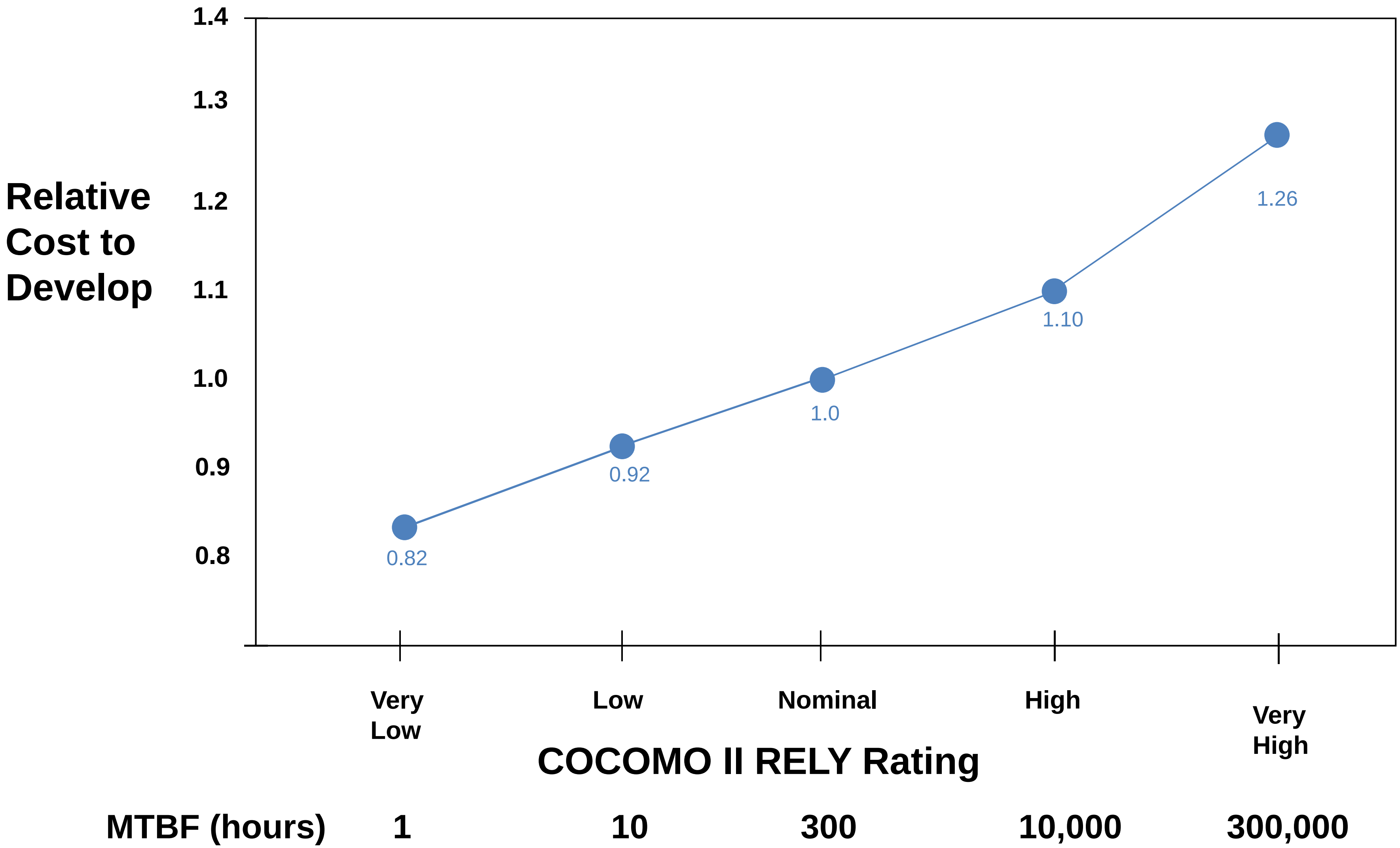
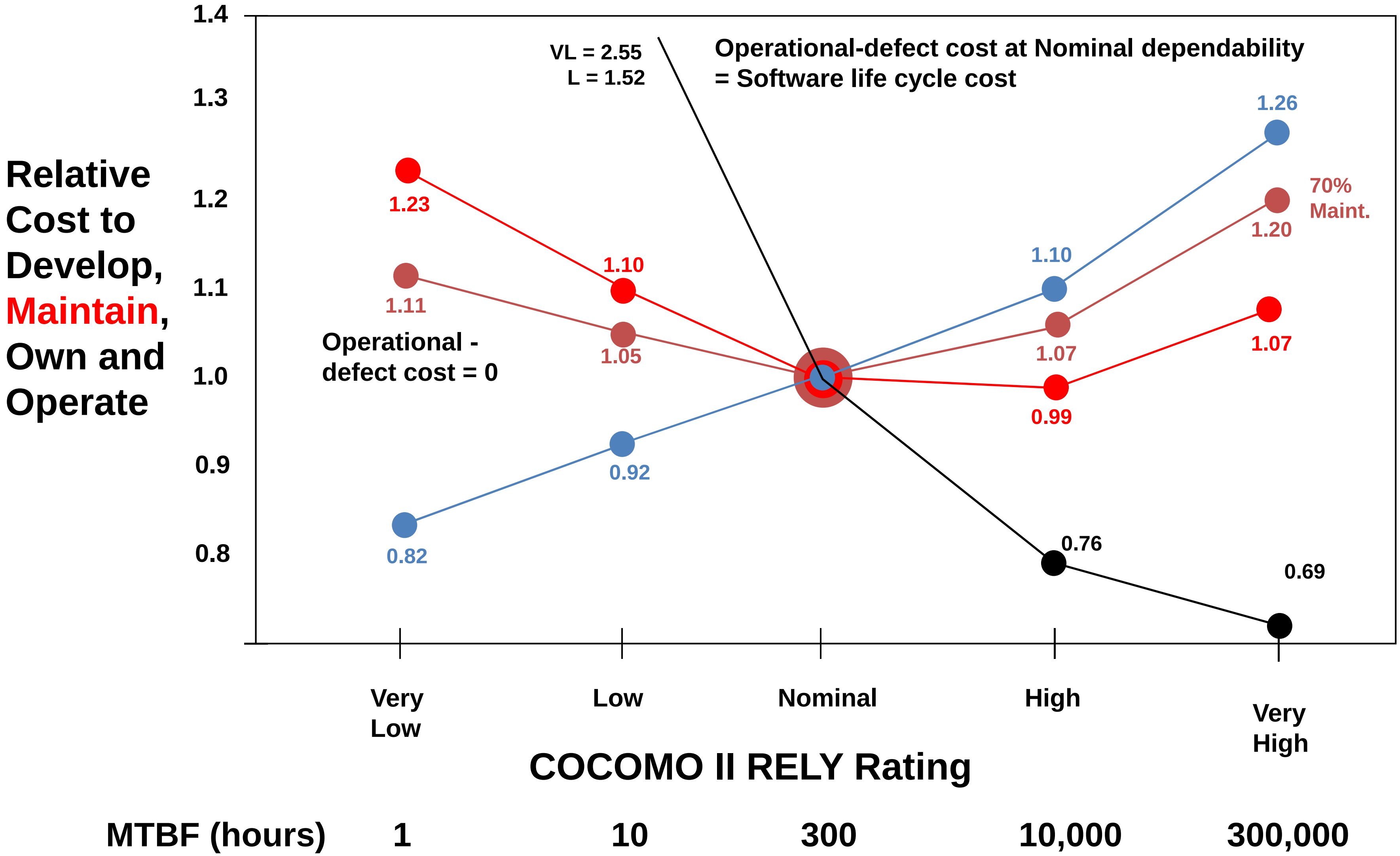
Architecture Strategy Synergy-Conflict Matrix

	Reliability	Modifiability	Interoperability	Cost
Reliability		• Nanosensor-based smart monitoring improves reliability, makes mods more effective • Domain architecting (using domain knowledge in defining interfaces) improves reliability and modifiability • Modularity (high module cohesion, low module coupling) improves modifiability and reliability	• Domain architecting improves reliability, interoperability within the domain • High-cohesion, low-coupling modules improve interoperability and reliability • Common, multi-layered services and architecture improve interoperability and reliability	• Automated input, output validation reduces human costs • **Increased reliability reduces life cycle ownership costs** • Product line architectures reduce cost, increase reliability
Modifiability	• Reliability-optimized designs may complicate fault diagnosis, system disassembly • Domain architecting assumptions complicate multi-domain system modifiability		• Modularization around sources of change improves modifiability and interoperability • High-cohesion, low-coupling modules improve modifiability and interoperability • Open standards, service-oriented architectures improve both modifiability and interoperability	• Modularization around sources of change reduces life cycle costs • High-cohesion, low-coupling modules reduce life cycle costs • Domain architecting enables domain product lines, reducing costs • Providing excess capacity improves modifiability and decreases lifecycle cost
Interoperability	• Data redundancy improves reliability, but updates may complicate distributed real-time systems interoperability • Optimizing on reliability as liveness may degrade message delivery, accuracy	• Domain architecting assumptions complicate multi-domain system interoperability		• Common, multi-layered services and architecture reduce life cycle costs • Product line architecture improves interoperability, reduces cost of later systems
Cost	• **Increased reliability increases acquisition costs** • Hardware redundancy adds cost • Making easiest-first initial commitments reduces early costs but degrades later reliability, adds later costs • Formal verification adds cost	• Fixed-requirements, fixed-cost contracts generally produce brittle, hard-to-modify systems • Domain architecting increases multi-domain system costs • Providing excess capacity improves modifiability but increases acquisition cost	• Neglecting or deferring interfaces to co-dependent systems will reduce initial costs, but degrade interoperability • Product line architecture increases cost of initial system	

Software Development Cost vs. Quality



Software Ownership Cost vs. Quality



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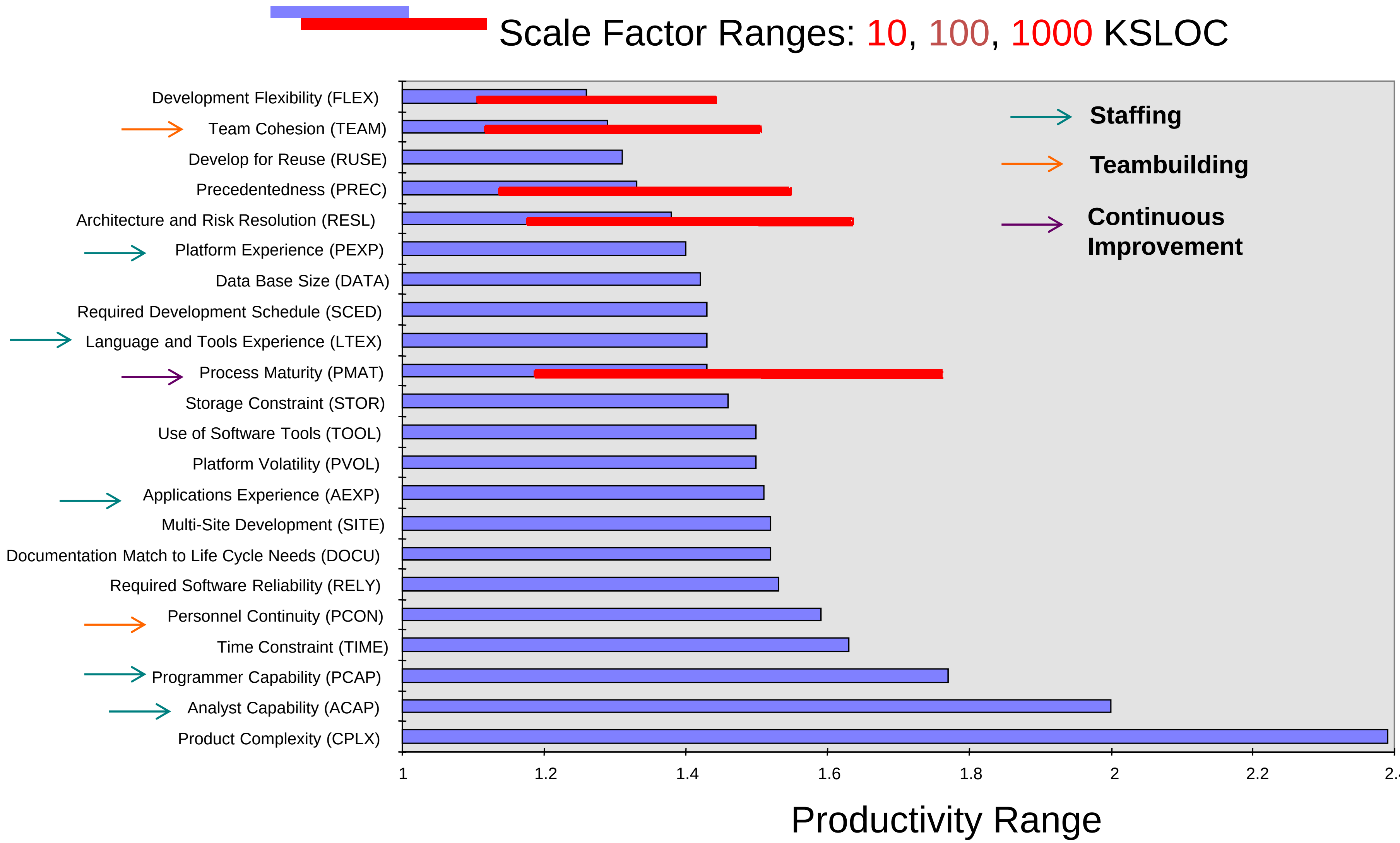
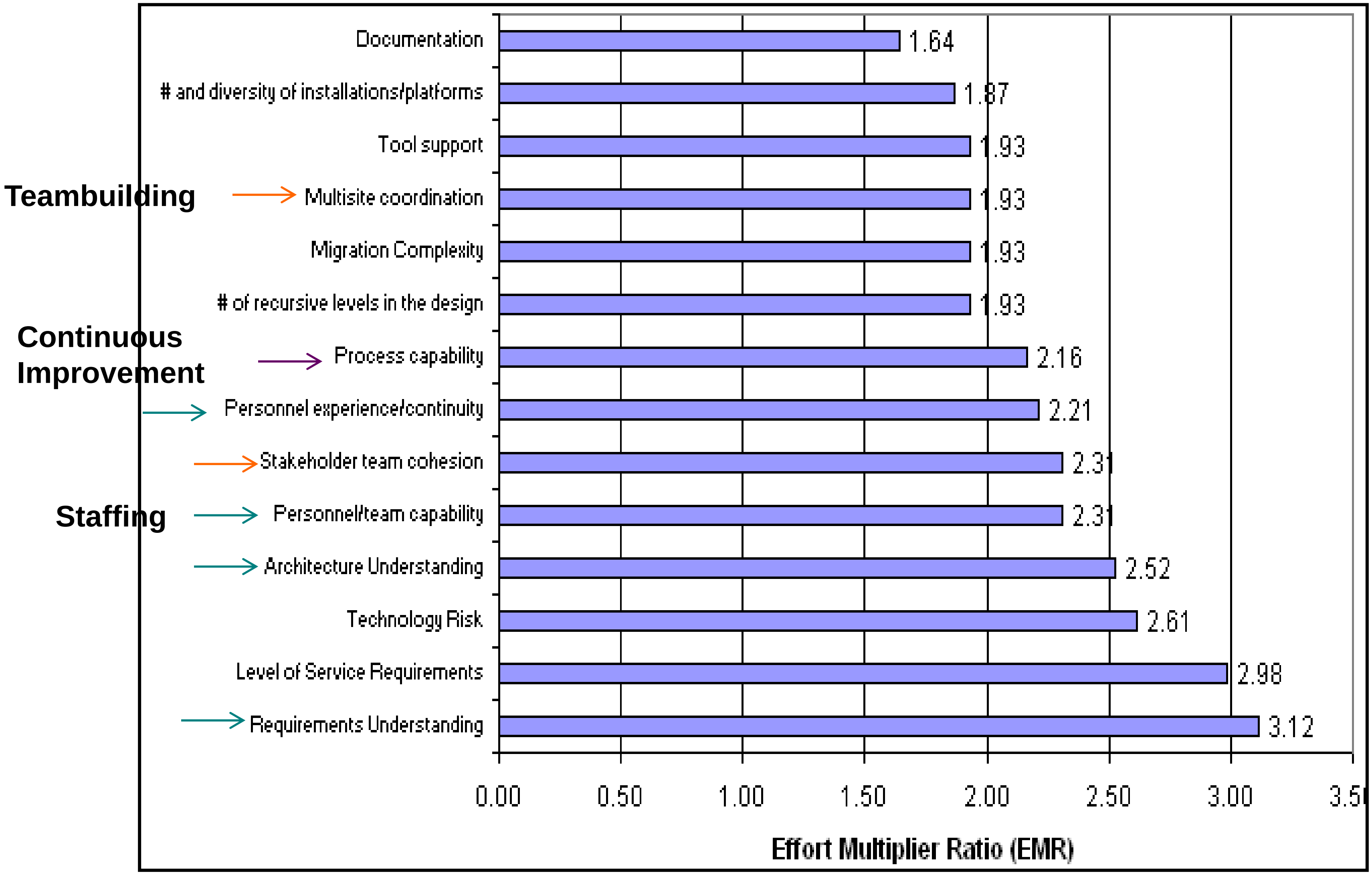
Costing Insights: COCOMO II Productivity Ranges



COSYSMO Sys Engr Cost Drivers



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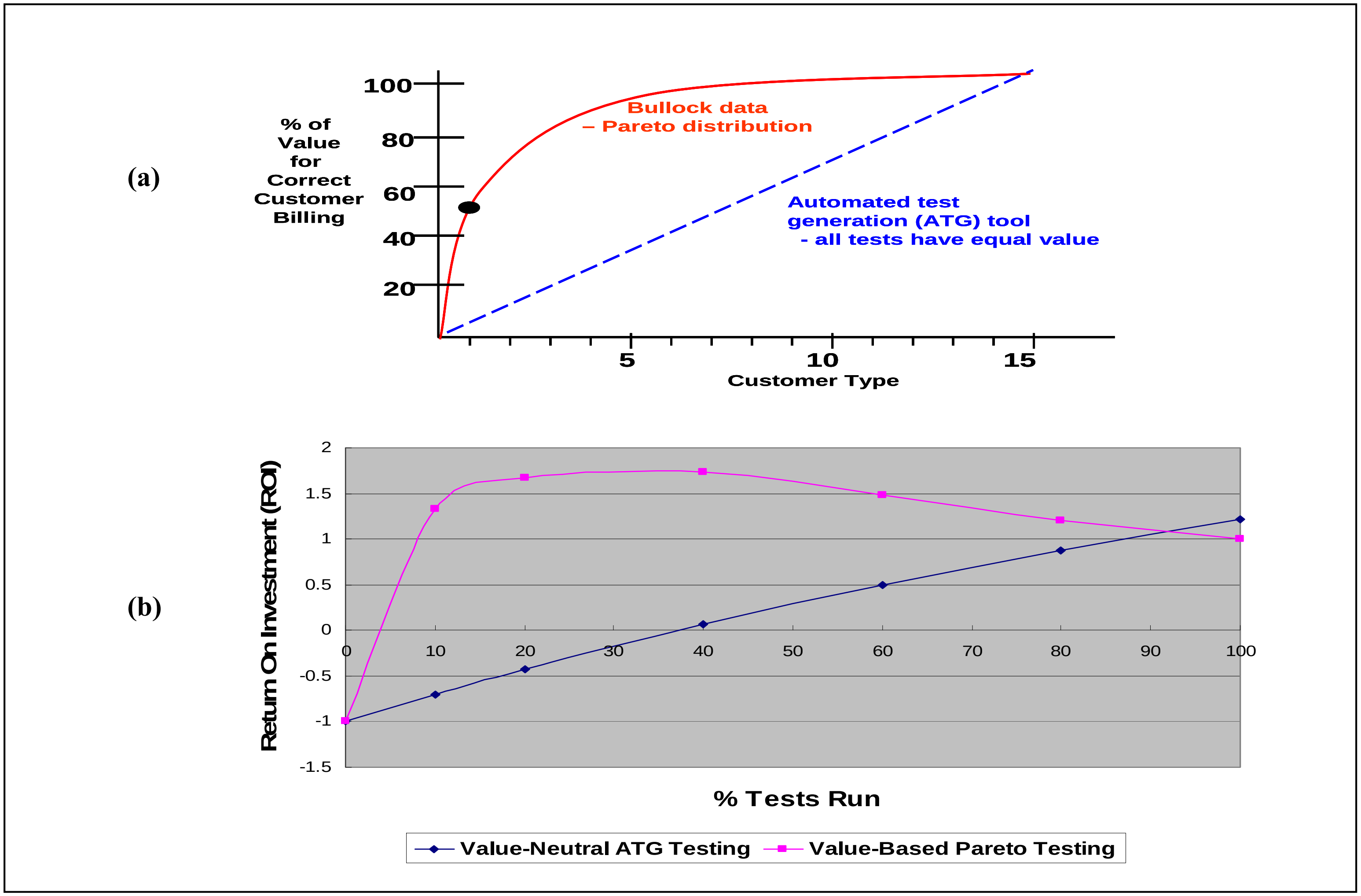
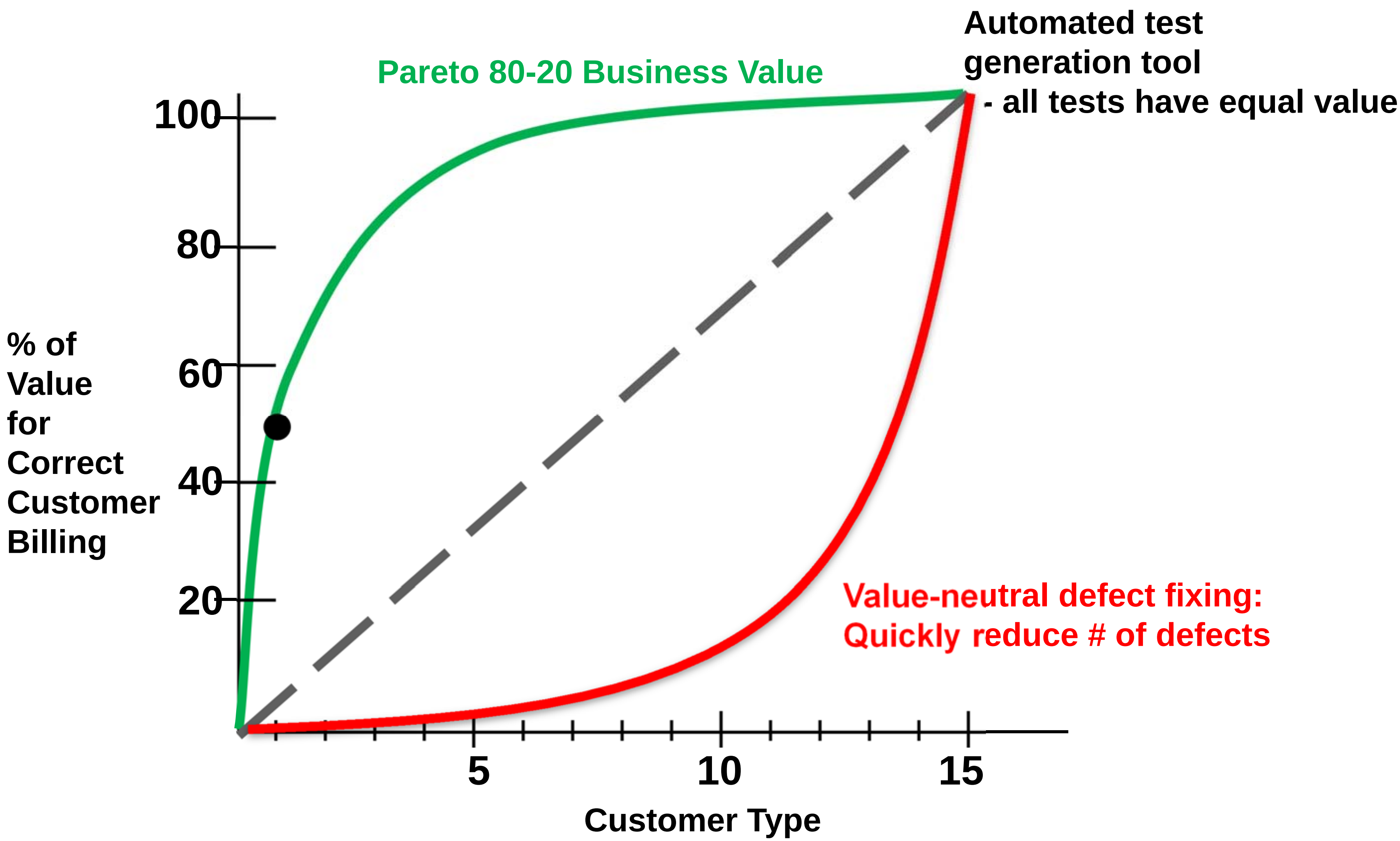
Value-Based Testing: Empirical Data and ROI

— LiGuo Huang, ISESE 2005



Value-Neutral Defect Fixing Is Even Worse



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Cost-Schedule Tradespace Analysis

- Generally, reducing schedule adds cost
  - Pair programming: 60% schedule * 2 people = 120% cost
- Increasing schedule may or may not add cost
  - Pre-planned smaller team: less communications overhead
  - Mid-course stretchout: pay longer for tech, admin overhead
- Can often decrease both cost and schedule
  - Lean, agile, value-based methods; product-line reuse
- Can optimize on schedule via concurrent vs. sequential processes
  - Sequential; cost-optimized: Schedule = 3 * cube root (effort)
    - 27 person-months: Schedule = 3*3=9 months; 3 personnel
  - Concurrent, schedule-optimized: Schedule = square root (effort)
    - 27 person-months: Schedule = 5.5 months; 5.4 personnel
- Can also accelerate agile square root schedule
  - SERC Expediting SysE study: product, process, people, project, risk

SERC Expediting SysE study:

Product, process, people, project; risk factors

Final Database

Over 30 Interviews with Gov't/ Industry Rapid Development Organizations

Over 23,500 words from interview notes

Product, Process, People … all in a Project Context

CORADMO-SE Rating Scales, Schedule Multipliers

Accelerators/Ratings	Very Low	Low	Nominal	High	Very High	Extra High
Product Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity	Extremely complex	Highly complex	Mod. complex	Moderately simple	Highly simple	Extremely simple
Element Reuse	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Low-Priority Deferrals	Never	Rarely	Sometimes	Often	Usually	Anytime
Models vs Documents	None (0%)	Minimal (15%)	Some (30%)	Moderate (50%)	Considerate (70%)	Extensive (90%)
Key Technology Maturity	>0 TRL 1,2 or >1 TRL 3	1 TRL 3 or > 1 TRL 4	1 TRL 4 or > 2 TRL 5	1-2 TRL 5 or >2 TRL 6	1-2 TRL 6	All > TRL 7
Process Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	Highly sequential	Mostly sequential	2 artifacts mostly concurrent	3 artifacts mostly concurrent	All artifacts mostly concurrent	Fully concurrent
Process Streamlining	Heavily bureaucratic	Largely bureaucratic	Conservative bureaucratic	Moderate streamline	Mostly streamlined	Fully streamlined
General SE tool support CIM (Coverage, Integration, Maturity)	Simple tools, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Project Factors	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)	Over 300	Over 100	Over 30	Over 10	Over 3	≤ 3
Collaboration support	Globally distributed weak comm. , data sharing	Nationally distributed, some sharing	Regionally distributed, moderate sharing	Metro-area distributed, good sharing	Simple campus, strong sharing	Largely collocated, Very strong sharing
Single-domain MMPTs (Models, Methods, Processes, Tools)	Simple MMPTs, weak integration	Minimal CIM	Some CIM	Moderate CIM	Considerable CIM	Extensive CIM
Multi-domain MMPTs	Simple; weak integration	Minimal CIM	Some CIM or not needed	Moderate CIM	Considerable CIM	Extensive CIM
People Factors	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)	Weak KSAs	Some KSAs	Moderate KSAs	Good KSAs	Strong KSAs	Very strong KSAs
Single-Domain KSAs	Weak	Some	Moderate	Good	Strong	Very strong
Multi-Domain KSAs	Weak	Some	Moderate or not needed	Good	Strong	Very strong
Team Compatibility	Very difficult interactions	Some difficult interactions	Basically cooperative interactions	Largely cooperative	Highly cooperative	Seamless interactions
Risk Acceptance Factor	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
	Highly risk-averse	Partly risk-averse	Balanced risk aversion, acceptance	Moderately risk-accepting	Considerably risk-accepting	Strongly risk-accepting

CORADMO-SE Calibration Data

Mostly Commercial; Some DoD

Application Type	Technologies	Person Months	Duration (Months)	Duration / √PM	Product	Process	Project	People	Risk	Multi-plier	Error %
Insurance agency system	HTML/VB	34.94	3.82	0.65	VH	VH	XH	VH	N	0.68	5%
Scientific/engineering	C++	18.66	3.72	0.86	L	VH	VH	VH	N	0.80	-7%
Compliance - expert	HTML/VB	17.89	3.36	0.79	VH	VH	XH	VH	N	0.68	-15%
Barter exchange	SQL/VB/ HTML	112.58	9.54	0.90	VH	H	H	VH	N	0.75	-16%
Options exchange site	HTML/SQL	13.94	2.67	0.72	VH	VH	XH	VH	N	0.68	-5%
Commercial HMI	C++	205.27	13.81	0.96	L	N	N	VH	N	0.93	-3%
Options exchange site	HTML	42.41	4.48	0.69	VH	VH	XH	VH	N	0.68	-1%
Time and billing	C++/VB	26.87	4.80	0.93	L	VH	VH	VH	N	0.80	-14%
Hybrid Web/client-server	VB/HTML	70.93	8.62	1.02	L	N	VH	VH	N	0.87	-15%
ASP	HTML/VB/SQL	9.79	1.39	0.44	VH	VH	XH	VH	N	0.68	53%
On-line billing/tracking	VB/HTML	17.20	2.70	0.65	VH	VH	XH	VH	N	0.68	4%
Palm email client	C/HTML	4.53	1.45	0.68	N	VH	VH	VH	N	0.76	12%

Schedule Acceleration Case Study:

From Plan-Driven to Agile

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity					X	
Process Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V	X					
Process Streamlining		X				
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	**1.08**	**1.04**	**1.0**	**0.96**	**0.93**	**0.9**
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)				X		
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility				X		
Risk Acceptance Factor	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
			X			

Case Study: From Plan-Driven to Agile

Initial Project: Focus on Concurrent SE

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	**1.09**	**1.05**	**1.0**	**0.96**	**0.92**	**0.87**
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity			X			
Process Factors	**1.09**	**1.05**	**1.[illegible]**	[illegible]	[illegible]	**0.87**
Concurrent Operational Concept, Requirements, Architecture, V&V				X		
Process Streamlining		X				
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	**1.08**	**1.04**	**1.0**	**0.9[illegible]**	[illegible]	**0.9**
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	**1.13**	**1.06**	**1.0**	**0.94**	**0.89**	**0.84**
General SE KSAs (Knowledge, Skills, Agility)			X			
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility			X			
Risk Acceptance Factor	**1.13**	**1.06**	**1.[illegible]**	[illegible]	**0.89**	**0.84**
			X			

Expected schedule reduction of 1.09/0.96 = 0.88 (green arrow)
Actual schedule delay of 15% due to side effects (red arrows)
Model prediction: 0.88*1.09*1.04*1.06*1.06 = 1.13

SYSTEMS ENGINEERING
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Case Study: From Plan-Driven to Agile

Next Project: Fix Side Effects; Reduce Bureaucracy

Accelerators/Ratings	VL	L	N	H	VH	XH
Product Factors	1.09	1.05	1.0	0.96	0.92	0.87
Simplicity			X			
Element Reuse	X					
Low-Priority Deferrals	X					
Models vs Documents		X				
Key Technology Maturity					X	
Process Factors	1.09	1.05			92	0.87
Concurrent Operational Concept, Requirements, Architecture, V&V					X	
Process Streamlining				X		
General SE tool support CIM (Coverage, Integration, Maturity)				X		
Project Factors	1.08	1.04	1.0	0.96	0.93	0.9
Project size (peak # of personnel)				X		
Collaboration support				X		
Single-domain MMPTs (Models, Methods, Processes, Tools)				X		
Multi-domain MMPTs		X				
People Factors	1.13	1.06	1.0	0.94	0.89	0.84
General SE KSAs (Knowledge, Skills, Agility)				X		
Single-Domain KSAs				X		
Multi-Domain KSAs		X				
Team Compatibility				X		
Risk Acceptance Factor	1.13	1.06		94	0.89	0.84
			X			

Model estimate: 0.88*(0.92/0.96)*(0.96/1.05) = 0.77 speedup

Project results: 0.8 speedup

Model tracks project status; identifies further speedup potential