Trust under Uncertainty - Quantitative Risk

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Quantitative Risk Research

Leading Indicators of Risk Exposure in DoD Acquisition Programs

Adaptive Adversary Risks & Technology Opportunities for Long-Lived DoD Systems

Risks & Risk Reduction in Model-Based Acquisition & Virtual Development

Leading Indicators of Risk Exposure in DoD Acquisition Programs

Traditional Risk Management

- Tornado **watch**: "A tornado has been sighted in your area"
- Arterial plaques mean there is risk of clotting or rupture causing blockage and heart damage

Risk Leading Indicators, Risk Scores & Risk Exposure

- Tornado **warning**: "Conditions are right for the formation of tornados"
- High triglyceride levels, limited exercise and smoking level indicate potential risk of heart disease: **practical warning thresholds and guidelines for proactive behavior**; no definitive chain of cause-and-effect; predicting risk of heart attack in 5 years remains controversial
- Credit scores combine diverse factors into **useful metrics** to identify "high risk" people for loan default, auto insurance, etc.

Need and Opportunity

- Extend and complement traditional risk management
- Quantitative and Objective
  - —Leading indicators from standard acquisition artifacts
  - —Evidence-based norms and benchmarks based
- Early warning
  - —Conditions favoring future problems and amplifying adverse consequences
  - —Detect conditions in time for pro-active actions
- Inform decision making of the risk-exposure of alternative choices
- Relate risk conditions to sources and causes for mitigation
- Leading indicators & scoring depend on phase & type of program

End-User Collaboration and Proof-of-Concept Piloting

- Active
  - US Army TARDEC
  - Armored Multi-Purpose Vehicle (AMPV) Program Office
  - OUSD ATL SE, Major Program Support
- Pending
  - US Army ERDC
  - NAVAIR

- TARDEC Co-Developer
  - Verify Practicality and Relevance
  - Access reference program artifact repositories
  - Integrate with and Transition to Systems Engineering Framework
  - Pilot the MPT with AMPV PMO
- AMPV PMO Pilot
  - Integrate With Traditional Risk Management
  - Assess Practicality and Value to AMPV Program Risk Management

Armored Multi-Purpose Vehicle (AMPV)

- AMPV Program
  - Non-Developmental Vehicle replacement for the M113, 5 variants, interoperable with M1 and M2, multiple functional modules
  - No formal Tech Dev competitive prototyping - requirements, costs, & schedule refined by iterations of draft RFPs & analysis
  - Single source EMD award envisioned
  - RFP issued Nov 2013, proposals due March 2014, decision May 2014
  - $1.8M per vehicle and $90/mile (raised from initial targets)
  - 5 year EMD $388M 29 prototypes, $1.08B 289 LRIP, $5B for 2,897 units
- Pilot Status
  - Agreement with AMPV PMO in Dec 2013
  - Analyzing risk exposure as of RFP release, annex to Technical Risk Assessment
  - Additional risk exposure assessment pending source selection

Root Causes & Indicators

Risk Scoring By System Type & Acquisition Stage

Artifacts

- Requirements
- Architecture
- Program Plan
- Program Organization
- Execution Past Performance

Root Cause Risk Breakdown Structure

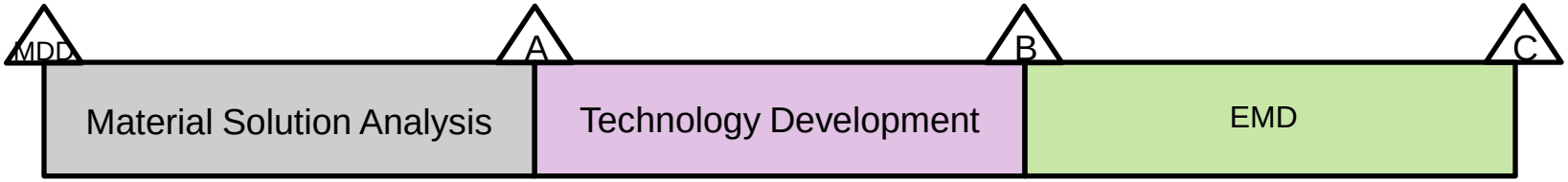
Work Content	Plans & Estimates	Execution & Management
• Turbulence	• Assumptions	• Staffing
• Size & Density	• Organization	• Stability
• Ambiguity	• Scheduling	• Performance
• Novelty	• Resourcing	
• Margin	• Margin	

Root Causes & Indicators

- Work Content
  - Size, complexity, stability, maturity (by WBS) of requirements, architecture, organization & execution plan
  - Number of "moving parts", scope, interdependencies & novelty
  - "Safety margin" / "Margin for error"
- Plans & Planning
  - Requirements, architecture, product teams and IPTs, & tasks / IMS
  - Consistency, resolution, stability
  - "Safety margin" / "Margin for error"
- Estimating
  - Performance, schedule, and EMD, AUPC & O&S costs
  - Resources allocated to WBS work elements matched to work content
  - "Safety margin" & "Margin for error"
- Execution & Management
  - Stability of work content, plans & estimates
  - Outcomes vs estimates on *this* program
  - "Safety margin" / "Margin for error"

Decision Breakdown Structure for Risk Informed Decision Making

Decision Choices Create the Exposure-to-Risk Environment



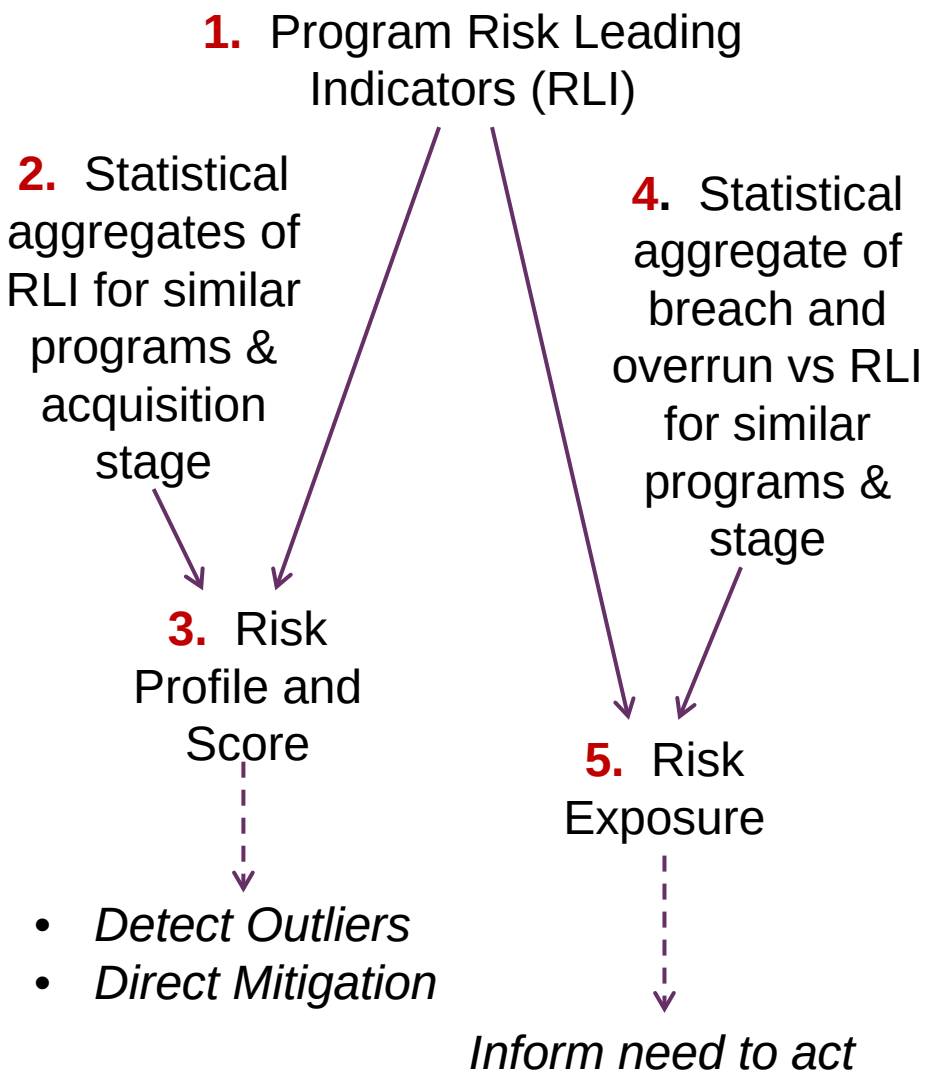
- Concept, Functions and Capabilities
- New Start, Non-Developmental Conversion or Block Upgrade
- Number & Diversity of AoA Alternatives
- Number & Diversity of Variants
- Waived Technical Review Entrance and/or Exit Criteria

- CDD KPP, KSA & APA Parameters and Values
- CDD Refinement Strategy - Prototyping, Industry Feedback, M&S, Judgment*
- Prototyping Source Selection (Criteria, Weights and Scoring)
- Extent of Testing , M&S, Analysis etc.
- Waived Technical Review Entrance and/or Exit Criteria

- Strategy: Single Source or Multiple EMD Awards
- Source Selection & Down-Selection (Criteria, Weights and Scoring)
- P-Spec, time & cost targets
- Component Technology Choices (TRL, MRL & IRL)
- Extent of Testing (DT and OT)
- Changes to P-Spec; Deferred or Waived Requirements
- Waived Technical Review Criteria and/or supporting analyses & testing

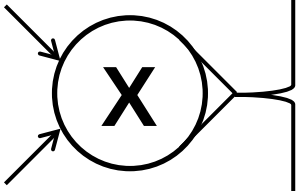
Method/Procedure/Tool Organization

1. Risk Leading Indicators
   - Objective measures from program artifacts and updates
2. Risk Profile & Score
   - Score: "How many standard deviations from the norm?" or "Which quartile?"
   - Profile: Breakdown by WBS, source and type of risk
3. Risk Exposure
   - Profile similarity to programs with breaches vs programs without breaches
   - Probability of delay > X; Expected delay if delay > X



Risk Leading Indicators

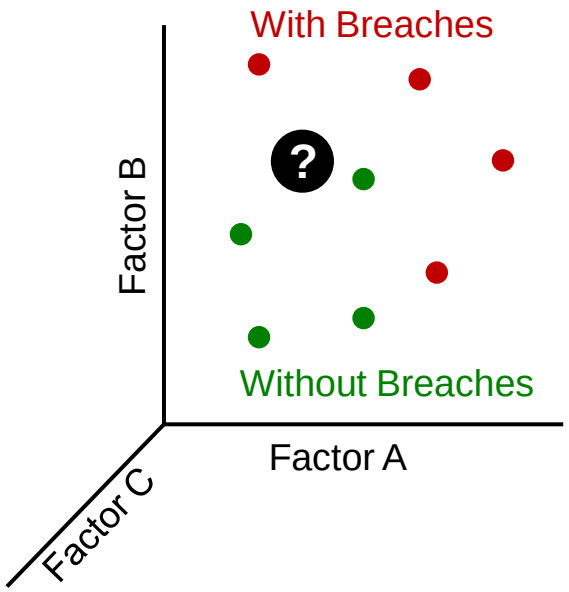
- RLI Areas
  - —Requirements
  - —Architecture & Technology
  - —Planning & Scheduling
  - —Organization & Staffing
  - —Technical Management
- RLI Types
  - —Density & Interdependence
  - —Turbulence/Stability
  - —Completeness & Consistency
  - —Sensitivity & Margins
  - —Ambiguity & Equivocation



- Performance margins
- Number of new or changed requirements since last review
- Numbers of variants, functions, configuration items & interfaces
- Proportion of configuration items without architecture diagrams
- Schedule margin by task
- Number and proportion of interfaces not covered by an IPT and an integration task
- TRL/IRL/MRL by config item
- Technical review element waivers
- Etc.

Risk Exposure Classification

How much does the risk profile resemble programs with breaches vs programs without breaches?



Initially we may not have many data points

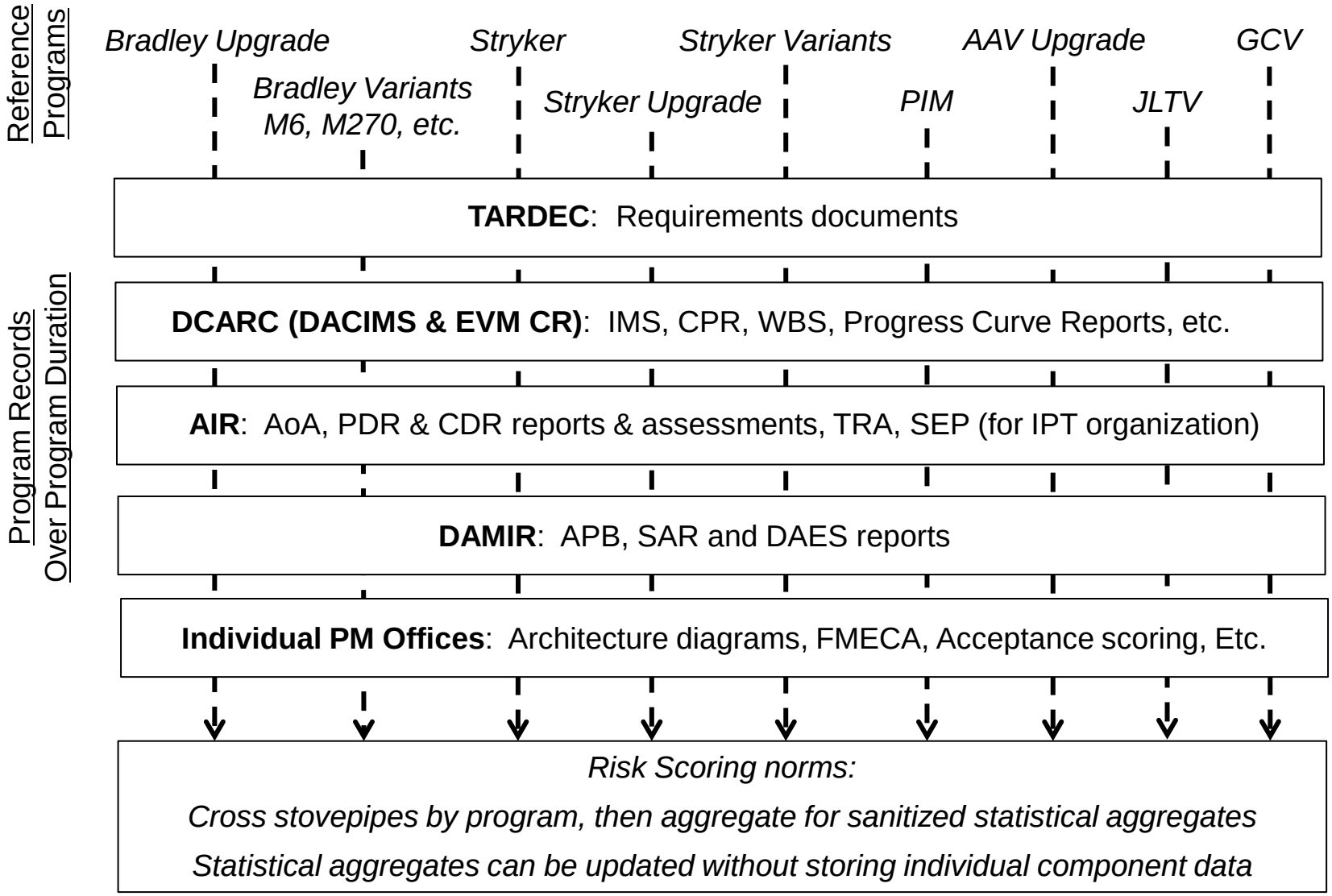
Evidence is being accumulated as repository and acquisition visibility initiatives

All programs are different, but risk profile patterns should emerge

This kinds of "AI" cluster analysis and analytics are widely used commercially

Which factors matter and the sensitivity and specificity of classification remains to be determined and will change as more evidence is accumulated

Potential Reference Programs and Artifact Repositories



Plan & Schedule

- Risk Leading Indicator, Scoring and Exposure tools
  - —Initial: May 2014
  - —Final: Feb 2015
- Pilot application reports
  - —Quarterly
- Technical report on tools, transition and pilot application
  - —Feb 2015

Concept, Needs & Opportunities

Adaptive Adversary Risks & Technology Opportunities for Long-Lived DoD Systems

"Long-Lived" DoD Systems

- Product lines / families / classes in the inventory for 30-60 years
- Individual items with upgrades have 15-60 year service lives

Risks and Opportunities

- Adversaries adapt to avoid our systems' strengths and exploit their limitations by their choice of battlefields, tactics, and equipment
- US systems design to be adapted to counter adversary adaptations and exploit maturation of our emerging technologies
- Challenge: System requirements
  - To deter and defeat current threats
  - To enable cost-effective upgrade & adaptation

Reserve Capacity & Adaptability Issues

- Levels of reserve capacity to build into the system infrastructure to enable cost-effective upgrade options
- Tradeoffs between initial, integral capabilities and cost versus later upgrade/modification capabilities and costs
- Risks of adversary adaptation within our acquisition cycle to avoid our systems' strengths and exploit their limitations
- Keeping open options for potential new technologies despite uncertain maturation, change costs, burdens, and performance

Practical and relevant issues in the current DoD acquisition environment

Marine Corps on Amphibious Combat Vehicle (ACV) Adaptability

"I don't foresee a grand slam on the first pitch where we're going to deliver a fixed capability for the life of the vehicle. We've got to be knowledgeable enough to recognize the environments change, threats change, new technology starts to come to pass, and we want to make sure this design will allow for that growth in the future. … I think we're at a point in time where you really wanting deep thinking, good ideas that can help influence design, requirements, trade and cost at a stage in the program where it can make a difference "

Dr. J. Burrow, Executive Director, Marine Corps Systems Command & Director, USMC ACV Team, Inside the Navy, March 25, 2013

- 30 to 50 year system service life
- 7 to 10 years from program initiation to IOC
- 15 to 20 year useful life for individual vehicles
- Continuous modernization
  - In-theater upgrade kits
  - RECAP at depot
  - New production

Army 2012 Posture Statement On Equipment Modernization

"The Army aims to develop and field a ***versatile*** and ***affordable*** mix of equipment to enable Soldiers and units to succeed across a full range of missions today and tomorrow and to maintain our decisive advantage over any adversary we face. "***Versatile***" encompasses the characteristics of ***adaptable*** (to changing missions and environments); ***expansible*** (able to add, update or exchange capabilities in response to changed circumstances); and networked (to enable interoperability within our formations and with those of our partners). "***Affordable***" relates to making fiscally informed decisions that provide greatest capability value in accordance with senior leader priorities, within projected ***resources*** and within acceptable ***risk*** parameters.

Transformational equipping strategies from the turn of the century were envisioned to skip marginal technology improvements and orient on "game-changing", "leap-ahead" technologies intended to revolutionize military operations. A more appropriate force development concept, ***Incremental Modernization***, enables us to deliver new and improved capabilities to the force by leveraging mature technologies, shortening development times, ***planning growth potential*** and integrating increments of those capabilities that give us the greatest advantage in the future while ***hedging against uncertainty***."

Upgrade Kits – Real Options to Extend Capabilities

- Platforms provide infrastructure for upgrade kits
- Kits for different functions, enhance capabilities, improve interoperability, and/or improve sustainability
  - Reliability growth – replace low reliability subsystems
  - O&S cost reduction – more efficient engine and/or transmission
  - Survivability enhancement – armor "B" kit, APS
  - Mission Function – Air Defense pod, RSTA pod, winch and excavator arm, etc.
  - Commonality (logistics footprint) – common components between systems
  - Interoperability – replace comms & software for compatibility
- "Kits" are also a design and manufacturing practice

HMMWV Kit Conversions

Bolt on armor required upgraded suspension, engine, and steering

Additional armor and cupola raise the CG and increase rollovers

Mattracks or wheels

Upgrades:
- Increased cab space
- Increased payload capacity
- Strengthened frame

Upper deck space is always at a premium

Imbalance in cupola required motorized drive

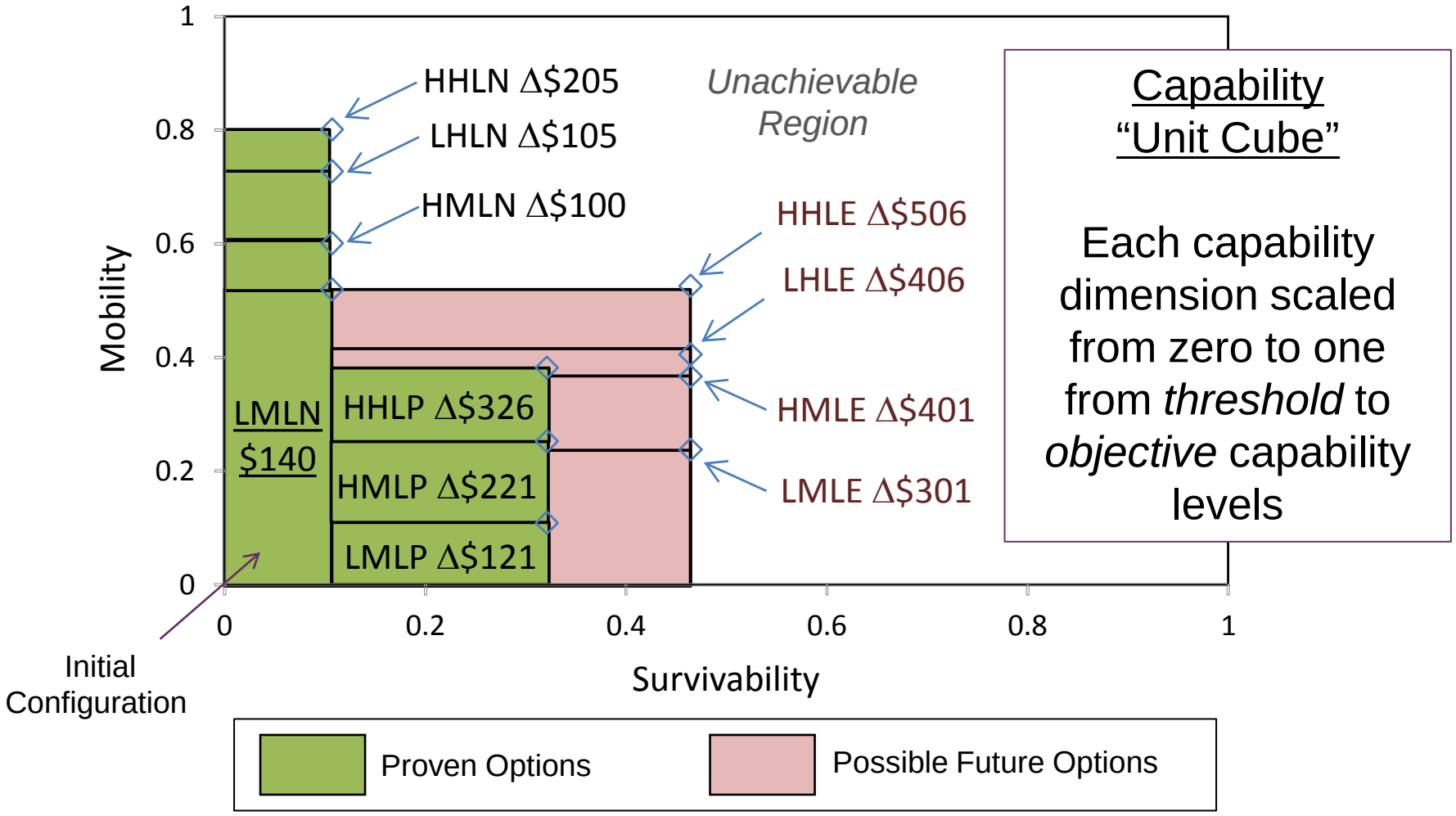
Suspension and steering for CG shift

Base cab & flatbed with mission modules

Reserve Capacity Conceptual Framework

- Enhanced Set-Based Design with Real Options
  - Infrastructure reserve capacity keeps options open & costs down for future upgrades & enables future capability tailoring decisions
  - Initial design consideration: **What is the region of capability space that can be reached with affordable upgrade options?**
  - Goal: Near-optimal over a range of maturity, budget scenarios & adversary adaptation models
- Adversarial Risk Analysis
  - Intelligent adaptive adversaries favor battlefields, tactics and equipment where the capabilities needed are **"inverse"** to the capabilities we field
- Technology Maturation Risks and Opportunities
  - Robust solutions can exploit emerging technologies, but are effective even without them

Capability Upgrade Options and Costs



Capability "Unit Cube"

Each capability dimension scaled from zero to one from *threshold* to *objective* capability levels

Capability Shortfall & Adversarial Risk

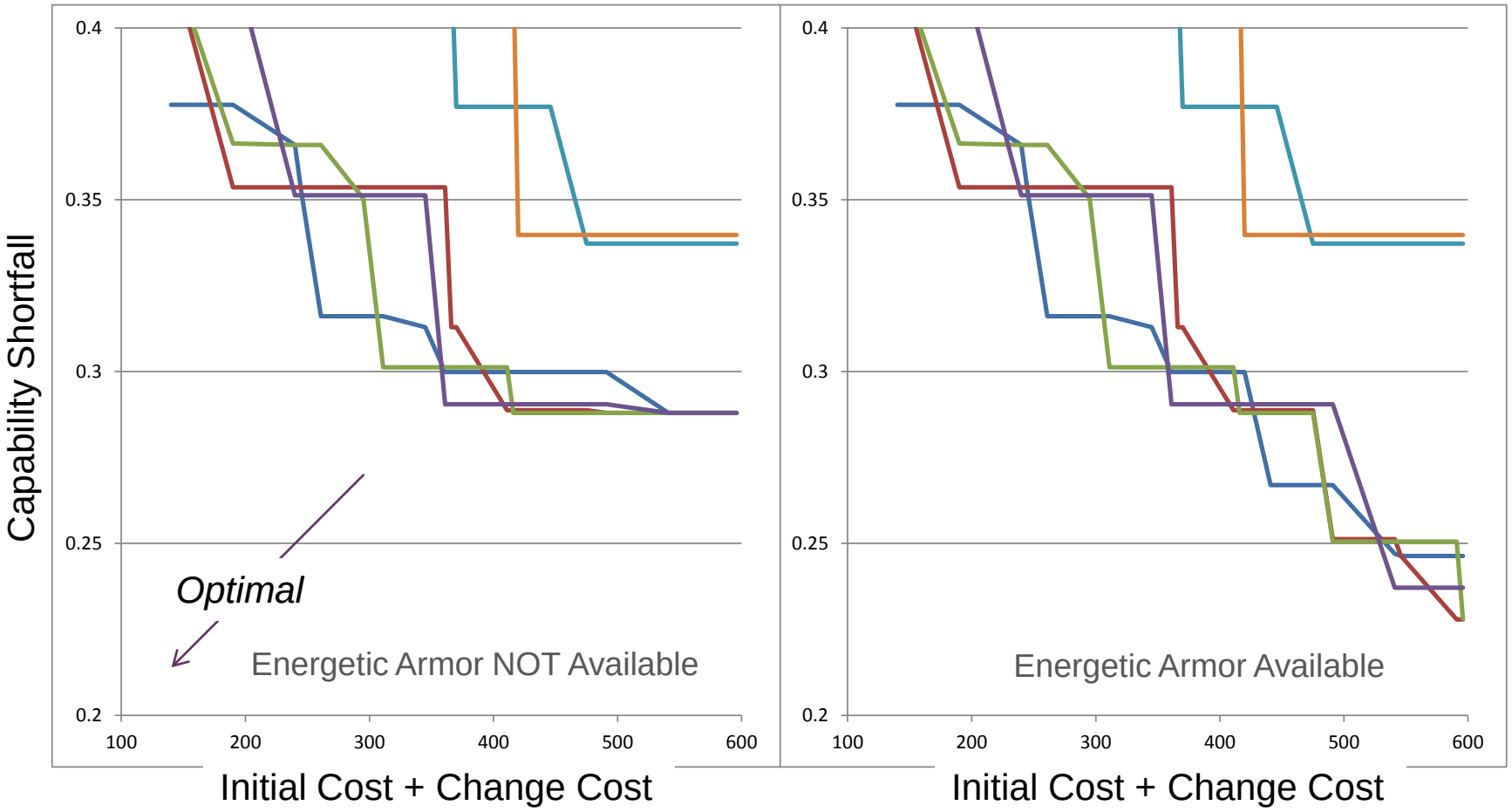
Conditional Shortfall

- Average distance from points in the unachievable region to the closest point in the achievable region
- Adversary situations are independent of fielded capabilities

Adversarial Shortfall

- Conditional shortfall weighting based on the distance from the achievable region
- Adversaries seek situations in which the capabilities needed are farther from our capabilities
- Adversary “adapt to” models
  - Initial configuration only
  - Game sequence of upgrade “moves”

Choosing a Robust and Versatile Initial Configuration



<u>Goal</u>:

*An initial configuration with capability shortfall **near** optimum at cost, over a **range of budget scenarios**, **whether or not** technologies mature*

Status And Plans

- Prototype tool under development
  - —Extend for capability hierarchies and response times
  - —Adversarial model sensitivity
    - Number of moves
    - Distance function
- Discussions with potential end-users and collaborators in progress
  - —NAVSEA Rapid Ship Design Environment & Engineered Resilient Systems projects
    - Ship and Marine Corps Amphibious Combat Vehicle potential applications
  - —TARDEC
    - Ground Combat Vehicle may be reorganized as a Technology Demonstrator
    - Program goals remain to develop a adaptable & extensible platform

High-Fidelity Modeling and Simulation

Risks & Risk Reduction in Model-Based Acquisition & Virtual Development

Opportunities

- Rapid assessment of more alternatives
- Learn more from limited prototyping
- Avoid cost-prohibitive destructive testing

Needs

- Methods to limit the risks of M&S limitations
  - On system performance and cost
  - On development program time, cost and

Partners & Interests

- NAVAIR (sponsoring RT48 “Transforming Acquisition with MBSE”)
  - —MSA phase to generate and screen move and diverse options
  - —Tech Dev phase to ensure feasibility of requirements & preview risks
  - —EMD phase for virtual integration, transitioning to prototype system
- NAVSEA Rapid Ship Design Environment & CREATE-Ships
  - —Uncertainty propagation in high-fidelity physics based modeling of complex systems subject to high-energy events
  - —Mine blast tests on ship are a cost-prohibitive development strategy
  - —Complicated multi-functional systems with many failure & degraded modes
  - —Highly non-linear, multi-stage, multi-scale, multi-physics events
  - —Making the best use of limited and sub-scale testing
  - —Limitations interpreting M&S results
- TARDEC Survivability interests similar to NAVSEA

Modeling & Simulation Concerns

- Calibration and validation strategies for highly non-linear events and limited test & observation opportunities
- Models used out of context, outside validation & calibration
- Limitations, assumptions, and phenomena omitted, not often not well articulated
- Deterministic chaos phenomena where small change in boundary conditions (inputs) produces rapid divergence in outputs
- Sensitivity to complex and often unknown boundary conditions
- Gaps in understanding multi-scale, multi-physics phenomena
- Human behavior, knowledge, cognition – flight safety, damage control
- Level of M&S different form level of analysis and decision
- Incompatible scope, resolution, terminology with test procedures

Approach Components

- Multi-scale experimental design to calibrate and validate M&S for complex systems and highly non-linear events
- Knowledge integration framework for limited field observation and limited test data with M&S outputs across multiple scales, physics, measurement uncertainty and test control
  - Hybrid system with virtual prototypes, subscale testing, etc
  - M&S sensitivity analysis test and observation data points
  - Boundary condition uncertainty scattering/resampling around test and observation data to reduce biasing
  - Estimate expected reduction in overall uncertainty value of additional testing
  - Expert judgment, informed by observation and test, designs tests and models, and is another component of the hybrid mix

Mine Blast Modeling and Analysis Issues

- Difficult to instrument
- Complex phenomena
  - Initial blast
  - Bubble collapse and water jet effects
  - Reflected waves
- Complex effects
  - Shock wave structural effects, damage to pipes and electronics
  - Compartment penetration, gas overpressure & fireball, flooding
  - Secondary projectiles, fire, ammunition deflagration
  - Damage to battle damage control systems – pumps, fire suppression, evacuation routes

Quantitative Risk (QR) Portfolio

- **DoD Acquisition Risk Leading Indicators** – Informing Decisions, Warning ("conditions are right for") complementing traditional RM "watch" (for a specific thing)
- Engineering Resilience for Long-Lived Systems using **Adversarial Risk** and **Real Options** Possibility Analyses – Sizing the Infrastructure for Cost-Effective Extension and Adaptation
- **Risk in Model-Based Acquisition** and Model-Based Systems Engineering Transformation – Risks in MBA & MBSE, Modeling Risk for MBA and MBSE
- Error and Uncertainty Propagation in **High-Fidelity Physics-Based Models** of "High-Energy" Events for Complex Systems