Quantifying Uncertainty for Early Lifecycle Cost Estimation (QUELCE)
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Problem: DoD Program Cost Overruns

Source: December 2009 SAR; analysis by CSIS Defense-Industrial Initiatives Group

Cost and Time Overruns for Major Defense Acquisition Programs, 2010
Technical Challenge: Early Lifecycle Cost Estimation

Weapon Systems Acquisition Reform Act of 2009 - Public Law 111-23 **Requires Pre-Milestone A Cost Estimates with Confidence Level**

Challenges:
1) Mismatch between available information and inputs to existing Cost Estimation Relationships (CERs),
2) Lack of transparency into assumptions and constraints using analogies
Adding Transparency to Cost Estimates

**Constraints**
- Cost, Schedule
- Resource limits
- Other

**Directives**
- policy, publication...

**Resources**
- Skilled people
- Tools, methods
- Organization

**Estimating**

**QUELCE uses Scenario Planning Workshop techniques to discover unrecorded assumptions and constraints**

**Scoping**
- Deliverables
- Requirements
- Complexity
- Lifecycle

**Estimate**
- Size, defects, costs, duration, staffing
- Documented inputs, assumptions
- Estimating method
- Comparable projects
- Sensitivity analysis
New 2015 Cost Challenge: Incorporating Capability Tradeoffs

DoD recommends the Use of Multi-Attribute Decision Model (MADM)

“…use the knowledge of capability trade-offs to determine where a small trade in capability (e.g., top speed of an aircraft) could be adjusted for large cost savings.”

Cost Capability Analysis, by Frank Delsing, Defense AT&L: September–October 2015, p12

**QUELCE more richly supports this challenge using scenario analysis within the Bayesian Belief Network (BBN) probabilistic model**
### The QUELCE Solution

1. Expand Number of Change Drivers and Alternatives
2. Cause and Effect Analysis. Reduce Complexity
3. Assign Conditional Probabilities Build BBN Model
4. Apply Uncertainty to Cost Formula Inputs for Basis and Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

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### 1. Driver State Matrix

<table>
<thead>
<tr>
<th>Scope</th>
<th>DAES, SRDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUELCE Change Repository</td>
<td>Query DoD Experience &amp; Context</td>
</tr>
</tbody>
</table>

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### 2. Dependency Structure Matrix

<table>
<thead>
<tr>
<th>Causes</th>
<th>Effects</th>
<th>Change Drivers - Causes &amp; Effects Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission / CONOPS</td>
<td>Change in Strategic Vision</td>
<td></td>
</tr>
<tr>
<td>Capability Definition</td>
<td>Advocacy Change</td>
<td></td>
</tr>
<tr>
<td>Closing Technical Gaps (CBA)</td>
<td>Building Technical Capability &amp; Capacity (CBA)</td>
<td></td>
</tr>
<tr>
<td>Interoperability</td>
<td>Systems Design</td>
<td></td>
</tr>
<tr>
<td>Functional Measures</td>
<td>Interdependency</td>
<td></td>
</tr>
<tr>
<td>Scope Definition</td>
<td>Functional Solution Criteria (measure)</td>
<td></td>
</tr>
<tr>
<td>Funding Schedule</td>
<td>Acquisition Management</td>
<td></td>
</tr>
<tr>
<td>Program Mgt - Contractor Relations</td>
<td>Project Social / Dev Env</td>
<td></td>
</tr>
<tr>
<td>Manning at program office</td>
<td>Prog Mgt Structure</td>
<td></td>
</tr>
</tbody>
</table>

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### 3. BBN Model

![Bayesian Network Diagram]

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### 4. Cost Factor Distributions by Scenario of Change

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>XH</th>
<th>VH</th>
<th>L</th>
<th>N</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>CONOPS</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

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### 5. Monte Carlo with Cost Estimation Tools (e.g., COCOMO, SEER-SEM)

![Monte Carlo Simulation Diagram]
Results Pre-FY15

- SEI TR “The QUELCE Method”
- Presentation to Systems & Software Technology Conference (SSTC)
- Presentation to Int’l Cost Estimating and Analysis Association (ICEAA)
- Presentation to COCOMO Workshop at Univ. of Southern California
- SEI TR “Building a Domain Repository”
- Year 1 LENS Began
- QUELCE iTunes Podcast
- QUELCE SEI Webinar & Podcast
- DACS Journal of Software Technology
- SEI TR “Expert Judgment”
- SEI TR Webinar
- QUELCE SEI Webinar
- QUELCE Paper Published with Acquisition Research Symposium (ARS)
- SEI paper “A QUELCE Retrospective”

Timeline:
- 2010
- 2011
- 2012
- 2013
- 2014

- Socialization at 44th DoD Cost Analysis Symposium (DODCAS)
- 3 SEI Blog Post Series related to QUELCE
- QUELCE Paper Published with Acquisition Research Symposium (ARS)
Identification of New Change Drivers

- Confirmed expert reproducibility (coding change drivers in artifacts)
- Expanded taxonomy with sustainment/modernization change drivers

DoD and Defense Contractor Use

Machine learning to automatically recognize change drivers

- Created Coding Tool to create training data sets
- Implementing Natural Language Processing and Machine Learning Recognition of “Change Drivers”

Group expert judgment experiments

- Will be quantifying benefit of calibrated group judgment over individual judgment
- Will inform modeling of judgment uncertainty and affects deployment
Identification of New Change Drivers

<table>
<thead>
<tr>
<th>A</th>
<th>Acquisition Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1</td>
<td>Acquisition Category (ACAT) Status</td>
</tr>
<tr>
<td>A.2</td>
<td>Governance, Policies, and Standards</td>
</tr>
<tr>
<td>A.3</td>
<td>External Interdependencies / Coordination</td>
</tr>
<tr>
<td>A.4</td>
<td>External Stakeholders</td>
</tr>
<tr>
<td>A.5</td>
<td>External Events</td>
</tr>
<tr>
<td>A.6</td>
<td>Other: Acquisition Environment</td>
</tr>
<tr>
<td>B</td>
<td>Acquisition Management</td>
</tr>
<tr>
<td>B.1</td>
<td>Acquisition Strategy</td>
</tr>
<tr>
<td>B.2</td>
<td>Contracting</td>
</tr>
<tr>
<td>B.3</td>
<td>Management Structure</td>
</tr>
<tr>
<td>B.4</td>
<td>Program Scope</td>
</tr>
<tr>
<td>B.5</td>
<td>Budget</td>
</tr>
<tr>
<td>B.6</td>
<td>Schedule</td>
</tr>
<tr>
<td>B.7</td>
<td>Staffing</td>
</tr>
<tr>
<td>B.8</td>
<td>Facilities, Support Technology, and Equipment</td>
</tr>
<tr>
<td>B.9</td>
<td>Program Information Management</td>
</tr>
<tr>
<td>B.10</td>
<td>Program-Contractor Performance</td>
</tr>
<tr>
<td>B.11</td>
<td>Other: Acquisition Management</td>
</tr>
<tr>
<td>C</td>
<td>Engineering Solution / Work Products</td>
</tr>
<tr>
<td>C.1</td>
<td>Conceptual Design / Requirements</td>
</tr>
<tr>
<td>C.2</td>
<td>System Architecture and Design</td>
</tr>
<tr>
<td>C.3</td>
<td>Production and Construction</td>
</tr>
<tr>
<td>C.4</td>
<td>Certification and Accreditation</td>
</tr>
<tr>
<td>C.5</td>
<td>Deployment, Operations, and Support</td>
</tr>
<tr>
<td>C.6</td>
<td>Technology Maturity / Readiness</td>
</tr>
<tr>
<td>C.7</td>
<td>Estimated Complexity / Difficulty</td>
</tr>
<tr>
<td>C.8</td>
<td>Supply Chain Products</td>
</tr>
<tr>
<td>C.9</td>
<td>Other: Engineering Solution / Work Products</td>
</tr>
</tbody>
</table>

Sample of Additional Sustainment/Modernization Change Drivers

- Knowledge Transfer During Handoff from Contractor to DoD Organic
- Relationships among the variety of sustainment stakeholders
- Information assurance/cybersecurity surprises require redesign of HW/SW
- Redesign needed to evolving requirements
- Administrative and organizational aspects of the evolving security situation
- Engineering Information Assurance and Cybersecurity Design
- Contracting difficulties
- Color of money during sustainment/modernization
- Adaptive Maintenance
- Perfective Maintenance
- Corrective Maintenance
- Staff recruitment and retention
- Disparate commercial tools
- Facility rework
- Data Rights

Approximately 20 additional drivers for sustainment projects

Reproducibility experiments yielded reasonable Kappa agreement scores 0.6 – 0.75
DoD and Defense Contractor Use

DoD Space and Missile Command program
1. Identified 47 applicable change drivers, majority of which were not documented in a previous cost estimate supplied to CAPE
2. Dramatic learning curve in expert judgment calibration across 6 key experts
3. Positive verbal and written feedback from program

Commercial Defense Contractor program
1. Primarily valued the expert judgment calibration training and improvement
2. Praised value of the change driver and scenario discussion and SEI dependency structure matrix (DSM) tool
3. Using QUELCE for a major program bid (Oct-Dec) with initial feedback:

   “...qualitatively seen a difference in our product owners' understanding and thought process associated with estimation...”
Machine Learning: Highlight Annotation Tool (Tool updates occurring in October)

Replacing commercial proof of concept tool with customized, free tool for future use by SEI and clients to code artifacts against a taxonomy

Will expand community contributions to the QUELCE repository producing a "living" profile of change driver frequency by program type/context

Experts to query repository during QUELCE workshops to inform judgment
Documents are represented in a generic UIMA format that can be consumed by existing tooling. Contains original text and metadata.

There can be one to many AEs. Each AE processes the document text or meta data and enhances the meta data.

AEs are loosely coupled and can be added or removed without major code changes.

Leverages CMU Watson techniques!
Group Expert Judgment Experiments
(October – December)

**Week 1**
- Test 1
  - 20 Questions
  - 52 Participants
  - Baseline of Untrained & UnCalibrated Experts & Groups

**Week 2**
- Test 2
  - 20 Questions
  - 52 Participants
  - Baseline of Newly Trained Experts

**Week 3+**
- Test 3
  - 20 Questions
  - 52 Participants
  - Baseline of Moderately Trained Experts

- Test 4
  - 20 Questions
  - 52 Participants
  - Baseline of Trained & Steady State Experts & Groups

Score / Feedback / Train

13 Groups of 4
Future Deployment Steps

Complete transition artifacts
- Process aids, checklists, online training, automation templates and custom tools

Establish a community of practice
- Integrate into DoD cost community at DoD and Service Level
- Integrate into DAU curriculum
- Host evolving QUELCE repository with community contributions

Engage with cost estimation tool vendors
- Arrange for seamless QUELCE automated front-end plug-and-play to existing tools

Deploy stand-alone on-line training and testing for calibration of expert judgment

Integrate QUELCE with Security Engineering Risk Analysis (SERA)
Summary

Novel Solution:
1. Scenario planning workshop techniques
2. Calibrated expert judgment
3. Sources of uncertainty in program execution
4. Modeled within a Bayesian Belief Network (BBN)
5. Connects to the input side of existing Cost Estimating Relationships (CERs) using Monte Carlo simulation

Impact:
1. Additional change drivers informed the next DoD program estimate
2. Change driver taxonomy and BBN supported Contractor scenarios
3. Validation highlighted direct primary benefits of calibrating expert judgment
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