# Quantifying Uncertainty in Early Lifecycle Cost Estimation for DOD MDAPs


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# Early cost estimation methods often result in highly inaccurate program cost predictions – and it continues to worsen

**Table 1: Analysis of DOD Major Defense Acquisition Program Portfolios**

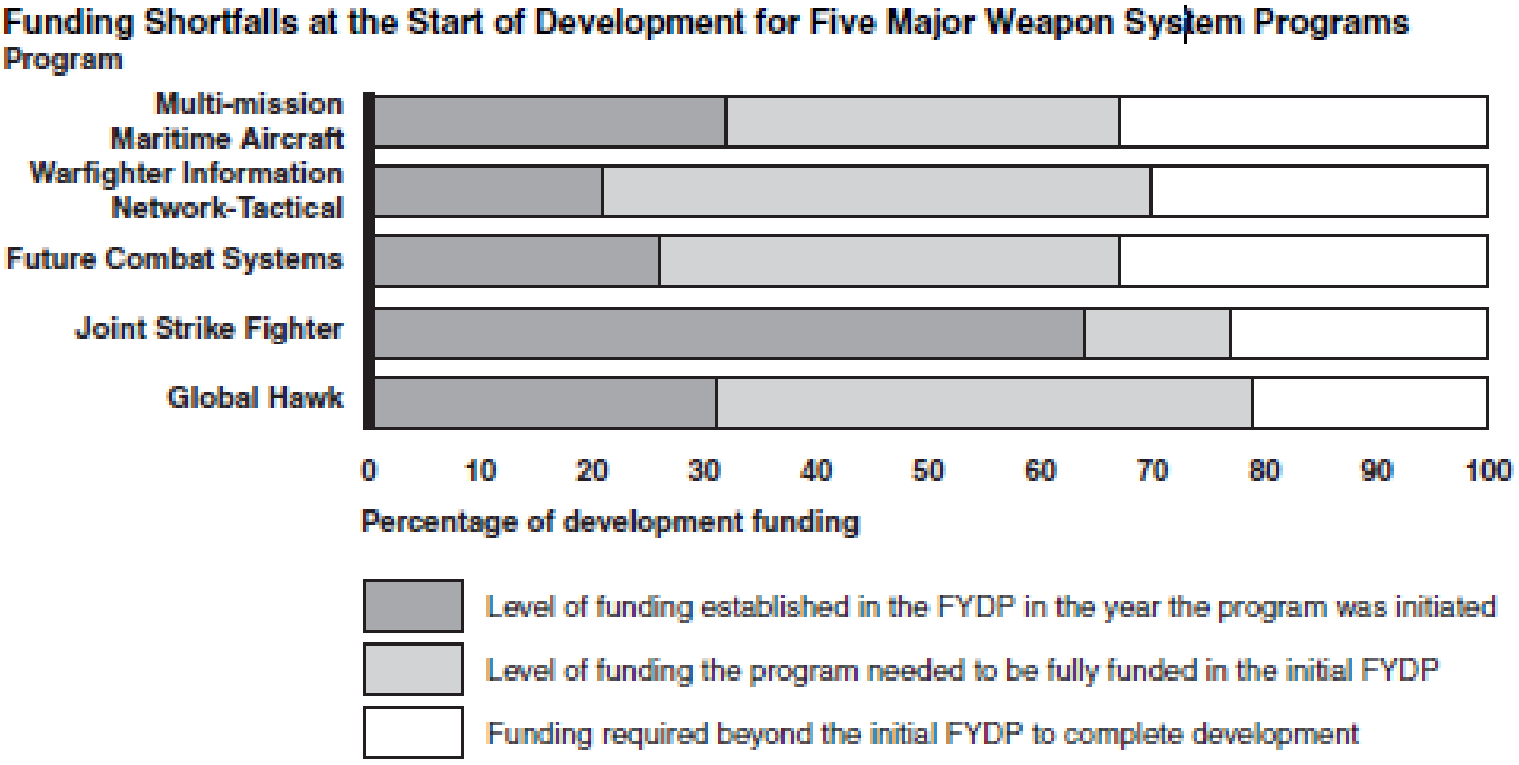
| Fiscal year 2008 dollars | | | |
|---|---|---|---|
| | Fiscal year | | |
| | 2000 portfolio | 2005 portfolio | 2007 portfolio |
| **Portfolio size** | | | |
| Number of programs | 75 | 91 | 95 |
| Total planned commitments | $790 Billion | $1.5 Trillion | $1.6 Trillion |
| Commitments outstanding | $380 Billion | $887 Billion | $858 Billion |
| **Portfolio performance** | | | |
| Change to total RDT&E costs from first estimate | 27 percent | 33 percent | 40 percent |
| Change in total acquisition cost from first estimate | 6 percent | 18 percent | 26 percent |
| Estimated total acquisition cost growth | $42 Billion | $202 Billion | $295 Billion |
| Share of programs with 25 percent or more increase in program acquisition unit cost | 37 percent | 44 percent | 44 percent |
| Average schedule delay in delivering initial capabilities | 16 months | 17 months | 21 months |

Source: GAO analysis of DOD data.

Unsustainable negative trend in cost predictions

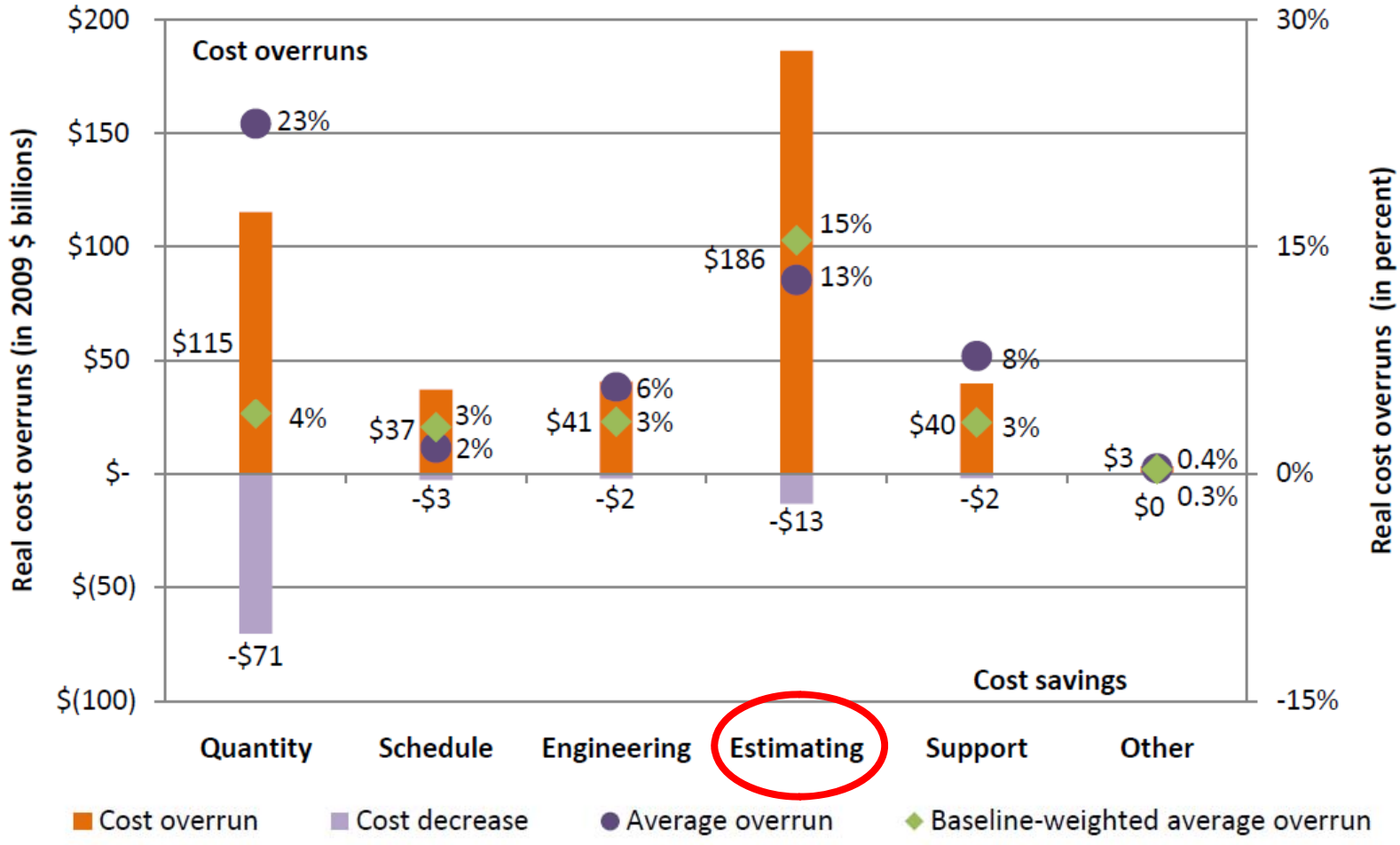
**Source: *Fundamental Changes Are Needed to Improve Weapon Program Outcomes*, GAO Testimony Before the Subcommittee on Federal Financial Management, Government Information, Federal Services, and International Security, Committee on Homeland Security and Governmental Affairs, U.S. Senate, Sept 25, 2008 GAO-08-1159T**

**"DOD's flawed funding process is largely driven by decision makers' willingness to accept unrealistic cost estimates and DOD's commitment to more programs than it can support. DOD often underestimates development costs—due in part to a lack of knowledge and optimistic assumptions about requirements and critical technologies." ***




***Source:** ***A Knowledge-Based Funding Approach Could Improve Major Weapon System Program Outcomes*****, GAO Report to the Committee on Armed Services, U.S. Senate s, U.S. Senate, July, 2008 GAO-08-619**

# Functional reasons for cost overruns




Source: December 2009 SAR; analysis by CSIS Defense-Industrial Initiatives Group
***Cost and Time Overruns for Major Defense Acquisition Programs***, 2010

# The Uncertainty Problem

“”..programs that breach appear to have the strongest relationship with three factors: the total dollar size of a project, the quantity change cost category, and the estimating cost changes.

...

Much of the data collected now does not help decision-makers determine why a breach or unit-cost-growth has occurred or what programmatic changes would improve performance.

...

The available information makes it difficult to assert any conclusions definitively because all factors appear interrelated, which means that an unconsidered exogenous variable may be confounding all conclusions.”

*The Effect Of The Nunn–McCurdy Amendment On Unitcost- Growth Of Defense Acquisition Projects,* By Jacques S. Gansler, William Lucyshyn, and Adam Spiers , Univ of MD Center for Public Policy and Private Enterprise, July 2010

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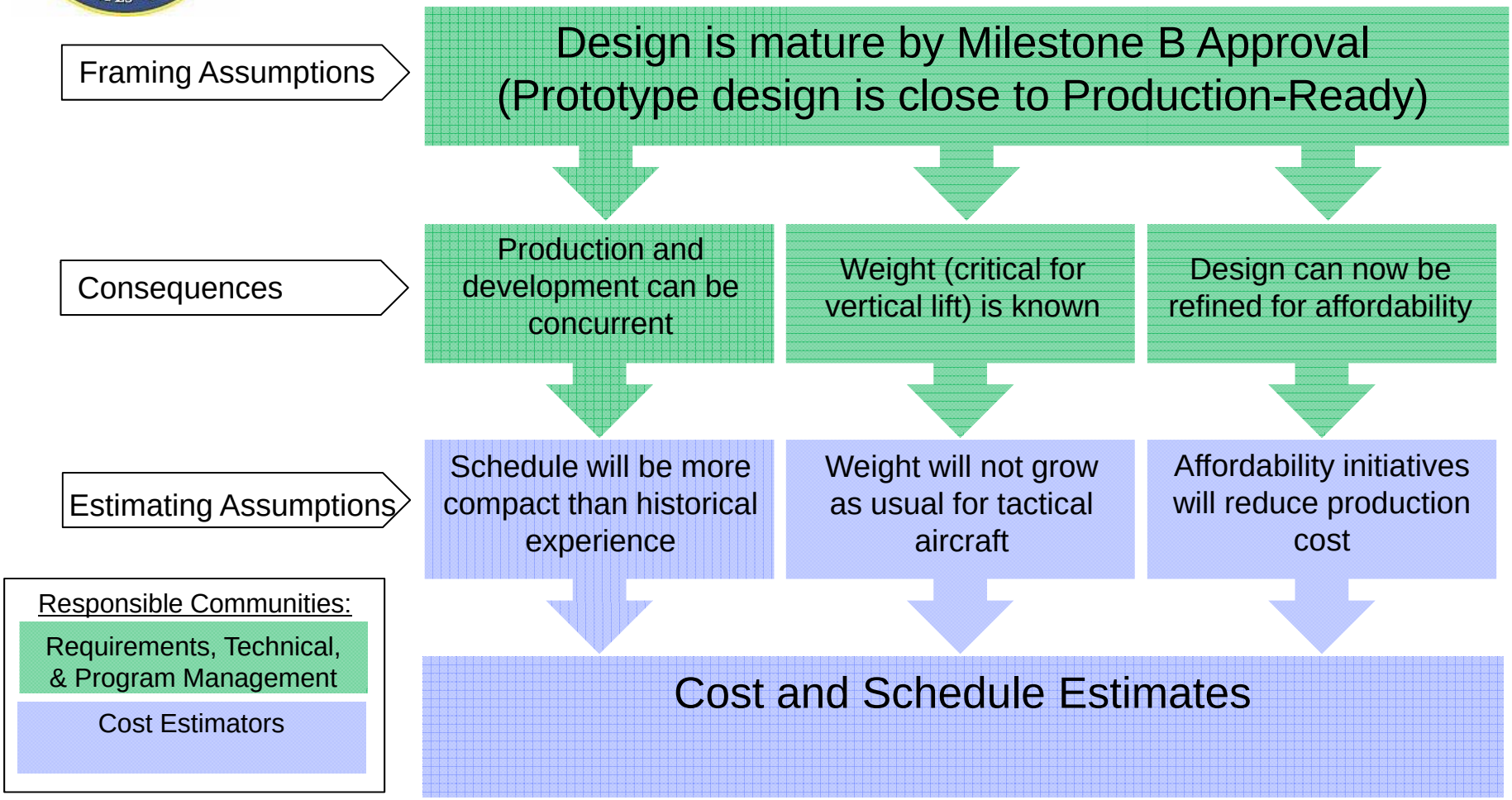
“Unrealistic estimates are caused by the invalidity of major cost-estimating assumptions, *not* methodological errors... PARCA deems an estimate to be unrealistic if it is based on an uncertain assumption. Such assumptions might concern technical issues, related programs, organizational relationships, threats, policy matters or the industrial base.”

*Inside the Pentagon*, Vol. 27, No. 46, November 17, 2011

# Estimating Assumptions Flow from Framing Assumptions




* adapted from: *Observations from AT&L/PARCA's Root Cause Analyses*, David Nicholls (PARCA) at DODCAS 2012

# How do we address the challenges of early estimation?

Account for change and uncertainty during the DoD acquisition life cycle.

- Synthesis of *Dependency Structure Matrix techniques*, *Bayesian Belief Network (BBN) modeling* and *Monte Carlo simulation* into a method that models uncertainties among **program change drivers as inputs** to cost models
- Use of domain expert judgment and data-based inputs

DoD domain-specific method for improving **expert judgment** regarding uncertainty in program change drivers, their relationships, and impacts on cost drivers.

- Expert judgment is optimistic and uncalibrated.

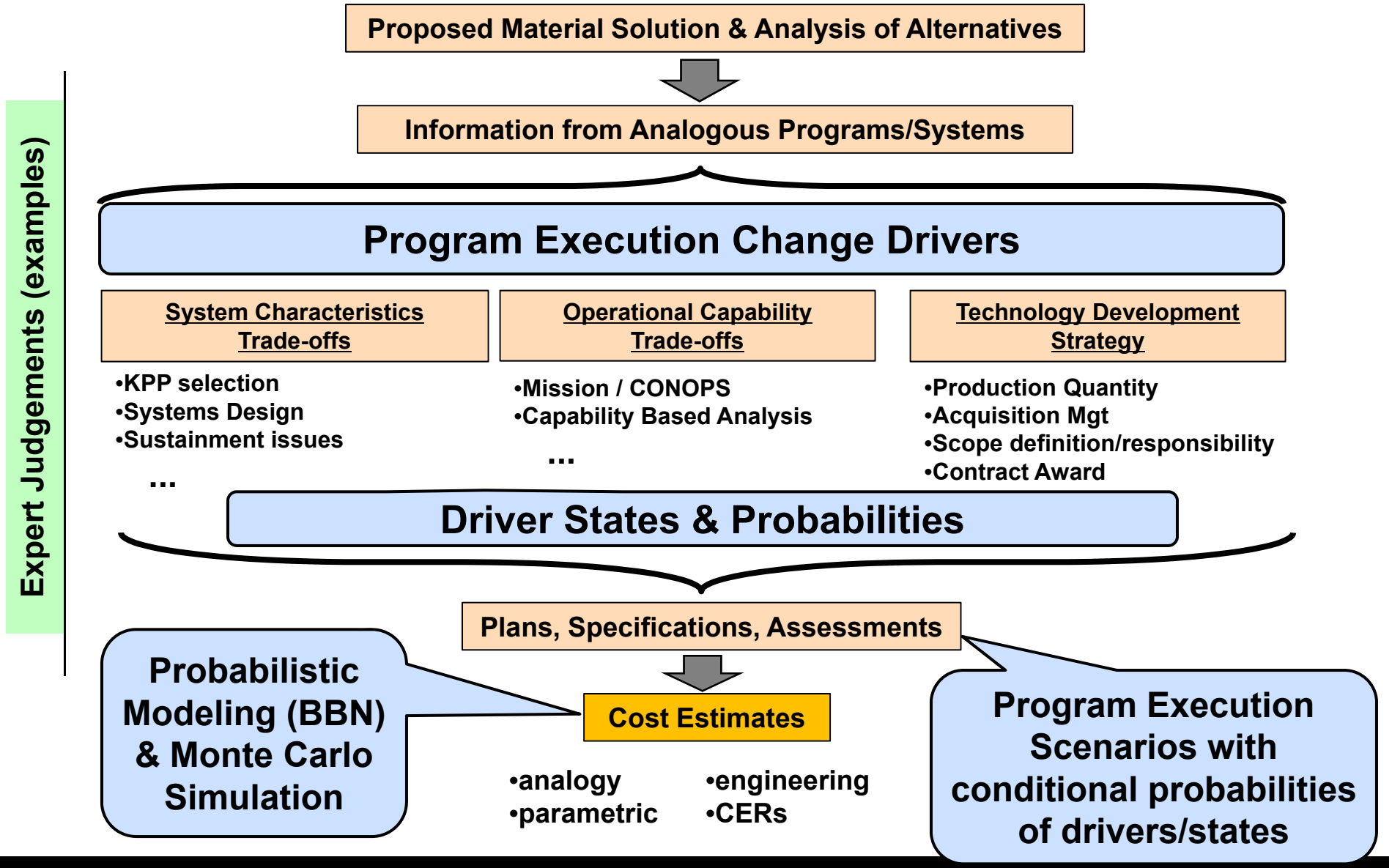
Information available at the start is not in a form typically used in preparing an estimate.

- Program does not yet have detailed scope and specifications.
- Can we model the uncertainties not captured by the estimate?
- **Visual depiction** of influential relationships, scenarios and outputs to aid team-based model development, and explicit description and documentation underlying an estimate.

Interdependencies cause problems to cascade.

- When a project goes off the rails there is often a cascade of problems before the magnitude of the problem becomes clear.
- Scenario modeling and simulation makes impact of changes visible.

# Information Flow for Early Lifecycle Estimation



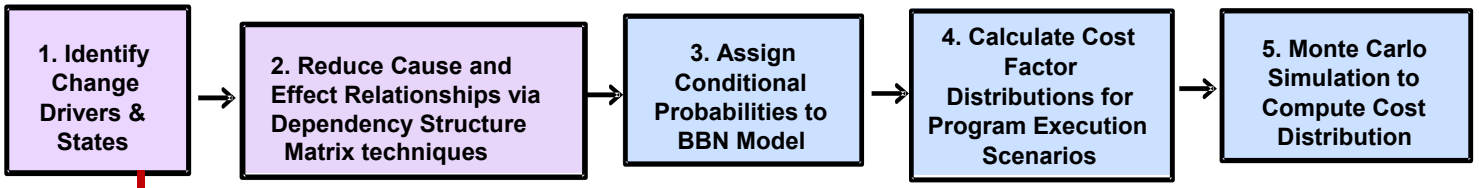
# Create a Method for Quantifying the Uncertainty of Cost Estimation Inputs and Resulting Estimates

| | |
|---|---|
| **1. Identify Change Drivers & States** | Explicitly identify potential change due to assumptions & external events. |
| **2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques** | Use "Dependency Structure Matrix (DSM) techniques to reduce complexity of interactions between change drivers. |
| **3. Assign Conditional Probabilities to BBN Model** | BBN modeling of a larger number of program change drivers for estimation than previous research. |
| **4. Calculate Cost Factor Distributions for Program Execution Scenarios** | Scenario modeling of alternate program executions to assess influence of various underlying assumptions. |
| **5. Monte Carlo Simulation to Compute Cost Distribution** | Monte Carlo simulation applied to estimation input parameters rather than output values. |

**Technical Problem** **Modeling Uncertainty** **Complexity Reduction**

# Step 1: Identify Change Drivers and States

**Materiel Solution Analysis Phase – Pre Milestone Estimate** **A**




| Change Driver | Nominal State | Alternative States | | | | |
|---|---|---|---|---|---|---|
| Scope Definition | Stable | Users added | Additional (foreign) customer | Additional deliverable (e.g. training & manuals) | Production downsized | Scope Reduction (funding reduction) |
| Mission / CONOPS | defined | New condition | New mission | New echelon | Program becomes Joint | |
| Capability Definition | Stable | Addition | Subtraction | Variance | Trade-offs [performance vs affordaility, etc.] | |
| Funding Schedule | Established | Funding delays tie up resources {e.g. operational test} | FFRDC ceiling issue | Funding change for end of year | Funding spread out | Obligated vs. allocated funds shifted |
| Advocac Change | | | | | Advocate | Service owner |
| Closing Technical Gaps (CBA) | Selected Trade studies are sufficient | Technology does not achieve satisfactory performance | Technology is too expensive | Selected solution cannot achieve desired outcome | Technology not performing as expected | New technology not testing well |
| • | ~~~~ | ~~~~ | ~~~~ | | | |
| • | ~~~~ | ~~~~ | ~~~~ | ~~~~ | | |
| • | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ | ~~~~ |

**Domain-Specific Program Change Drivers Identified**

# Step 2: Reduce Cause and Effect Relationships via Dependency Structure Matrix Techniques

**Materiel Solution Analysis Phase – Pre Milestone Estimate** A

1. Identify Change Drivers & States → 2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques → 3. Assign Conditional Probabilities to BBN Model → 4. Calculate Cost Factor Distributions for Program Execution Scenarios → 5. Monte Carlo Simulation to Compute Cost Distribution

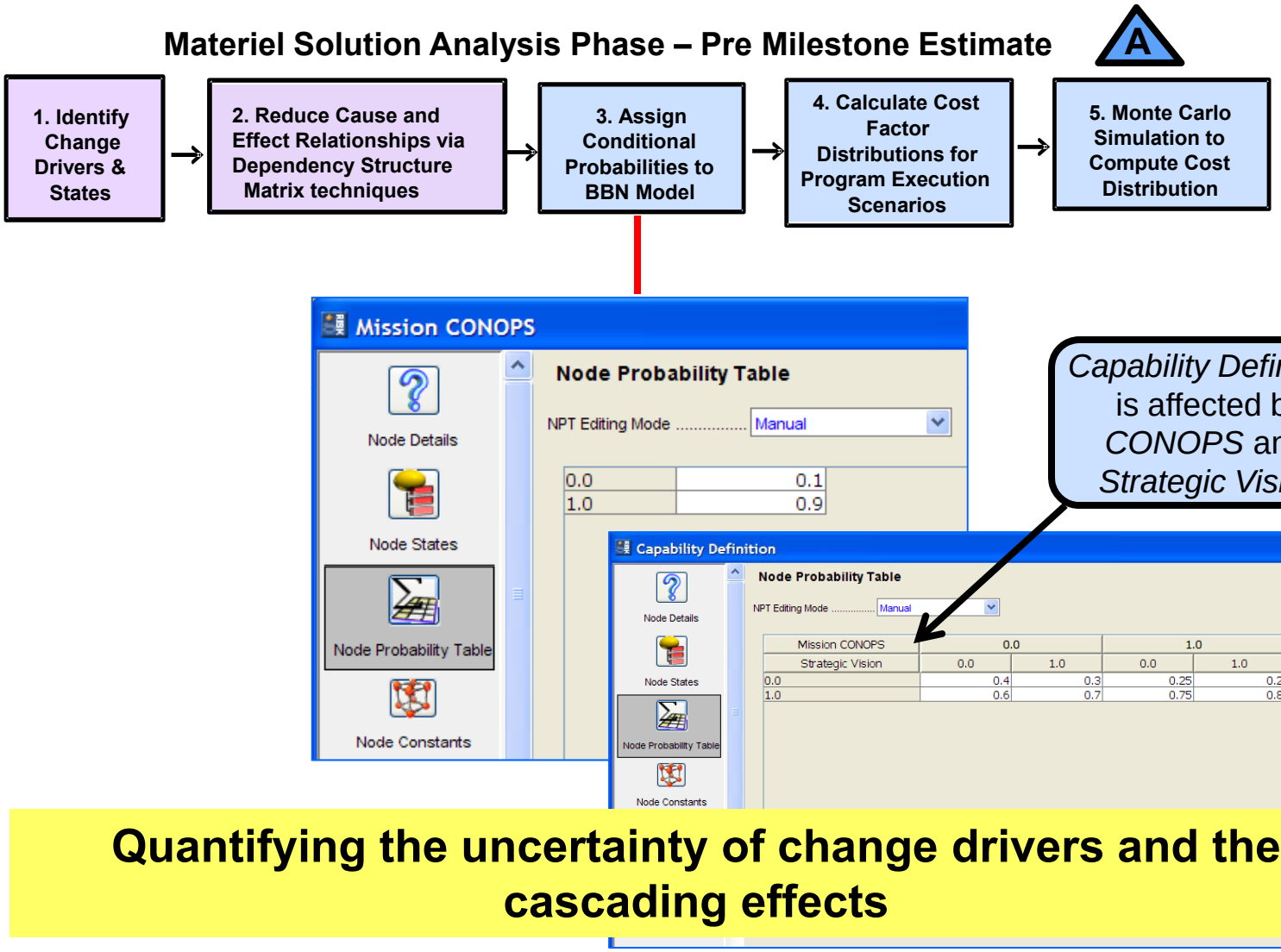
Change Drivers - Cause & Effects Matrix

| Causes \ Effects | Mission / CONOPS | Change in Strategic Vision | Capability Definition | Advocacy Change | Closing Technical Gaps (CBA) | Building Technical Capability & Capacity (CBA) | Interoperability | Systems Design | Interdependency | Functional Measures | Scope Definition | Functional Solution Criteria (measure) | Funding Schedule | Acquisition Management | Program Mgt - Contractor Relations | Project Social / Dev Env | Prog Mgt Structure | Manning at program office | Scope Responsibility | Standards/Certifications | Supply Chain Vulnerabilities | Information sharing | PO Process Performance | Sustainment Issues | Contract Award | Production Quantity | Data Ownership | Industry Company Assessment | Cost Estimate | Test & Evaluation | Contractor Performance | Size | Project Challenge | Product Challenge | Total | Number right of diagonal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mission / CONOPS | | | 3 | | | | | | | | 3 | | | | | | | | 0 | | | | | | | | | | | | | | | 6 | 0 |
| Change in Strategic Vision | | | 3 | 3 | | 3 | | | 2 | | | | 2 | | | | | | | | | 2 | | 2 | 2 | 3 | | 2 | 3 | 2 | | | | 29 | 0 |
| Capability Definition | | | | | | | | 3 | | | | | 0 | 2 | 1 | 1 | 0 | 0 | | 2 | 2 | 2 | 0 | 1 | 0 | 2 | 0 | | | | 0 | | | | 16 | 0 |
| Advocacy Change | | | | | | | | | | | 2 | | | 1 | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | 6 | 0 |
| Closing Technical Gaps (CBA) | | | | | | 2 | 1 | 3 | 1 | 2 | | 2 | | 1 | 2 | 2 | | | 1 | 1 | 2 | 1 | 0 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | | | | 34 | 0 |
| Building Technical Capability & Capacity (CBA) | | | | | | | | | 1 | 1 | | 2 | | 1 | 2 | 2 | 1 | | | | 2 | 3 | | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | | | | 27 | 0 |
| Interoperability | | | | | | 1 | | 2 | 1 | | 1 | 1 | | 1 | 1 | 1 | | | 1 | 1 | 2 | 1 | 1 | 2 | | | 1 | | 1 | 3 | 1 | 2 | 2 | 2 | 29 | 1 |
| Systems Design | | | | | | 1 | 2 | | 2 | 2 | | 2 | | | | | | | 1 | | 1 | 1 | | 1 | | | 1 | 2 | 2 | 3 | | | | | 21 | 3 |
| Interdependency | | | | | 1 | | 2 | 2 | | | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | | | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 33 | 5 |
| Functional Measures | | | | | | | | | | | | 2 | | | 2 | 2 | | | | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | | 2 | 1 | | | | 16 | 0 |
| Scope Definition | | | | | | | | | | | | | | | | | 1 | 1 | 3 | | | | | | | | | | | | | | | | 5 | 0 |
| Functional Solution Criteria (measure) | | | | | | | | | 1 | | | | | | 2 | 2 | | | | 1 | | | | | | | | 1 | | 2 | 1 | | | | 10 | 1 |
| Funding Schedule | | | | | | | | | | | | | | 1 | | | | 1 | | | | | 2 | | | | | | | | 1 | | | | 5 | 0 |
| Acquisition Management | | | | | | | | | | 1 | | 1 | | | 2 | 3 | | | | | 1 | 1 | 2 | | 2 | | 1 | 1 | 1 | | 2 | | | 1 | 19 | 2 |
| Program Mgt - Contractor Relations | | | | | | | | | | 1 | | 1 | | | | 2 | | | | | | 1 | 1 | 1 | | | | | | 1 | 2 | | | 2 | 12 | 2 |
| Project Social / Dev Env | | | | | | | | | | | | | | 1 | 1 | | | | | | | 1 | 2 | | 2 | | 1 | | | 1 | 2 | 1 | 1 | 1 | 14 | 2 |
| Prog Mgt Structure | | | | | | | | | | | | | | | | | 1 | 2 | | | | 1 | 2 | | | | | | | | | | | | 6 | 1 |
| Manning at program office | | | | | | | | | | | | | | | | | 2 | | | | | 1 | 2 | | | | | | | | | | | | 5 | 2 |
| Scope Responsibility | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | 1 | | | | | | | | | | | | 6 | 5 |
| Standards/Certifications | | | | | | 1 | | | | | | 1 | | | | | | | | | 1 | | | 1 | 1 | | | 1 | | 3 | 1 | | | | 10 | 2 |
| Supply Chain Vulnerabilities | | | | | | | | 1 | | | | | 1 | 1 | | | | | | 1 | | | | | | 2 | | | | | 1 | | | | 7 | 4 |
| Information sharing | | | | | 1 | 1 | | 1 | | | | | | | | | | | | | | 1 | 1 | | | | 1 | | | | 1 | | | | 7 | 3 |
| PO P | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sust | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cont | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Prod | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Data | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Indu | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cost | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Test | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cont | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Size | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Project Challenge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 |
| Product Challenge | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0 | 0 |
| Totals | 0 | 0 | 6 | 4 | 1 | 9 | 5 | 12 | 8 | 7 | 7 | 13 | 4 | 10 | 15 | 18 | 7 | 7 | 8 | 8 | 14 | 17 | 17 | 15 | 12 | 9 | 10 | 13 | 11 | 20 | 19 | 5 | 5 | 17 | | |
| Below diagonal | 0 | 0 | 0 | 1 | 1 | 4 | 4 | 4 | 1 | 2 | 0 | 3 | 1 | 3 | 2 | 2 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |

**Capturing interrelationships among change drivers and reducing the complexity of the network**

# Step 3: Assign Conditional Probabilities to BBN Model

**Materiel Solution Analysis Phase – Pre Milestone Estimate**



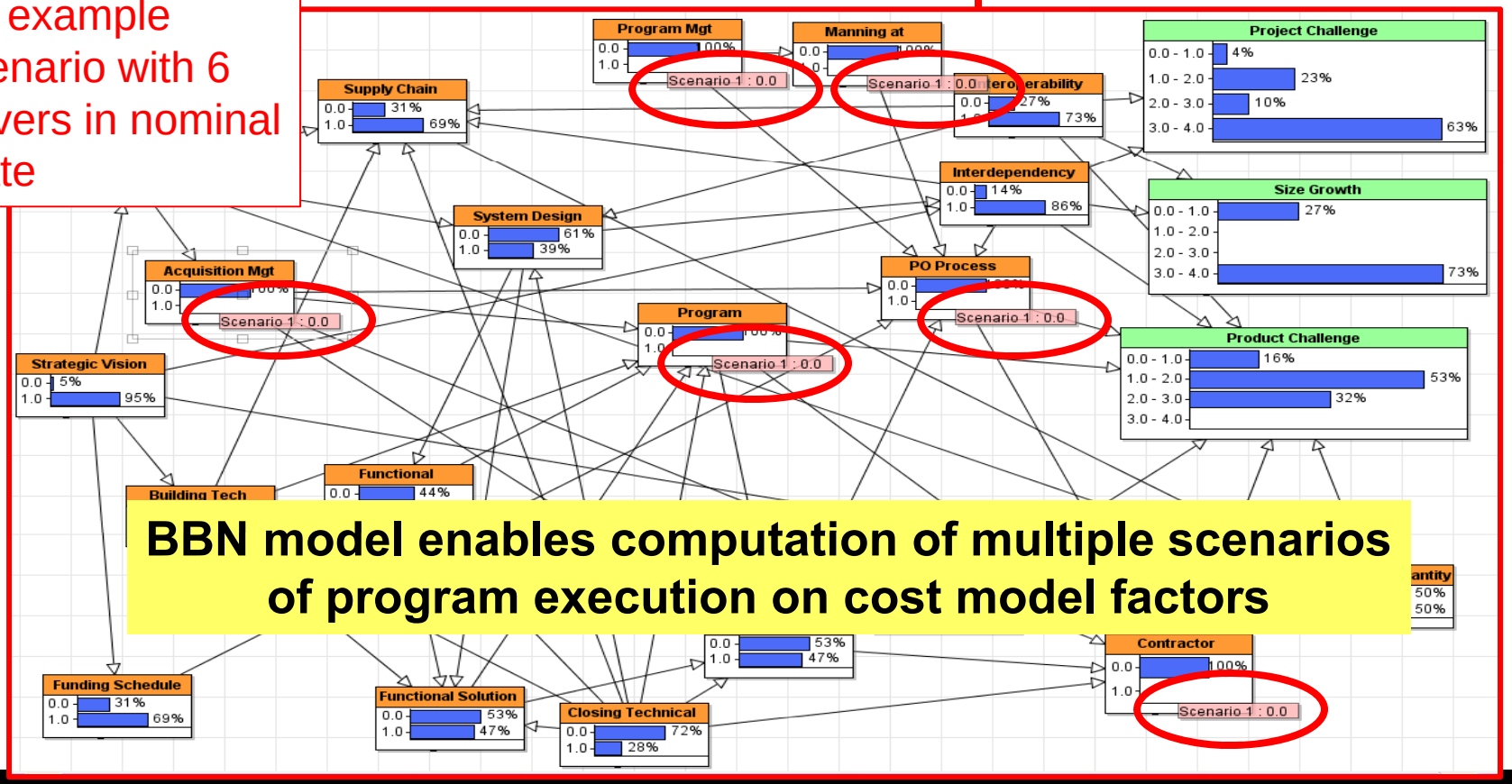

**Quantifying the uncertainty of change drivers and the cascading effects**

# Step 4: Calculate Cost Factor Distributions for Program Execution Scenarios

**Materiel Solution Analysis Phase – Pre Milestone Estimate** 


1. Identify Change Drivers & States → 2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques → 3. Assign Conditional Probabilities to BBN Model → 4. Calculate Cost Factor Distributions for Program Execution Scenarios → 5. Monte Carlo Simulation to Compute Cost Distribution

An example scenario with 6 drivers in nominal state




**BBN model enables computation of multiple scenarios of program execution on cost model factors**

# Step 5a: Monte Carlo Simulation to Compute Cost Distribution

**Materiel Solution Analysis Phase – Pre Milestone Estimate** (A)

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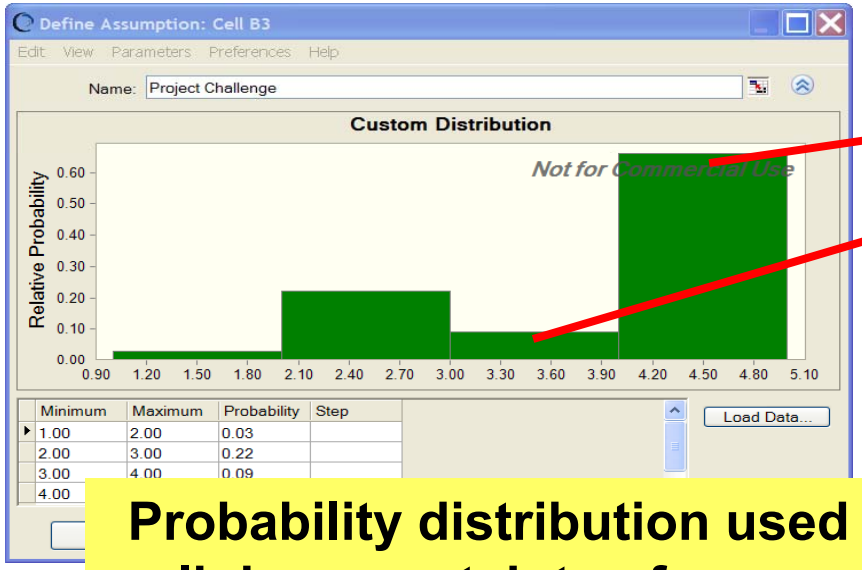
**BBN output distributions mapped to COCOMO input values**




| Drivers | XL | VL | L | N | H | VH | XH | Product | Project |
|---|---|---|---|---|---|---|---|---|---|
| **Scale Factors** | | | | | | | | | |
| PREC | | 6.20 | 4.96 | 3.72 | 2.48 | 1.24 | 0.00 | | <X> |
| FLEX | | 5.07 | 4.05 | 3.04 | 2.03 | 1.01 | 0.00 | <X> | |
| RESL | | 7.07 | 5.65 | 4.24 | 2.83 | 1.41 | 0.00 | <X> | |
| TEAM | | 5.48 | 4.38 | 3.29 | 2.19 | 1.10 | 0.00 | | <X> |
| PMAT | | 7.80 | 6.24 | 4.68 | 3.12 | 1.56 | 0.00 | | <X> |
| **Effort Multipliers** | | | | | | | | | |
| RCPX | 0.49 | 0.60 | 0.83 | 1.00 | 1.33 | 1.91 | 2.72 | X | |
| RUSE | | | 0.95 | 1.00 | 1.07 | 1.15 | 1.24 | X | |
| PDIF | | | 0.87 | 1.00 | 1.29 | 1.81 | 2.61 | X | |
| PERS | 2.12 | 1.62 | 1.26 | 1.00 | 0.83 | 0.63 | 0.50 | <X> | |
| PREX | 1.59 | 1.33 | 1.12 | 1.00 | 0.87 | 0.74 | 0.62 | | <X> |
| [illegible] | | | | | | | | | <X> |
| [illegible] | | | | | | | | | <X> |

**Probability distribution used for input to cost estimation model links uncertainty of program change drivers to cost drivers**

# Step 5b: Monte Carlo Simulation to Compute Cost Distribution

**Materiel Solution Analysis Phase – Pre Milestone Estimate** (A)

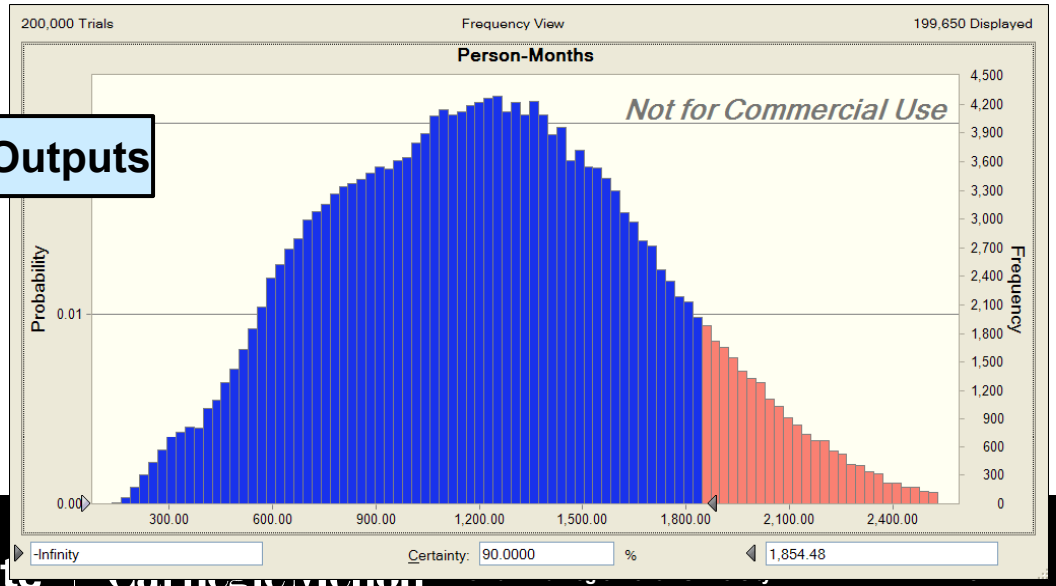
1. Identify Change Drivers & States
2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques
3. Assign Conditional Probabilities to BBN Model
4. Calculate Cost Factor Distributions for Program Execution Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

**Monte Carlo simulation using program change factor distributions uses uncertainty on the input side to determine the cost estimate distribution**

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Effect | | | |
| 2 | Product Challenge | 5 | | |
| 3 | Project Challenge | 4 | | |
| 4 | Estimated Size (KSLOC) | 50 | | |
| 5 | Product Challenge factors | | 5 | |
| 6 | COCOMO Parameter | | XL | VL |
| 7 | Scale Factors | PREC | | 4 |
| 8 | | Val | | 6.2 |
| 9 | | FLEX | | 5 |

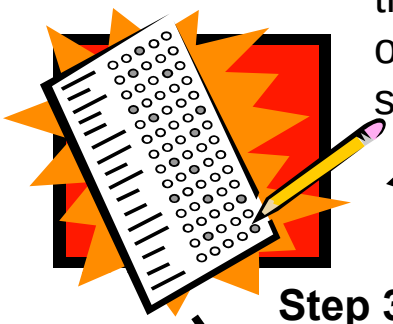
BBN Outputs

Mapped COCOMO value

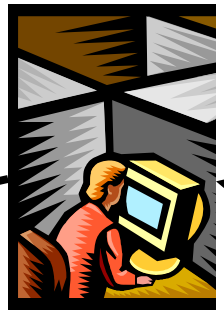


# Develop Efficient Techniques To Calibrate Expert Judgment of Program Uncertainties

Solution



**Step 2**: Iterate through a series of domain specific tests

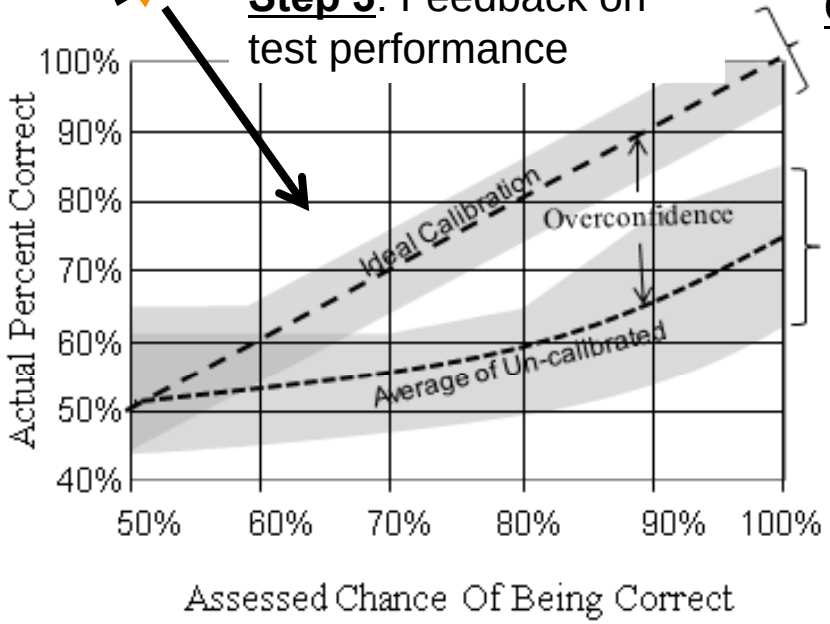


**Step 1**: Virtual training using reference points

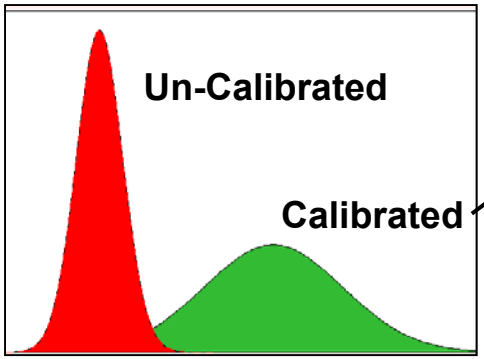
**DoD Domain-Specific reference points**

1) **Size of ground combat vehicle targeting feature xyz in 2002 consisted of 25 KSLOC Ada**
2) **Size of Army artillery firing capability feature abc in 2007 consisted of 18 KSLOC C++**
3) **…**

**Step 3**: Feedback on test performance



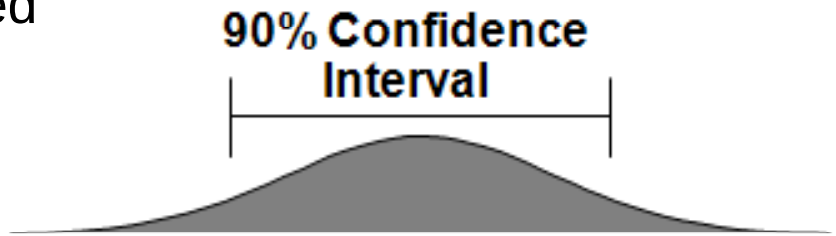

**Outcome**: Expert renders calibrated estimate of size




Calibrated = more realistic size and wider range to reflect true expert uncertainty

# Experts Tend to Be Over-Confident

Most people are significantly ***overconfident*** about their estimates, especially educated professionals




(AIE = Hubbard Generic Calibration Training)

| Group | Subject | % Correct (target 90%) |
|---|---|---|
| Harvard MBAs | General Trivia | 40% |
| Chemical Co. Employees | General Industry | 50% |
| Chemical Co. Employees | Company-Specific | 48% |
| Computer Co. Managers | General Business | 17% |
| Computer Co. Managers | Company-Specific | 36% |

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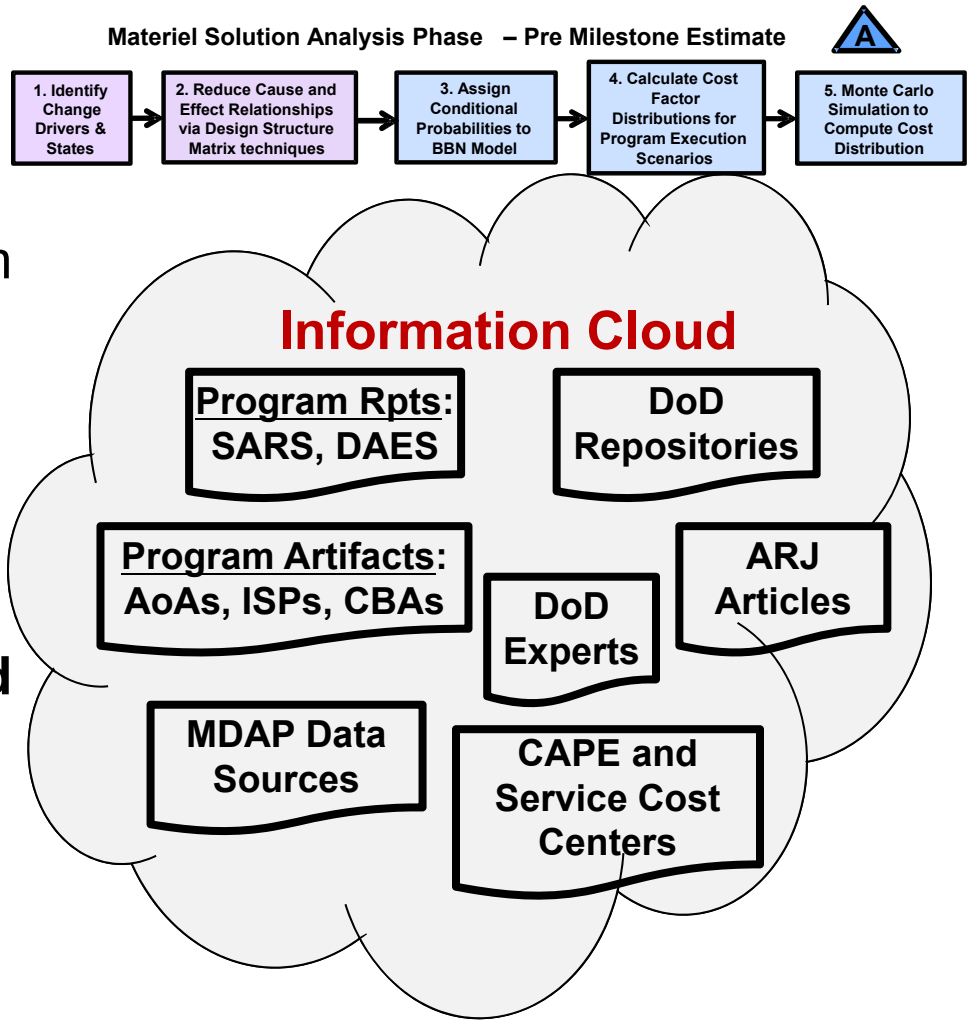
# Future Research Activities

# Create Repository for Quantifying Program Execution Uncertainties

Subject Matter Experts need DoD MDAP **data about uncertainty** to quantify relationships of program change drivers and their impact on program execution.

**Why Hard**? Empirical data need to be identified, accessed, extracted and analyzed from a **myriad of sources**. Data about program change is **not structured nor quantified** for use in estimation.

**DoD Need**: Quantified information about **cost driver uncertainty** should inform estimates.

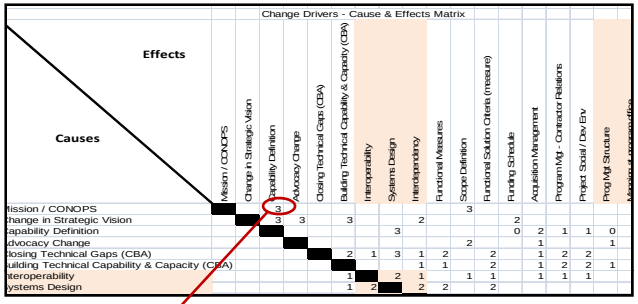


# Quantifying Uncertainty in Early Life Cycle Cost Estimation

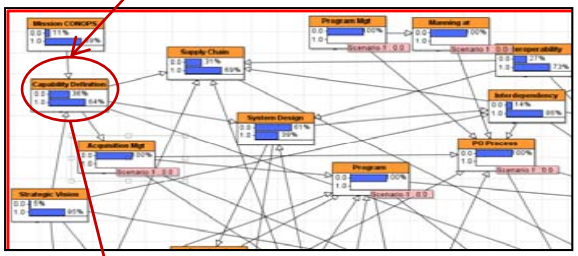
**Materiel Solution Analysis Phase – Pre Milestone Estimate** (A)

1. Identify Change Drivers & States
2. Reduce Cause and Effect Relationships Via Matrix transformation
3. Assign Conditional Probabilities to BBN Model
4. Calculate Cost Factor Distributions for Program Execution Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

**Program Change Factor Matrix**




**BBN Model**



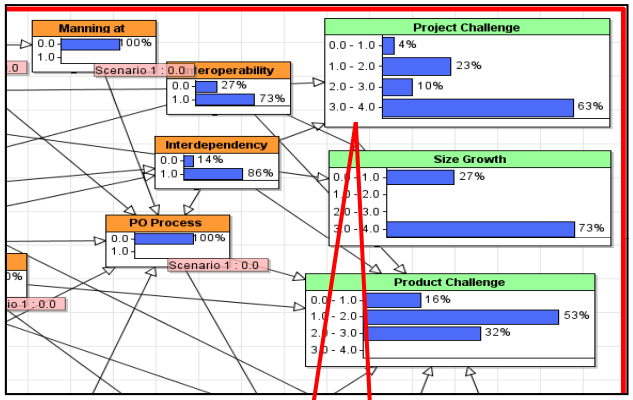
**BBN Probabilities**

**Node Probability Table (Capability Definition)**

NPT Editing Mode ..... Manual

| Mission CONOPS | 0.0 | | 1.0 | |
|---|---|---|---|---|
| Strategic Vision | 0.0 | 1.0 | 0.0 | 1.0 |
| 0.0 | 0.4 | 0.3 | 0.25 | 0.2 |
| 1.0 | 0.6 | 0.7 | 0.75 | 0.8 |

**BBN Model linked to Cost Model Inputs**




| Drivers | XL | VL | L | N | H | VH | XH | Product | Project |
|---|---|---|---|---|---|---|---|---|---|
| **Scale Factors** | | | | | | | | | |
| PREC | | 6.20 | 4.96 | 3.72 | 2.48 | 1.24 | 0.00 | | <X> |
| FLEX | | 5.07 | 4.05 | 3.04 | 2.03 | 1.01 | 0.00 | <X> | |
| RESL | | 7.07 | 5.65 | 4.24 | 2.83 | 1.41 | 0.00 | <X> | |
| TEAM | | 5.48 | 4.38 | 3.29 | 2.19 | 1.10 | 0.00 | | <X> |
| PMAT | | 7.80 | 6.24 | 4.68 | 3.12 | 1.56 | 0.00 | | <X> |
| **Effort Multipliers** | | | | | | | | | |
| RCPX | 0.49 | 0.60 | 0.83 | 1.00 | 1.33 | 1.91 | 2.72 | X | |
| RUSE | | | 0.95 | 1.00 | 1.07 | 1.15 | 1.24 | X | |
| PDIF | | | 0.87 | 1.00 | 1.29 | 1.81 | 2.61 | X | |
| PERS | 2.12 | 1.62 | 1.26 | 1.00 | 0.83 | 0.63 | 0.50 | <X> | |
| PREX | 1.59 | 1.33 | 1.12 | 1.00 | 0.87 | 0.74 | 0.62 | | <X> |
| FCIL | 1.43 | 1.30 | 1.10 | 1.00 | 0.87 | 0.73 | 0.62 | | <X> |
| SCED | | 1.43 | 1.14 | 1.00 | 1.00 | 1.00 | | | <X> |

# Repository: Analyze Existing Data to Model Program Execution Uncertainties - 1

## Solution

**Materiel Solution Analysis Phase – Pre Milestone Estimate** (A)

1. Identify Change Drivers & States
2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques
3. Assign Conditional Probabilities to BBN Model
4. Calculate Cost Factor Distributions for Program Execution Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

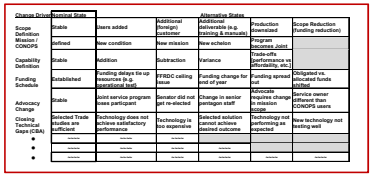
**Program Change Repository**

| Prog | State | Driver |
|---|---|---|
| DDG51 | cond 1 | CONOPS |
| | cond 2 | System |
| | cond 3 | CapDef |
| JTRS | cond 1 | InterOp |
| | cond 2 | Prod uc |
| F22 | cond 1 | Contract |
| | cond 2 | Function |
| | cond 3 | CONOPS |

For C2 systems, how often does Strategic Vision change?

**Records show that Strategic Vision changed in 45% of the MDAPS**

**Driver State Matrix**



**Problem 1 Solution**

Example: The **Materiel Solution** of a global network command and control system anticipates a possible change in **Strategic Vision** which will include allied participation.

Sharing information with allies creates new encryption requirements (a change in **Mission/CONOPs).**

These changes lead to changes in **Capability Definition**.

**Repository identifies historical probability of change in MDAP cost drivers.**

# Repository: Analyze Existing Data to Model Program Execution Uncertainties - 2

## Solution

**Materiel Solution Analysis Phase – Pre Milestone Estimate** A

1. Identify Change Drivers & States
2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques
3. Assign Conditional Probabilities to BBN Model
4. Calculate Cost Factor Distributions for Program Execution Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

**Program Change Repository**

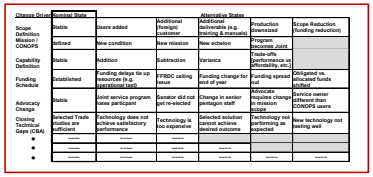
| Prog | State | Driver |
|---|---|---|
| DDG51 | cond 1 | CONOPS |
| | cond 2 | System De |
| | cond 3 | CapDef |
| JTRS | cond 1 | InterOpera |
| | cond 2 | Prod uctio |
| F22 | cond 1 | Contract |
| | cond 2 | Functional |
| | cond 3 | CONOPS |

If Strategic Vision changes, what else changes?

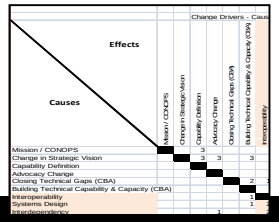
**70% of the time the Mission/CONOPS changes**

**Problem 2 Solution**

**Driver State Matrix**



**DSM Cause-Effect Matrix**




The **Materiel Solution** of a global network command and control system anticipates a possible change in **Strategic Vision** which will include allied participation.

Sharing information with allies creates new encryption requirements (a change in **Mission/CONOPs).**

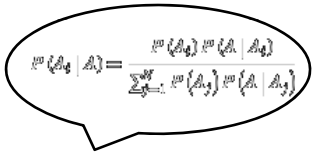
**Repository identifies cascading effects of change in MDAP cost drivers.**

# Repository: Analyze Existing Data to Model Program Execution Uncertainties - 3

## Solution

**Materiel Solution Analysis Phase – Pre Milestone Estimate**


1. Identify Change Drivers & States
2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques
3. Assign Conditional Probabilities to BBN Model
4. Calculate Cost Factor Distributions for Program Execution Scenarios
5. Monte Carlo Simulation to Compute Cost Distribution

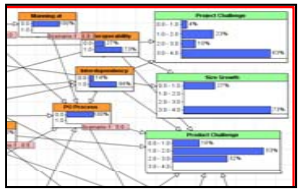


**When both Strategic Vision & Mission/CONOPs experience change, the BBN calculates that Capability Definition will also change 95% of the time.**

**Problem 2 Solution**

**Joint Conditional Probabilities can be calculated for downstream changes.**

**BBN Model**

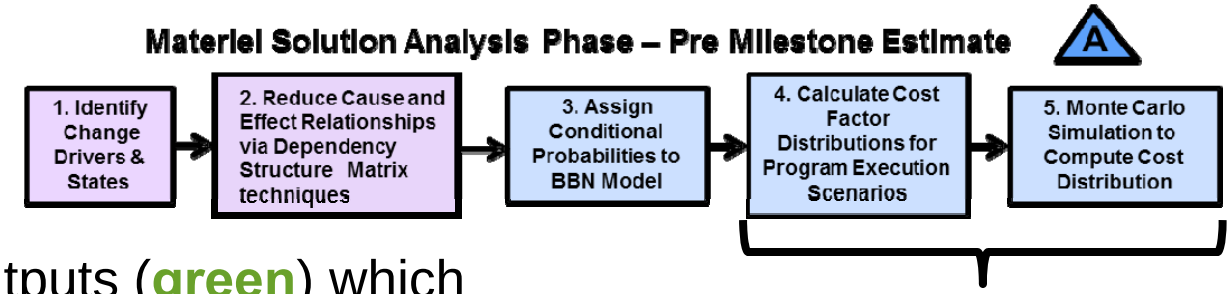


The **Materiel Solution** of a global network command and control system anticipates a possible change in **Strategic Vision** which will include allied participation.

Sharing information with allies creates new encryption requirements (a change in **Mission/CONOPs).**

These changes lead to changes in **Capability Definition**, which lead to cost impacts.

# Create a Method for Connecting BBNs to Cost Estimation Models - 1



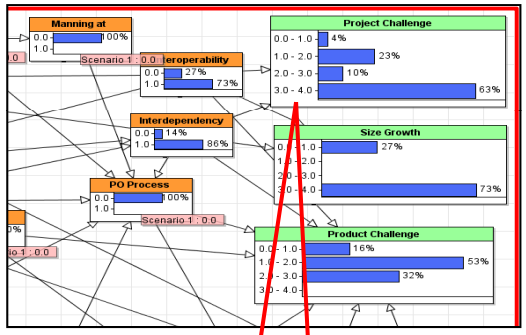

## Problem 1

Create a set of BBN outputs (**green**) which must be mapped to existing cost model input parameters (**red**).

**Why Hard?** DoD uses hundreds of Cost Estimation Relationships (CERs) and models. Each use different data and definitions for the many cost model input parameters.

**DoD Need**: Pre-Milestone A cost estimates need to incorporate uncertainty and cascading impacts of program change on cost drivers.

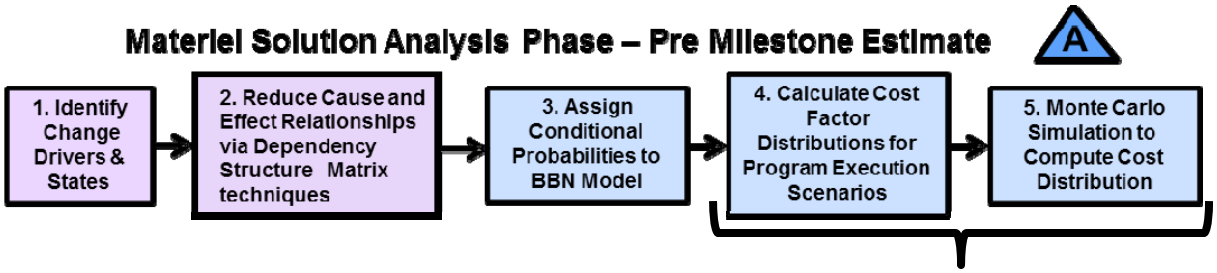
**BBN Model**




**COCOMO Cost Model Inputs**

| Drivers | XL | VL | L | N | H | VH | XH | Product | Project |
|---|---|---|---|---|---|---|---|---|---|
| **Scale Factors** | | | | | | | | | |
| PREC | | 6.20 | 4.96 | 3.72 | 2.48 | 1.24 | 0.00 | | <X> |
| FLEX | | 5.07 | 4.05 | 3.04 | 2.03 | 1.01 | 0.00 | <X> | |
| RESL | | 7.07 | 5.65 | 4.24 | 2.83 | 1.41 | 0.00 | <X> | |
| TEAM | | 5.48 | 4.38 | 3.29 | 2.19 | 1.10 | 0.00 | | <X> |
| PMAT | | 7.80 | 6.24 | 4.68 | 3.12 | 1.56 | 0.00 | | <X> |
| **Effort Multipliers** | | | | | | | | | |
| RCPX | 0.49 | 0.60 | 0.83 | 1.00 | 1.33 | 1.91 | 2.72 | X | |
| RUSE | | | 0.95 | 1.00 | 1.07 | 1.15 | 1.24 | X | |
| PDIF | | | 0.87 | 1.00 | 1.29 | 1.81 | 2.61 | X | |
| PERS | 2.12 | 1.62 | 1.26 | 1.00 | 0.83 | 0.63 | 0.50 | <X> | |
| PREX | 1.59 | 1.33 | 1.12 | 1.00 | 0.87 | 0.74 | 0.62 | | <X> |
| FCIL | 1.43 | 1.30 | 1.10 | 1.00 | 0.87 | 0.73 | 0.62 | | <X> |
| SCED | | 1.43 | 1.14 | 1.00 | 1.00 | 1.00 | | | <X> |

# Create a Method for Connecting BBNs to Cost Estimation Models - 2

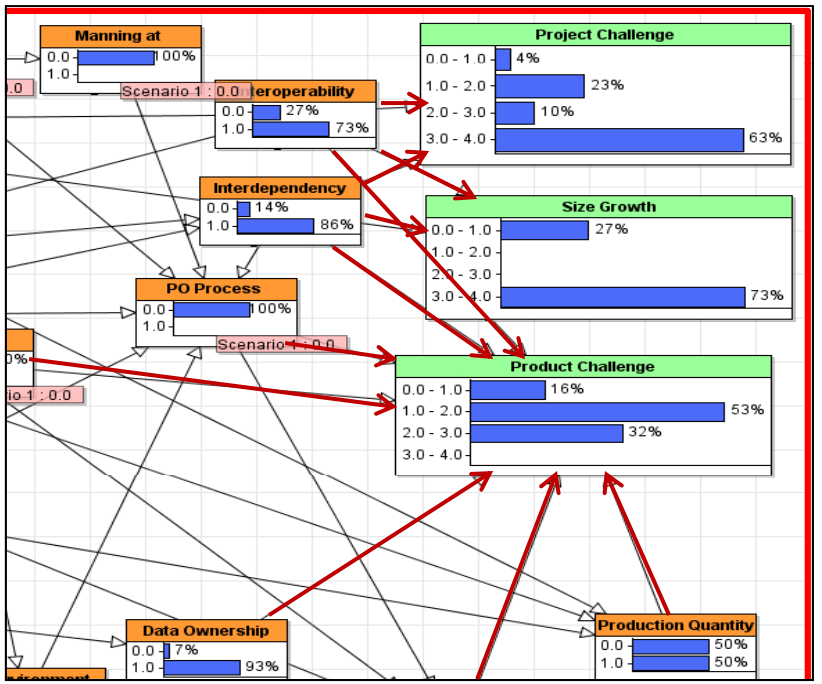



## Problem 2

A repeatable method is needed to map (**red arrows**) BBN change drivers (**orange**) to the new set of cost model inputs (**green**) .

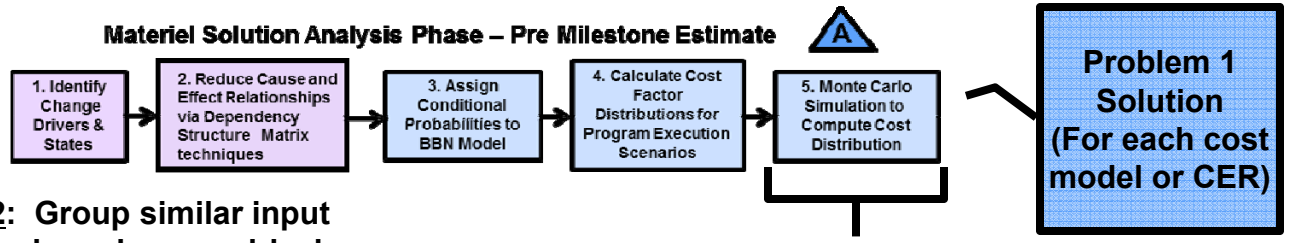
**Why Hard?** Several models are in use within the DoD and each program will need to produce its own specific mapping.

**DoD Need**: Need **high confidence in the range** of the estimate for budgeting and efficient portfolio management.



# Create a Method for Connecting BBNs to Cost Estimation Models - 3

## Solution




**Step 1**: Understand and analyze cost model input factors

**Step 2**: Group similar input factors based on empirical analysis in task 3.

**Step 3**: Use empirical analysis from Program Change Repository as basis to map scale (XL … EH) of original cost model input factors to scale (1…5) of newly-derived green input factors

| COCOMO Parameter | |
|---|---|
| Scale Factors | PREC |
| | FLEX |
| | RESL |
| | TEAM |
| | PMAT |
| Effort Multipliers | PERS |
| | RCPX |
| | PDIF |
| | PREX |
| | FCIL |
| | RUSE |

**Product Challenge factors** (1=low…5=high)

| COCOMO Parameter | | XL | VL | L | N | H | VH | EH |
|---|---|---|---|---|---|---|---|---|
| Scale Factors | PREC | | | 1 | 3 | 5 | | |
| | FLEX | | 1 | 2 | 3 | 5 | | |
| | RESL | 1 | 2 | 3 | 4 | 5 | | |
| Effort Multipliers | RCPX | | | 1 | 2 | 3 | 4 | 5 |
| | PDIF | | | 1 | 5 | | | |
| | RUSE | | | | 1 | 3 | 5 | |

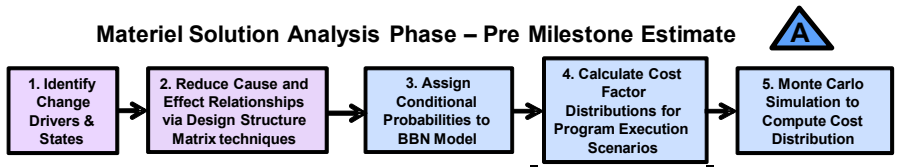
**Project Challenge factors** (1=low…5=high)

| COCOMO Parameter | | XL | VL | L | N | H | VH | EH |
|---|---|---|---|---|---|---|---|---|
| Scale Factors | TEAM | 1 | 3 | 5 | | | | |
| | PMAT | | 1 | 2 | 3 | 4 | 5 | |
| Effort Multipliers | PERS | | | 1 | 3 | 5 | | |
| | PREX | | | 1 | 2 | 3 | 4 | 5 |
| | | | | | 1 | 3 | 5 | |
| | D | 1 | 3 | 5 | | | | |

**Repository informs appropriate range of cost model input parameters**

# Create a Method for Connecting BBNs to Cost Estimation Models - 4

## Solution

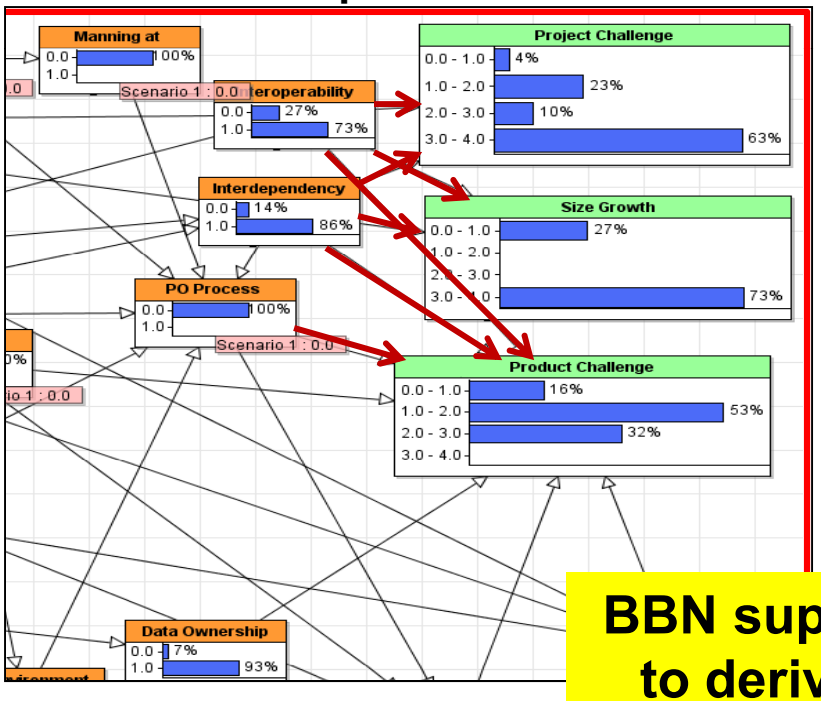



**Problem 2 Solution (For each MDAP program)**

**Retrospective #n**

**Retrospective #2**

**Retrospective #1**




After the cost model input factors (**green**) are derived, use empirical analysis of retrospectives from the Program Change Repository to establish the appropriate mappings (**red arrows**) of change drivers (**orange**) to cost model input factors (**green**).

**BBN supplies conditional probabilities to derived cost model input factors.**

# Collaboration Opportunities

- Currently analyzing information gathered from an MDAP retrospective workshop involving ASP participants – BBN in process.
- Upcoming second MDAP retrospective involves the CAIG Independent Cost Estimate documentation and personnel.
- Catalog the calibrated mappings of BBN outputs to Cost Estimation models and make available to the DoD cost community.
- Establish and maintain a repository to benchmark estimation accuracy as a function of differences in estimation practices including use of QUELCE.
- Create documentation to guide the revision of a program specific BBN for re-estimation during the life of the program.
- Engaged with AFCAA, ODASSA-CE and NCCA.
- Work with PARCA and CAPE to shadow live Independent Cost Estimate and/or Program Assessment.
- Data analysis from expert judgment calibration experiments at Carnegie Mellon. Further studies to follow with defense practitioners, graduate students, and faculty.

We are looking for opportunities to engage with a live action pre-Milestone A program cost estimate.

# Backup Slides
# FY13 Tasks

# Challenges of "End Nodes"

Four basic nodes identified for CERs.

- "**Size**:" each CER has a different sizing measure. BBN nodes that connect to the size parameter may differ by CER.
- **Product Challenge** reflects the newness of the technology, the performance requirements (KPIs) and dynamic complexity of the product.
- **Project Challenge** reflects the number of teams, locations, skills, subcontractors and diversity of users.
- **Program Challenge** reflects the number of sponsors and interdependent programs.

**Delay** is a program factor not covered by typical CERs. This kind of delay causes an overall slip during which a high percentage of the burn-rate continues but significantly less progress is achieved.

- Part goes end-of-life
- Subcontractor fails to perform and must be swapped
- GFE (or other resource) not available on time

# Benefits of Method in Use

Mitigation of select risks

- Since assumptions and consequences of change are more quickly and clearly identified, mitigation can be applied to 1) reduce probability of change or 2) mitigate effects at first impact.

Process Change

- Pilot program identified two process changes that could be employed to reduce uncertainty. One moved a configuration decision much earlier in the lifecycle. One added a step to early customer solicitation for a highly customized product.

Improvement in Expert Judgment

- Results to date are positive when using general knowledge questions and when using domain-specific questions.
- We do not have enough testing to know whether domain specific questions produce better overall results.