Quantifying Uncertainty in Early Lifecycle Cost Estimation (QUELCE)

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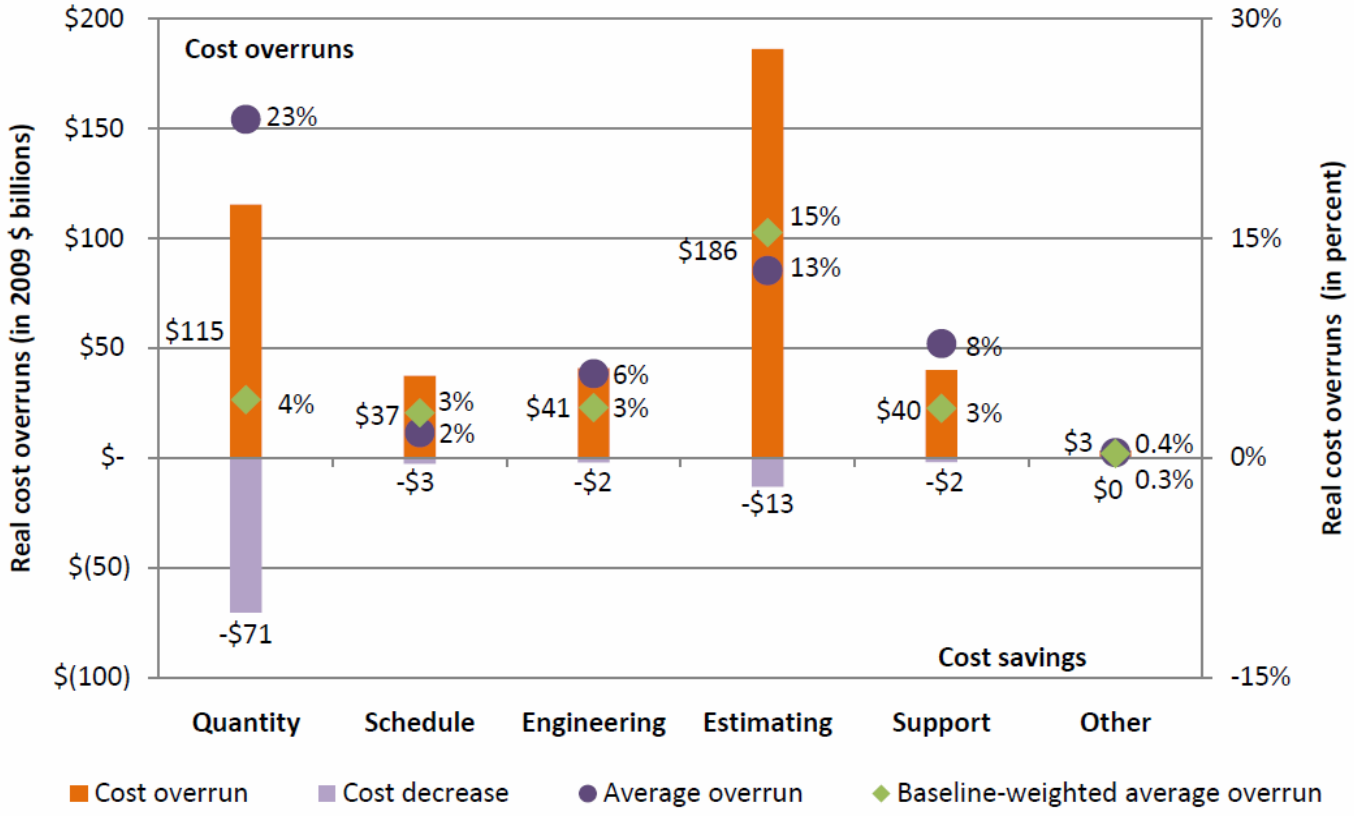
Changes in DOD's 2011 Portfolio of Major Defense Acquisition Programs over Time

Fiscal year 2012 dollars in billions	1 year comparison (2010 to 2011)	5 year comparison (2006 to 2011)	Since first full estimate (baseline to 2011)
Increase in total research and development cost	$14 billion 4 percent	$39 billion 14 percent	$113 billion 54 percent
Increase in total procurement cost	$61 billion 5 percent	$192 billion 19 percent	$321 billion 36 percent
Increase in total acquisition cost	$74 billion 5 percent	$233 billion 17 percent	$447 billion 40 percent
Average delay in delivering initial capabilities	1 month 2 percent	9 months 11 percent	23 months 32 percent

Source: ***DEFENSE ACQUISITIONS: Assessments of Selected Weapon Programs*****, GAO-12-400SP, March 2012**

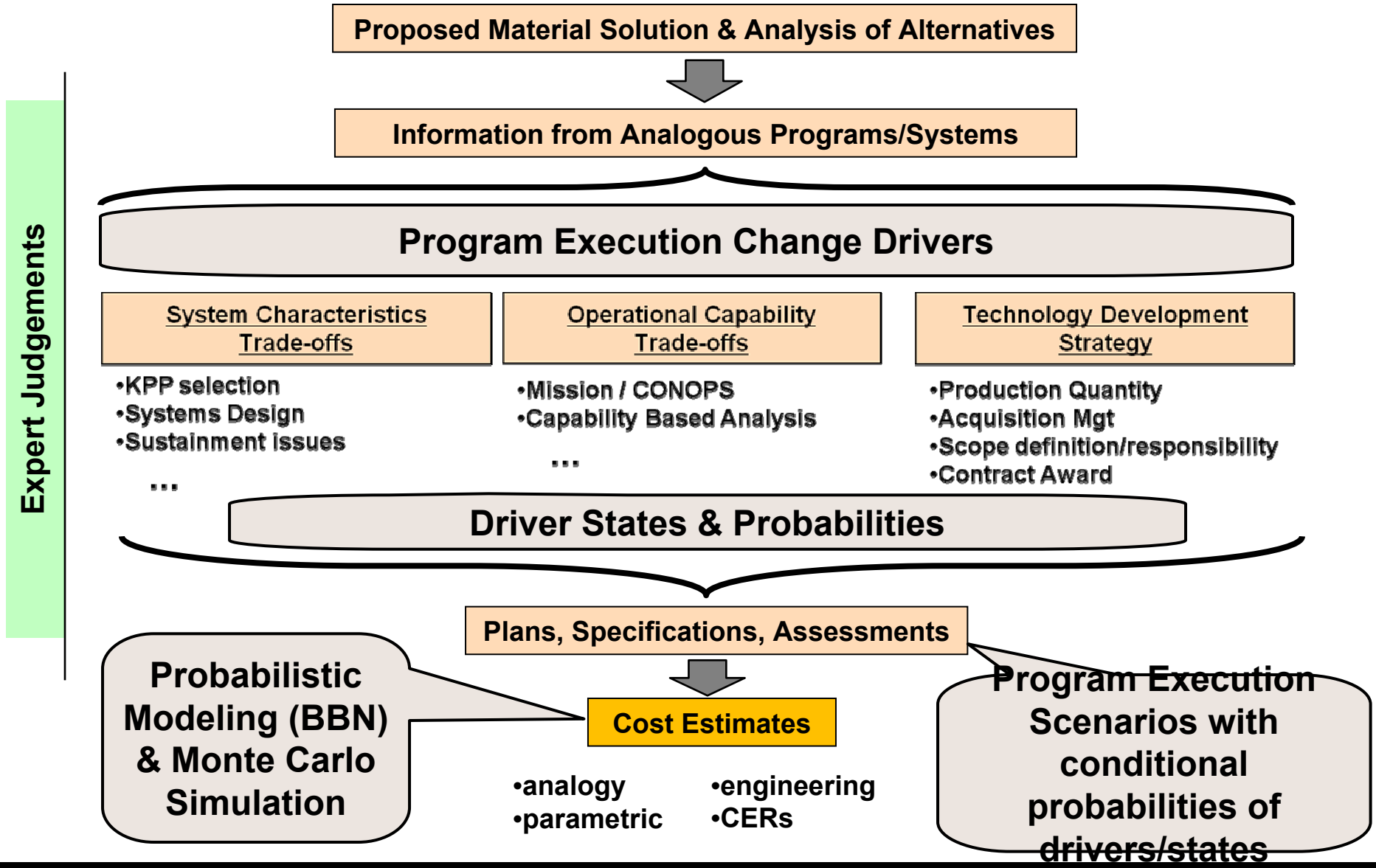
"DOD's flawed funding process is largely driven by decision makers' willingness to accept unrealistic cost estimates and DOD's commitment to more programs than it can support. DOD often underestimates development costs—due in part to a lack of knowledge and optimistic assumptions about requirements and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



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

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**

Information Flow for Early Lifecycle Estimation

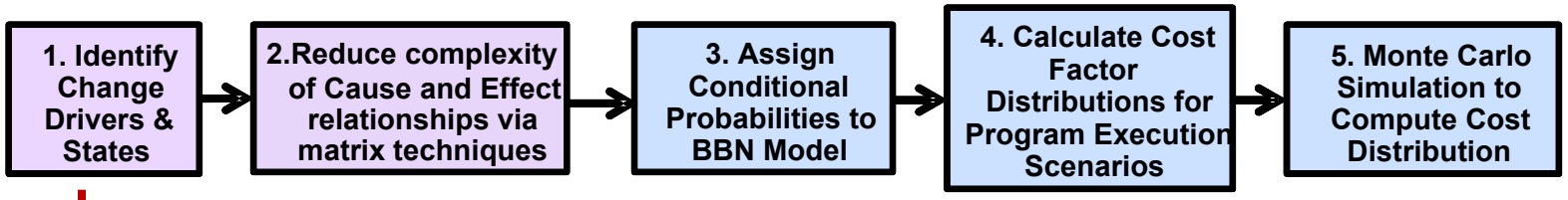


Quantifying the Uncertainty of Cost Estimation Inputs and Resulting Estimates

1. Identify Change Drivers & States	Explicit identification of domain specific program change drivers.
2. Reduce Cause and Effect Relationships via Dependency Structure Matrix techniques	Unique application of Dependency Structure Matrix techniques for cost estimation.
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 | **Complexity Reduction** | **Modeling Uncertainty**

Step 1: Identify Change Drivers and States



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	As 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
Advocacy Change	Stable	Joint service program loses particpant	Senator did not get re-elected	Change in senior pentagon staff	Advocate requires change in mission scope	Service owner different than CONOPS users
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
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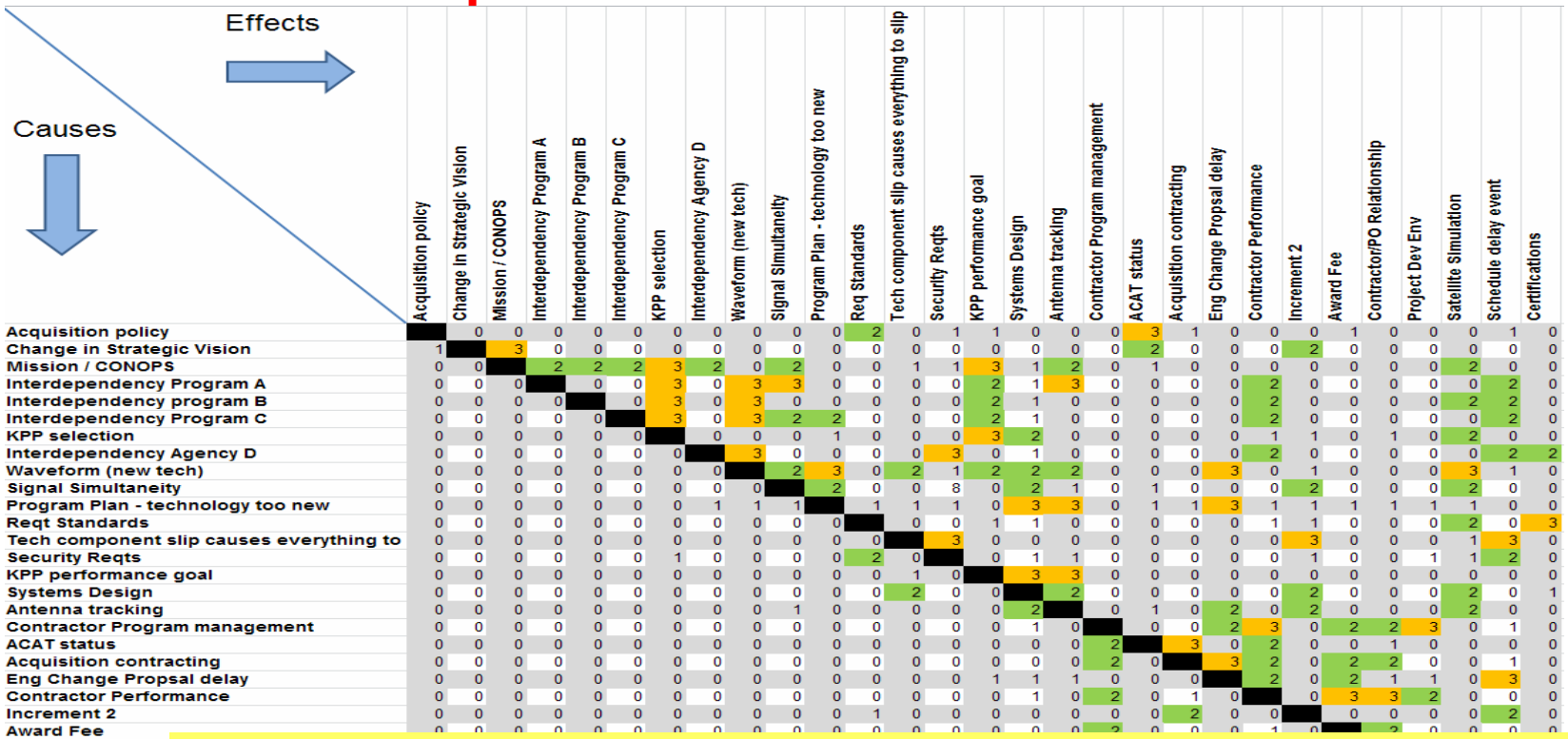
•						
•	~~~~	~~~~	~~~~	~~~~	~~~~	~~~~

Domain-Specific Program Change Drivers Identified

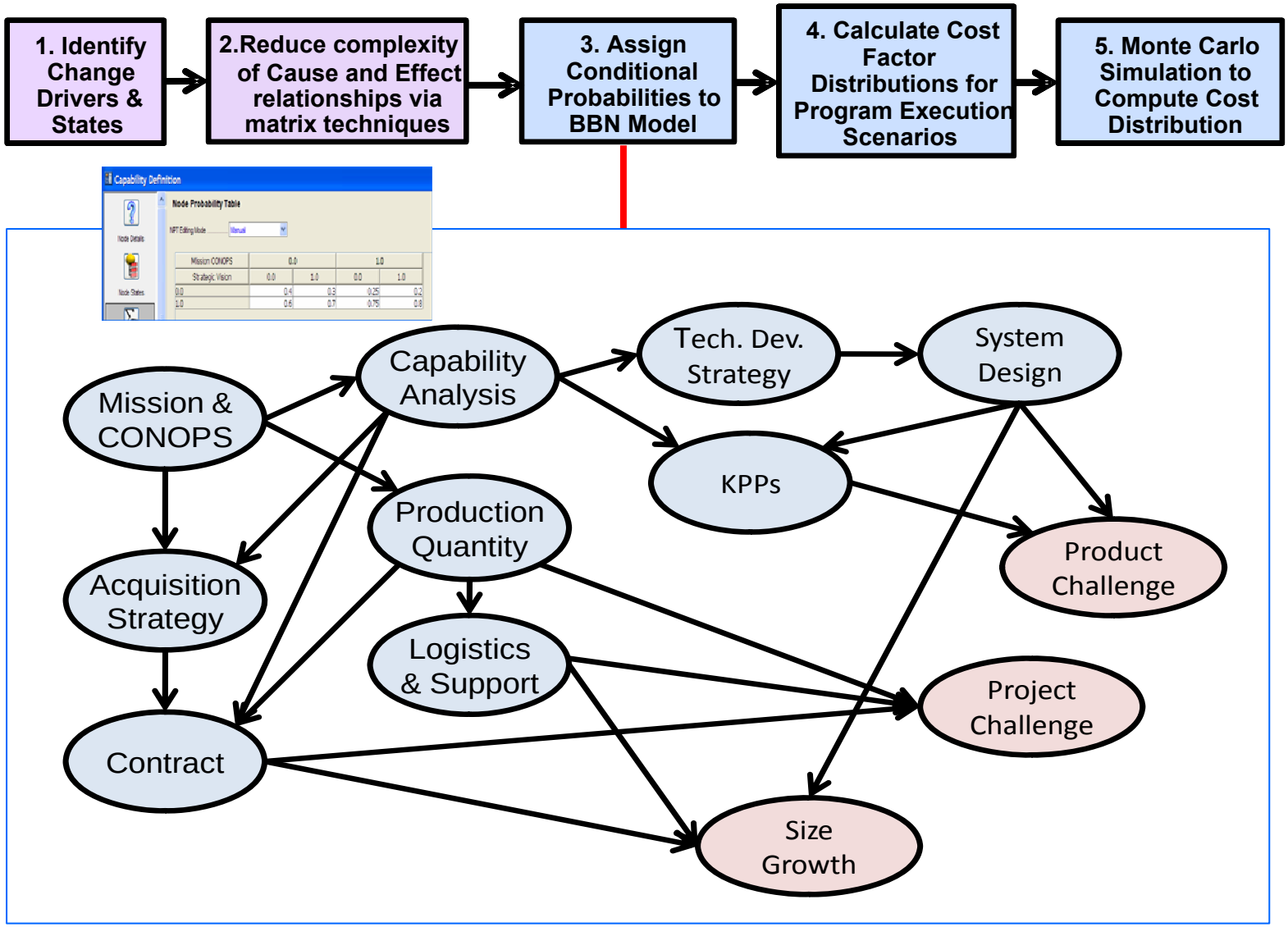
Step 2: Reduce Cause and Effect Relationships via Design Structure Matrix Techniques

1. Identify Change Drivers & States → 2.Reduce complexity of Cause and Effect relationships via 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

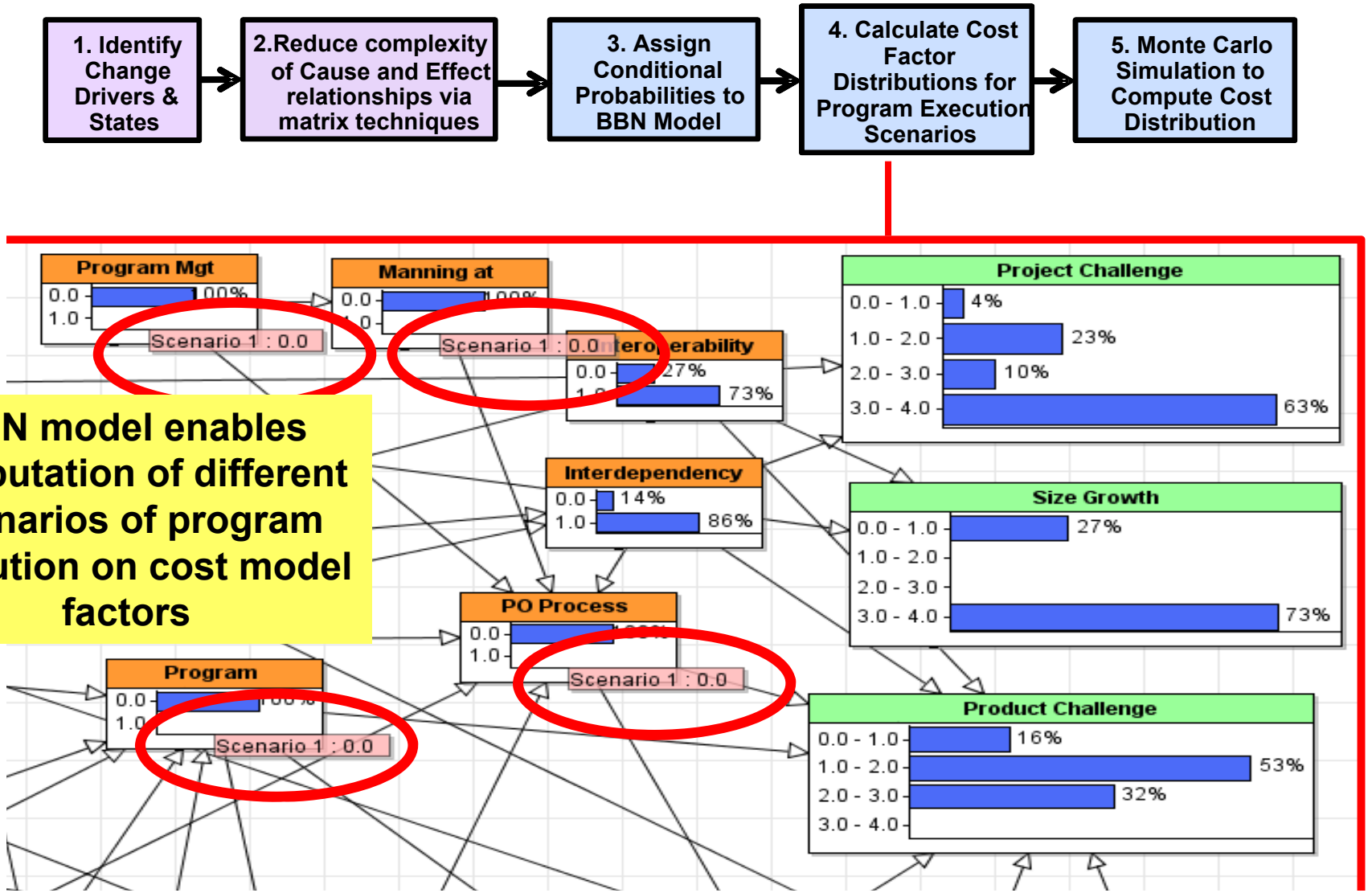


Capturing interrelationships among change drivers and reducing the complexity of the network

Step 3: Assign Conditional Probabilities to BBN Model

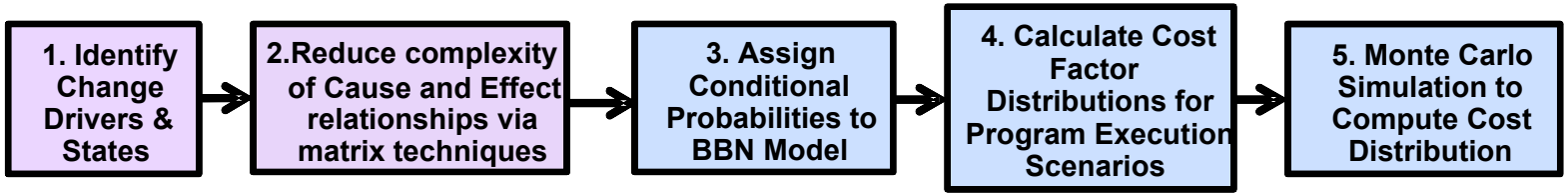


Step 4: Calculate Cost Factor Distributions for Program Execution Scenarios



BBN model enables computation of different scenarios of program execution on cost model factors

Connecting BBNs to Cost Estimation Models



Understand and analyze cost model input factors

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

Group similar input factors based on empirical analysis in task 3.

Use empirical analysis from Repository as basis to map scale (XL … EH) of original cost model input factors to scale (1…5) of BBN output factors

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
	FCIL				1	3	5	
	SCED	1	3	5				

Step 5: Monte Carlo Simulation to Compute Cost Distribution

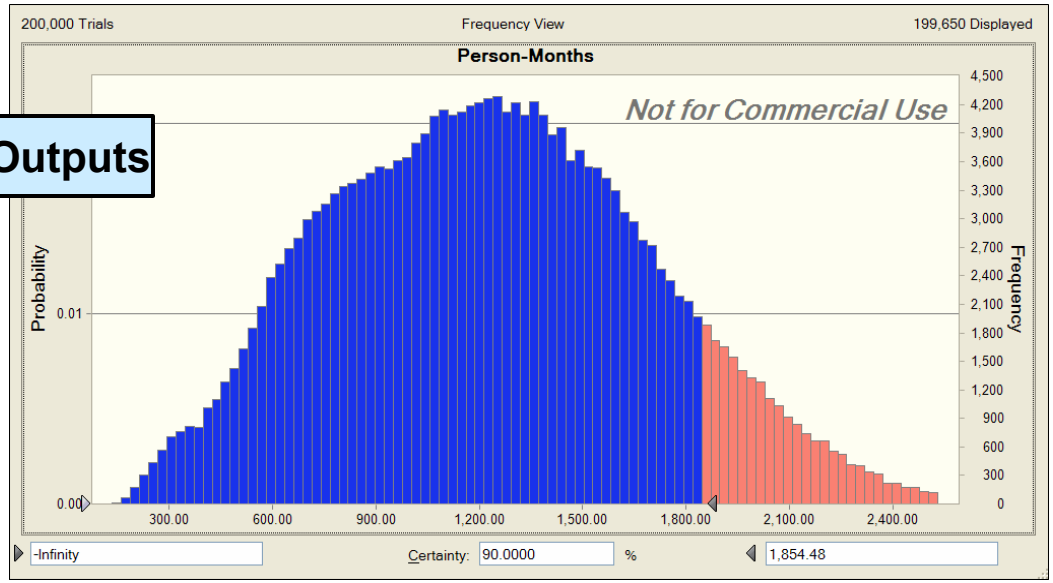
1. Identify Change Drivers & States → 2.Reduce complexity of Cause and Effect relationships via matrix techniques → 3. Assign Conditional Probabilities to BBN Model → 4. Calculate Cost Factor Distributions for Program Execution Scenarios → 5. Monte Carlo Simulation to Compute Cost Distribution

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

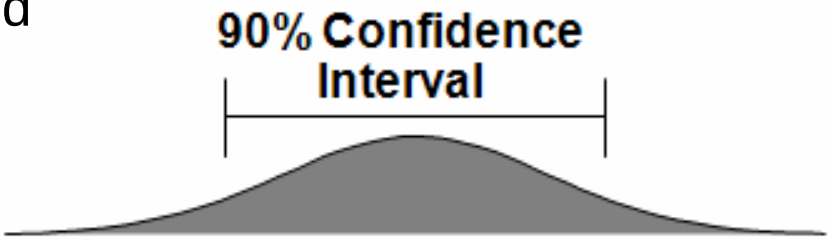
BBN Outputs

Mapped COCOMO value



Experts Tend to Be Over-Confident

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

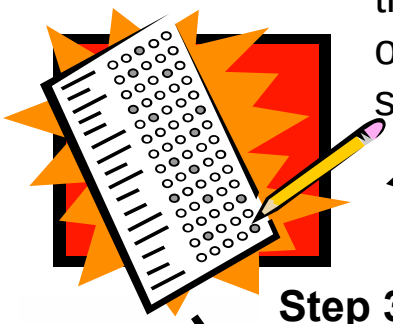


(AIE = Hubbard Generic Calibration Training)

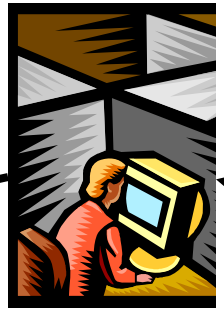
Group	Subject	% Correct (target 90%)
Harvard MBAs	General Trivia	40%
Chemical Co. Employees	General Industry	50%
Chemical Co. Employees	Company-Specific	48%
Computer Co. Managers	General Business	17%
Computer Co. Managers	Company-Specific	36%

Develop Efficient Techniques To Calibrate Expert Judgment of Program Uncertainties

Solution



Step 2: Iterate through a series of domain specific tests

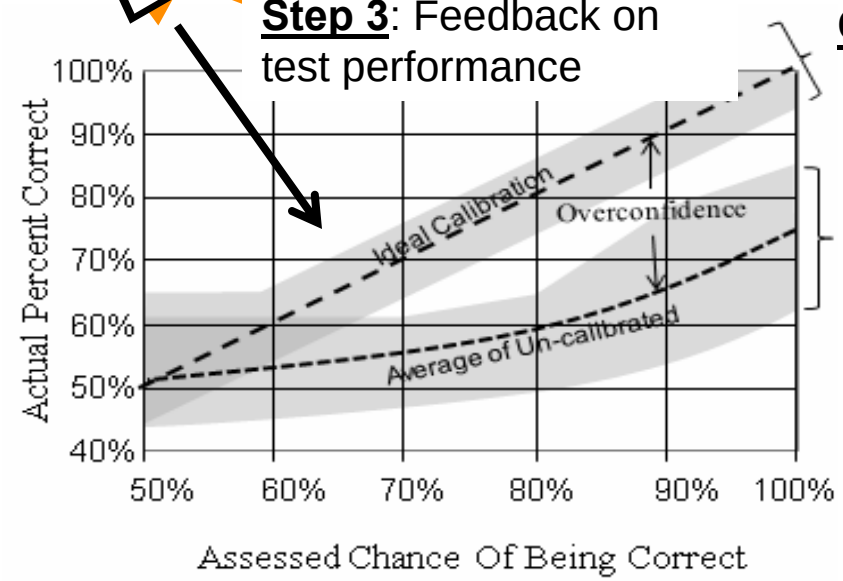


Step 1: Virtual training using reference points

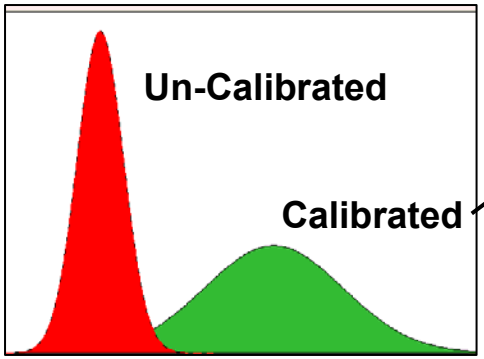
DoD Domain-Specific reference points

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



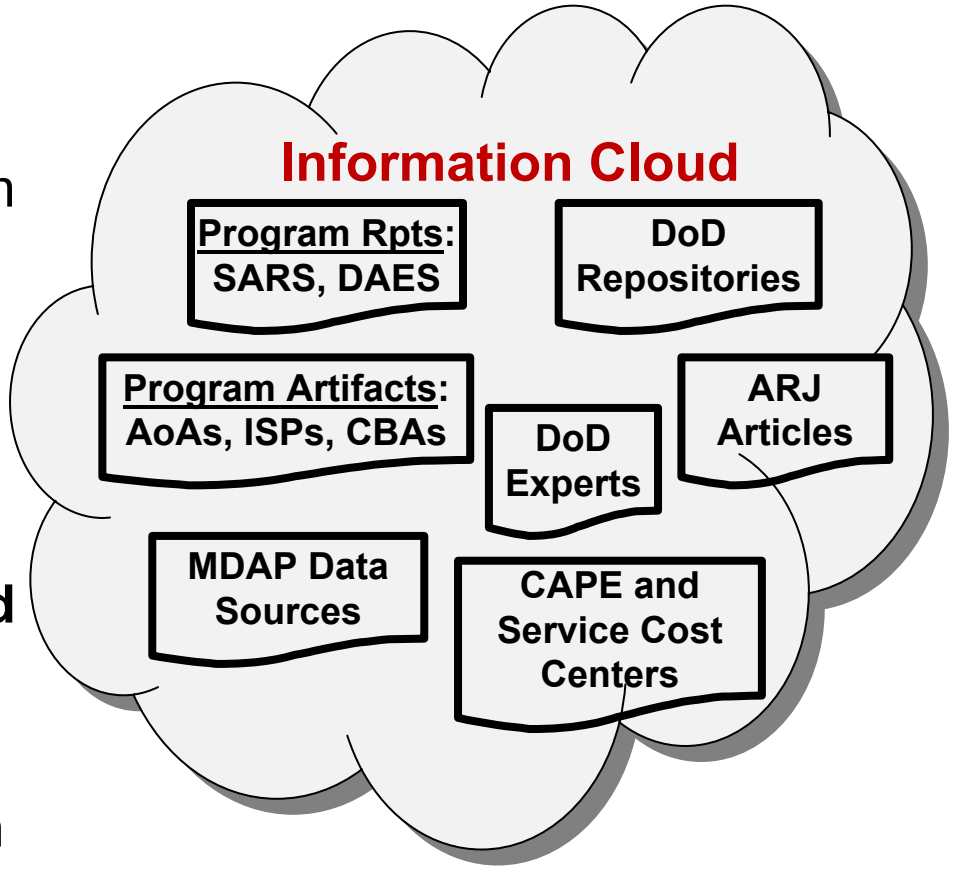
Calibrated = more realistic size and wider range to reflect true expert uncertainty

Create A Repository to Aid Expert Judgment

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.



Repository: Analyze Existing Data to Model Program Execution Uncertainties

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
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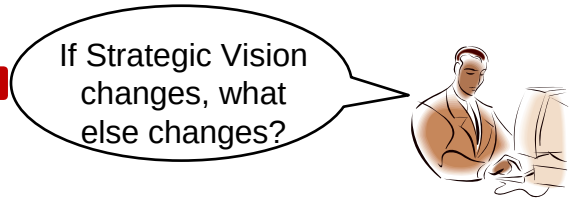
Program Change Repository

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

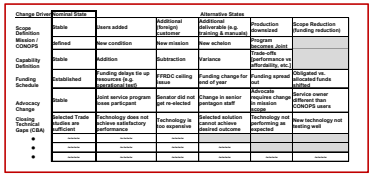


70% of the time the Mission/CONOPS changes

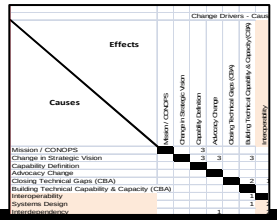
The **Materiel Solution** of a global network command and control system anticipates a possible change in **Strategic Vision** which will include allied participation.

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

Driver State Matrix



DSM Cause-Effect Matrix



Repository identifies cascading effects of change in MDAP cost drivers.

Repository: Analyze Existing Data to Model Program Execution Uncertainties

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
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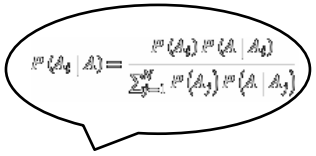
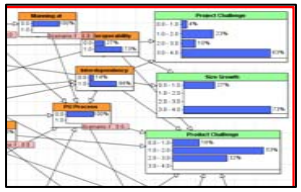


When both Strategic Vision & Mission/CONOPs experience change, the BBN calculates that Capability Definition will also change 95% of the time.

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**.

Summary

QUELCE includes the effects of uncertainty in the resulting estimate by:

- Making visible the quantified uncertainties that exist in basic assumptions.
- Calculating uncertainty of the input factors to the model rather than adjusting the output factors.
- Using scenario planning to calculate how specific changes might affect outcomes.

The method utilizes subjective and objective data as input

- Historical data can be used to populate the BBN nodes and establish the connections between the BBN and cost model inputs.
- Expert judgments are documented and made explicit.
- Information typically not used for estimation purposes can be leveraged.

The method explicitly includes factors that have been documented as sources of program failure in the past but are not typically captured by cost models

For More Information

QUELCE Technical Reports:
http://www.sei.cmu.edu/library/abstracts/reports/11tr026.cfm

http://www.sei.cmu.edu/library/abstracts/reports/13tr001.cfm

SEI Webinar (recorded Oct 31, 2012)

http://www.sei.cmu.edu/library/abstracts/webinars/Quantifying-Uncertainty-in-Early-Lifecycle-Cost-Estimation.cfm

SEI Blog http://blog.sei.cmu.edu

•"Improving the Accuracy of Early Cost Estimates for Software-Reliant Systems, First in a Two-Part Series"

•"A New Approach for Developing Cost Estimates in Software Reliant Systems, Second in a Two-Part Series"

•"Quantifying Uncertainty in Early Lifecycle Cost Estimation (QUELCE): An Update"

Journal of Software Technology
http://journal.thedacs.com/issue/64/207

"An Innovative Approach to Quantifying Uncertainty in Early Lifecycle Cost Estimation"

Acquisition Research Symposium (forthcoming)

"Quantifying Uncertainty for Early Lifecycle Cost Estimates"

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