Defense Acquisition in Transition

6TH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

Application of Real Options Theory to Software-Intensive System Acquisition

Man-Tak Shing, Albert Olagbemiro, Johnathan Mun

Naval Postgraduate School

Acknowledgement and Disclaimer

- The research was funded in part by a grant from the NPS Acquisition Research Program - OUSD_08.
- The views and conclusions in this talk are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the U.S. Government.

Outline

- Introduction
  - Uncertainties in Software-Intensive Weapon Acquisition
- Real Options Theory Approach to Risk Management
  - Real Options Framework
- Addressing Uncertainties
  - Uncertainties Elicitation and Quantification
  - Refining uncertainties quantification with Dempster Shaffer' Theory
- Options Development and Valuation
- Discussion

Uncertainties in Software-Intensive Weapon Acquisition

- Uncertainties in the system/software requirements and new/unproven technologies have been a leading problem in almost all software-intensive weapon systems acquisition
- We need a *proactive* way to manage the risks caused by these uncertainties
  - *Managing risk at the acquisition level, instead of at the development level*
  - *During the investment decision-making activities prior to the commitment to acquire and/or develop a software system*

Real Options Theory Approach to Risk Management

- Value strategic software acquisitions decisions as a portfolio of options or choices in real "assets"
- Provide the software manager with time-deferred and flexible choices (options) regarding future risks or changes of software

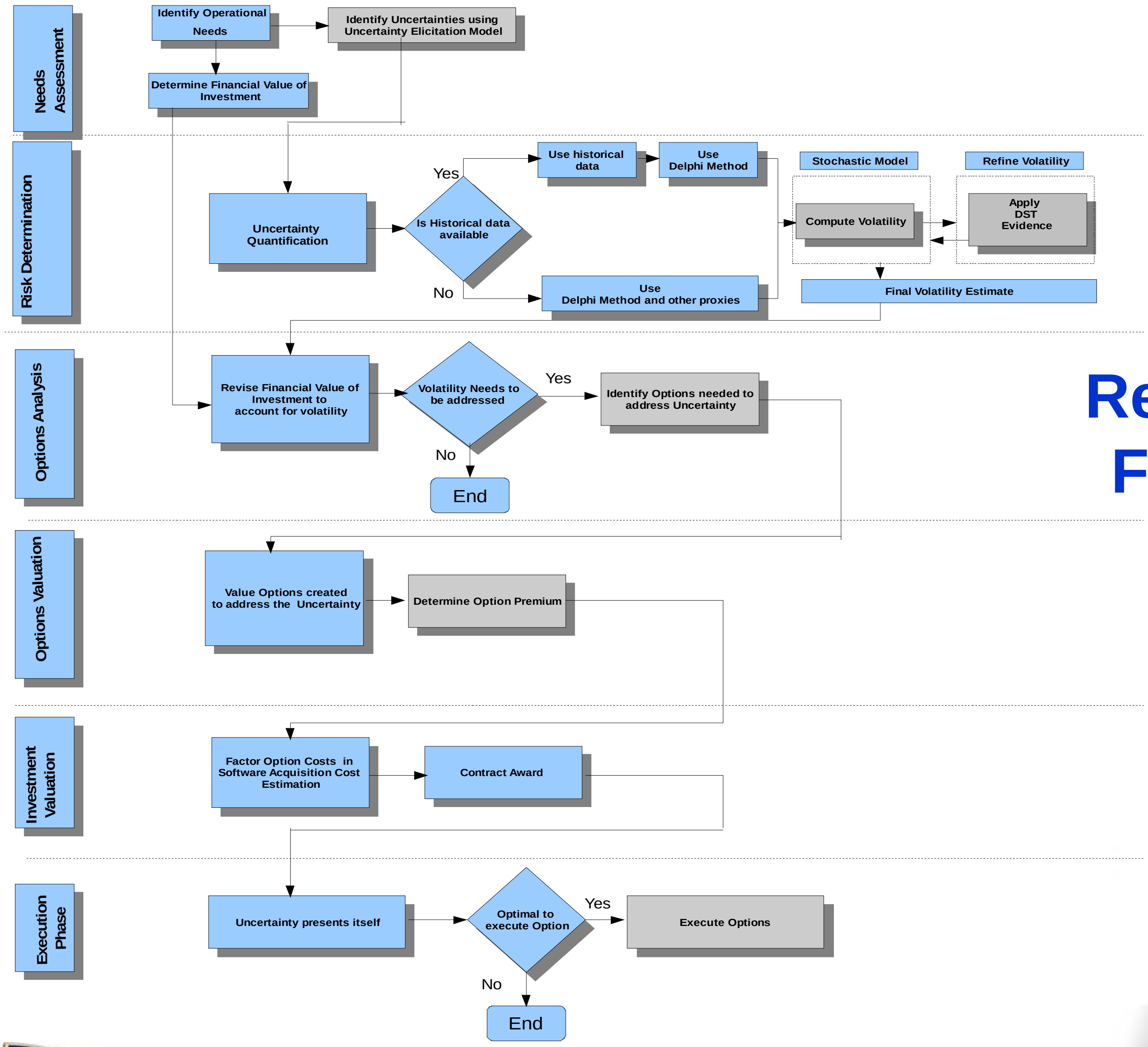
Pre-conditions for Effective Use of Real Options

- The existence of a basic financial model for "Real" assets.
- The existence of uncertainties.
- The uncertainties must introduce risks which directly impact the project.
- Management must have the flexibility or option to make *mid course* corrections when actively managing the project.
- Management must have the wisdom to execute the Real Options when it becomes optimal to do so.

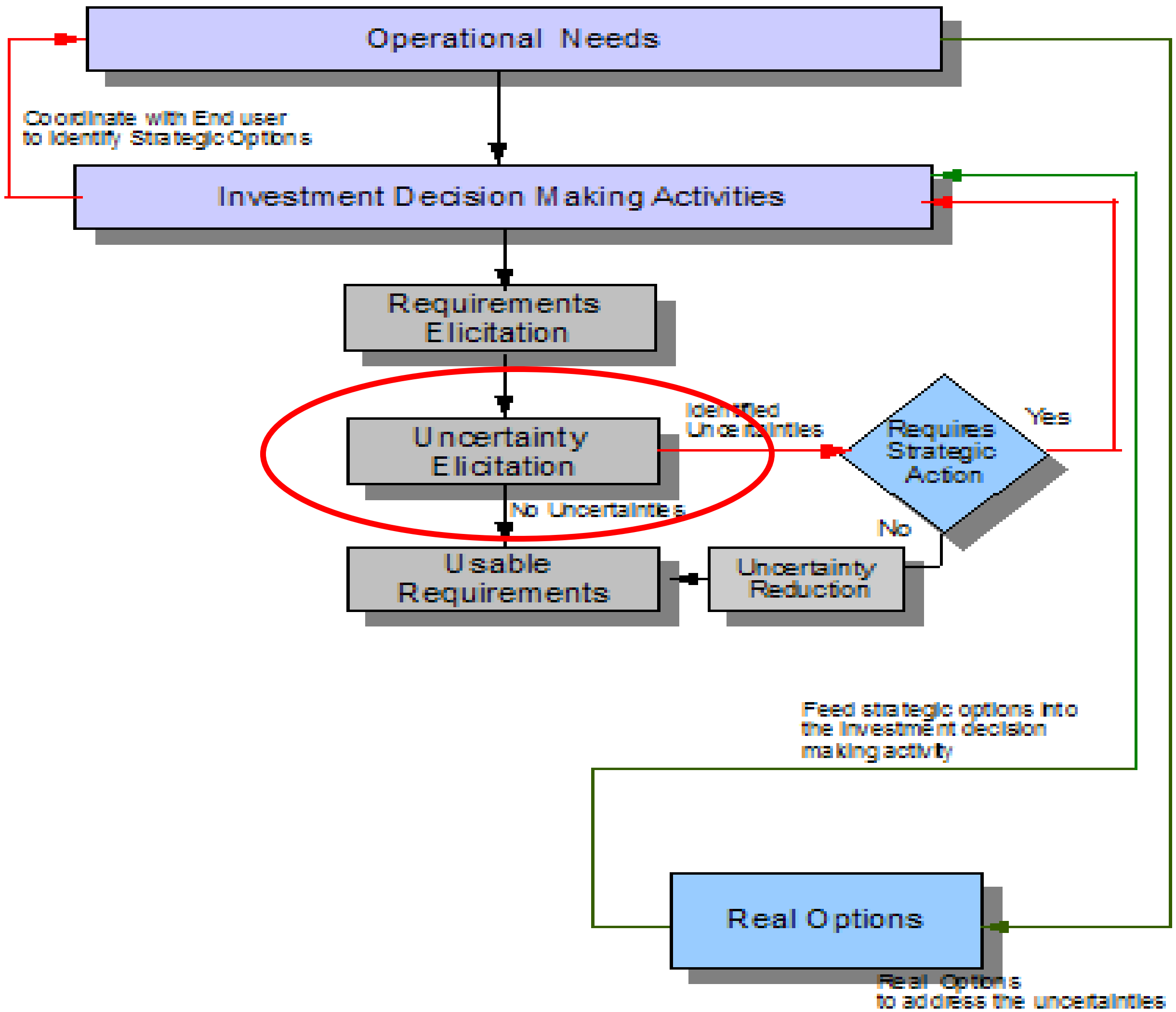
Meeting The Pre-conditions

- Establish compliance with Real Options methodology pre-conditions 1 - 3.
  - Develop a financial model for the benefits/cost of software acquisition
  - Identify the uncertainties in software acquisition
  - Quantify associated risks
- Option Identification.
- Option Valuation.

Real Options Framework



Identifying Uncertainties



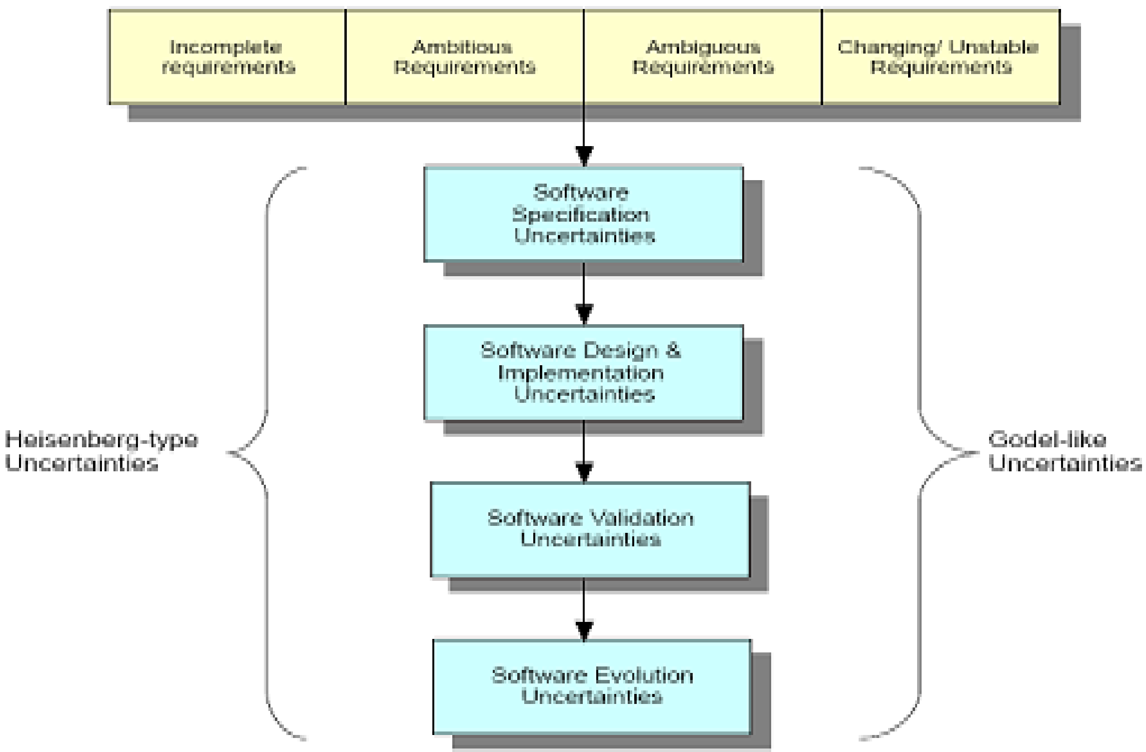
Managerial and Technical Uncertainties

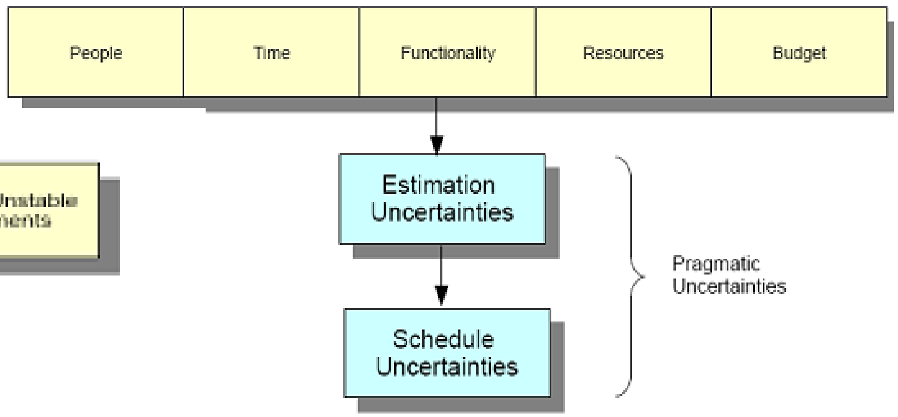
Technical Uncertainties:

Requirements uncertainties

Integration uncertainties

Performance uncertainties





Managerial Uncertainties:

Estimation uncertainties (size/cost)

Scheduling uncertainties

Quantifying Uncertainty

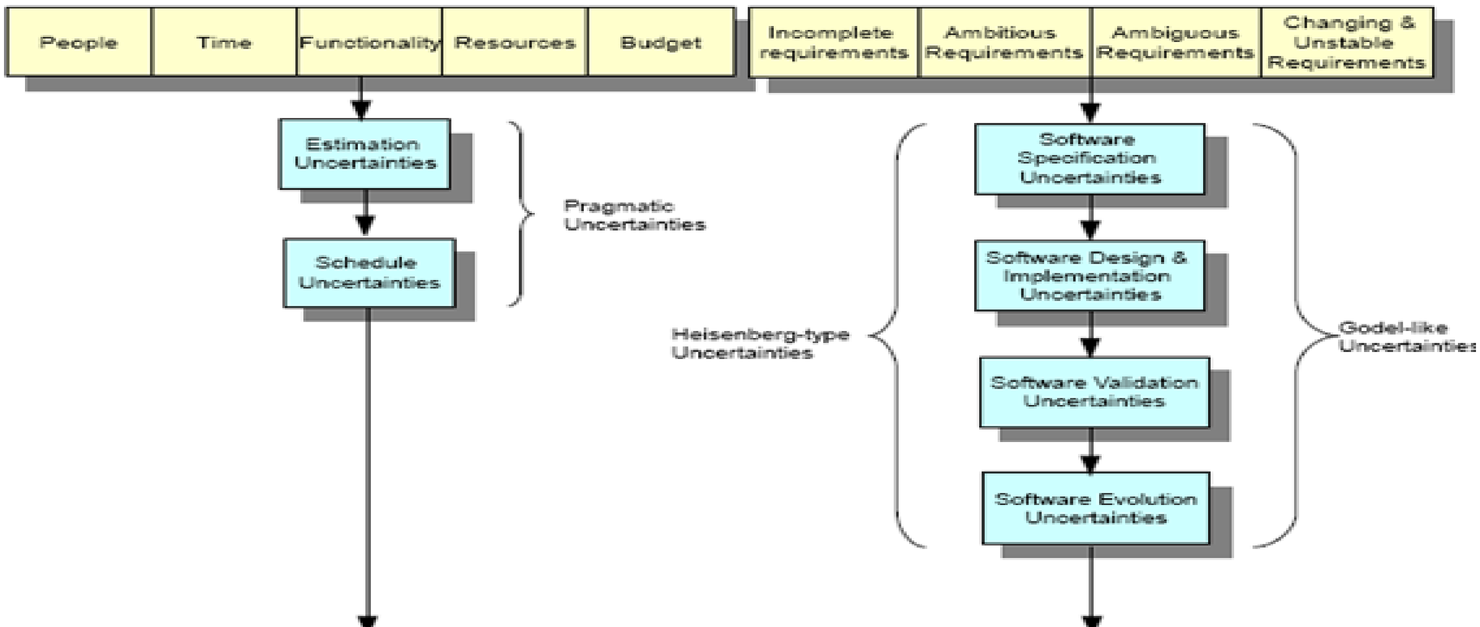
- Equate the uncertainties of the current investment effort to a quantifiable property (risk factor) in order to gauge the magnitude/impact of the risk on the underlying asset
  - E.g., determine the rate of requirements change and then estimate the effect of the requirements change on the program

Determine The Rate of Requirements Change

- Based on historical evidence from existing project or similar projects
- Based on expert opinions obtained using the Delphi method in the absence of historical data
- For example, to determine the rate of the requirements change in the Future Combat System Network (FCSN):
  - We use the Joint Strike Fighter (JSF) program as a proxy.
  - We apply the data from JSF to Capers Jones' formula and obtain an estimate of 12%.

Estimation of Requirements Volatility (RV)

- We use RV to quantify the effect of the risk as variations in the returns associated with the investment
- Determine RV by running a Monte Carlo simulation of the risk model using the Risk Simulator software



NPV of Future Returns on a Investment of $163.7 billion in an Asset Valued at $10 Trillion	Current Requirements (SLOC)	Planned Schedule (Months)	Planned Costs	Risk Factors: Requiements Creep Risk	Intergration Risk	Schedule Overrun	Performance Risk	Software Cost Estimation	Unit Cost	Monthly Cost	Final Costs Due to Risk Factors
$6,138,586,402,574.14	95000000	156	$163,700,000,000.00	190.90%	0.56%	-0.02%	9.38%	91.37%	$1,723.16	$1,364,166,666.67	$670,926,997,357.64

Reduction in FCS Returns from $6.4 Trillion to $6.1 Trillion (New Value)

Volatility = 0.0866 %

Applying Dempster-Shaffer Theory (DTS) to Refine RV Estimates (1/3)

- Also known as the Theory of Belief Functions
  - A generalization of the Bayesian theory of subjective probability
- DTS is based on two ideas
  - The idea of obtaining degrees of belief for one question from the subjective probabilities for a related question
  - Dempster' rule for combining such degrees of belief when they are based on independent items of evidences

Applying DTS to Refine RV Estimates (2/3)

- DST is well suited to address software uncertainties
  - Reduce epistemic uncertainties by increasing one's knowledge of the problem at hand
    - Epistemic uncertainties are reducible uncertainties due to lack of knowledge, lack of information and our own and others' subjectivity concerning an issue
  - Ability to represent ignorance in the face of uncertainty when there is no information

Applying DTS to Refine RV Estimates (3/3)

- For example, to improve the RV estimates of the Future Combat System Network (FCSN):
  - We use data from two independent source, Cost Analysis Improvement Group (CAIG) and Institute for Defense Analysis (IDA) to derive degrees of belief of the FCSN risk factors, then we use Dempster's rule to combine the degrees of beliefs
  - Where the combined functions reflected "belief" in our estimates, our estimates were considered to be valid and were left untouched, and in situations where the combined belief functions reflected conflict with our estimates, our estimates were revised accordingly.

Reduction in FCS Returns from $6.4 Trillion to $5.7 Trillion (Refined Value)

Volatility = 0.0947 %

Identifying Options (1/2)

- Scenario
  - FCSN can be broken down into 6 component systems
  - We consider a hypothetical scenario in which we assume that of the six component systems, the Systems of Systems Common Operating Environment, is not facing uncertainty while the other five software components are facing uncertainty

Identifying Options (2/2)

- We proceeded and developed two different options to address this scenario:
  - Strategy A - Compound Option
    - *Option to Contract and Scale Down* from an uncertain system,
    - *Option to Switch* resources to another system
    - *Options to Expand and Scale Up* staff assigned to the development of a system not facing uncertainty
  - Strategy B - Deferment Option
    - *Option to Wait and Defer, including the one not facing uncertainty*

Options Valuation using the Real Option SLS software (1/2)

- Strategy A - Compound Option
  - Input parameters:
    (1) Development/Implementation cost of FCSN is $163.7 billion, (2) Value of underlying asset is $6.4 Trillion, (3) The risk-free rate is 3.0%, (4) Volatility of the project is 0.0947, (5) Duration of software development is 13 years, and (6) Lattice steps was set to 300.
  - The value of the underlying asset was computed as $6.4 Trillion and the option analysis of the value of the compound option returned a value of $6.27 Trillion.
  - The intrinsic value of the compound option = $6.27 Trillion – $5.7 Trillion = $570 Billion.

Options Valuation using the Real Option SLS software (2/2)

- Strategy B - Deferment Option
  - Input parameters:
    (1) Development/Implementation cost of FCSN is $163.7 billion, (2) Value of underlying asset is $6.4 Trillion, (3) The risk-free rate is 3.0%, (4) Volatility of the project is 0.0947, (5) Duration for deferment option would be 3 years, and (6) Lattice steps was set to 300.
  - The value of the underlying asset was computed as $6.4 Trillion and the option analysis of the value of the deferment option returned a value of $6.25 Trillion.
  - The intrinsic value of the deferment option = $6.25 Trillion – $5.7 Trillion = $550 Billion.

Outcome of Real Option Analysis

- Current Approach
  - Net Present Value of FCS Network = $6.4 Trillion
  - Investment Cost = $163.7 Billion
  - Considers effect of risk, Net Present Value of FCS Network = $5.7 Trillion
- Option Premium for Strategy A = $570 Billion
- What this Means
  - Pay an extra premium that is less than $570 Billion today
  - Reduce the chance of losing $6.4 Trillion - $5.7 Trillion = $700 Billion

Conclusion

- We present a proactive approach to address the risks associated with software-related capital investments that emphasizes planning for and paying for risk up front
- Need to validate the proposed approach with detailed data from real acquisition program
- Need to create a repository of historical data to serve as a basis of comparison with current/future acquisition programs
- Formalize and create an automated software acquisition decision-making tool explicitly aimed at managing the risks associated with software-related capital investments using our Real Options approach

Backup Slides

Caper Jones' Formula for Rate of Requirements Change

$$r = \left(\sqrt[t]{\frac{SizeAtEnd}{SizeAtStart}} - 1 \right) \times 100$$

Delphi Method

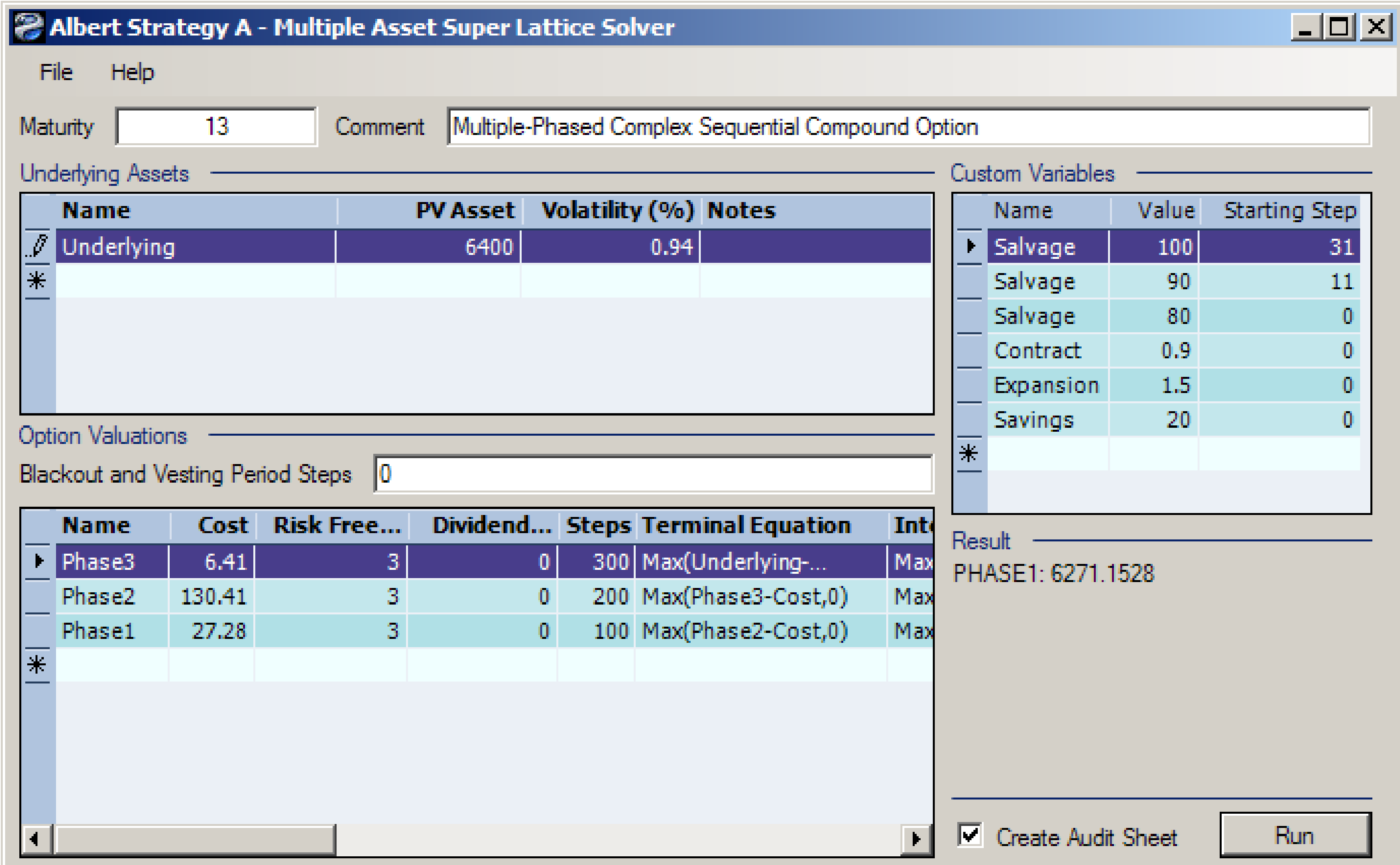
- A methodology for the elicitation of the opinion of an expert or groups of experts to guide decision making by the making predictions about future events
- A three step process of thesis, antithesis, and synthesis
  - In the thesis and antithesis steps, the team of experts present their opinion or views on the given subject, establishing views and opposing views.
  - Consensus is ultimately reached during the synthesis phase as opposing views are brought together to form the new thesis.

Applying DTS to Refine RV Estimates

- We ran the Monte Carlo simulation of the model with the revised risk estimates again.
- Based on the risk of requirements uncertainty presented in the FCSN, a resulting “refined” volatility of 0.0947% was obtained.
- The derived volatility which reflects an increase from the initial volatility estimate of 0.0866% results in a further reduction of NPV of the FCSN program from $6.1 Trillion to $5.7 Trillion.

Real Options Input Parameters

Symbol	Real Option on Software Acquisitions Project	Description
S	Value of underlying Asset: (Asset Price)	Current Value of expected cash flows. (Expected benefits realized from investing in the software effort (NPV))
K	Exercise Price / Strike Price	Price at which the created option would be realized (Investment Cost, of investing in options, which is an estimation of the likely costs of accommodating changes)
T	Time-to-expiration	The useful life of the option (Time until the opportunity disappears/ maturity date of the option contract)
r	Risk-free Interest Rate	Risk free interest rate relative to budget and schedule (Interest rate on US Treasury bonds)
cv	Volatility	Uncertainty of the project value and fluctuations in the value of the requirements over a specified period of time (Volatility in requirements, cost estimation and schedule estimation based on DST of Evidence)



Compound Option Model in the Real Options SLS software

FCSN Underlying Asset Value Lattice

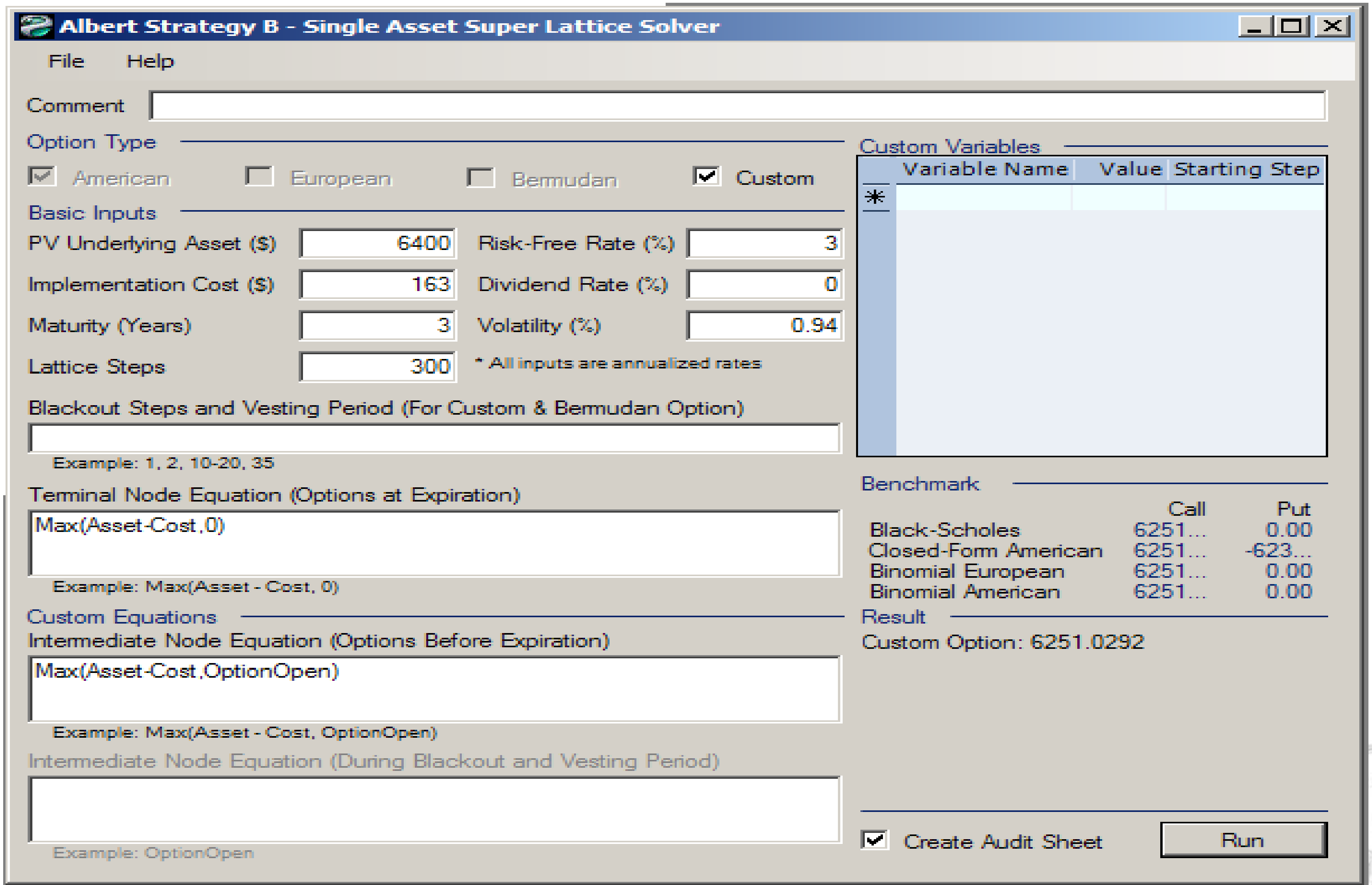
										6526.47
									6513.71	
								6500.97		6500.97
							6488.27		6488.27	
						6475.58		6475.58		6475.58
					6462.92		6462.92		6462.92	
				6450.29		6450.29		6450.29		6450.29
			6437.68		6437.68		6437.68		6437.68	
		6425.10		6425.10		6425.10		6425.10		6425.10
	6412.54		6412.54		6412.54		6412.54		6412.54	
6400.00		6400.00		6400.00		6400.00		6400.00		6400.00
	6387.49		6387.49		6387.49		6387.49		6387.49	
		6375.00		6375.00		6375.00		6375.00		6375.00
			6362.54		6362.54		6362.54		6362.54	
				6350.10		6350.10		6350.10		6350.10
					6337.69		6337.69		6337.69	
						6325.30		6325.30		6325.30
							6312.93		6312.93	
								6300.59		6300.59
									6288.28	
										6275.98

Lattice of Underlying Asset (FCS Network)

Strategy A Option Valuation Lattice

										6395.93
									6383.34	
								6370.78		6370.44
							6358.24		6357.90	
						6345.73		6345.39		6345.05
					6333.24		6332.90		6332.56	
				6320.77		6320.43		6320.10		6319.76
			6308.33		6307.99		6307.66		6307.32	
		6295.91		6295.58		6295.24		6294.90		6294.56
	6283.52		6283.18		6282.85		6282.51		6282.17	
6271.15		6270.82		6270.48		6270.14		6269.81		6269.47
	6258.47		6258.14		6257.80		6257.46		6257.13	
		6245.82		6245.48		6245.15		6244.81		6244.47
			6233.19		6232.85		6232.52		6232.18	
				6220.58		6220.25		6219.91		6219.57
					6208.00		6207.66		6207.33	
						6195.44		6195.11		6194.77
							6182.91		6182.57	
								6170.40		6170.06
									6157.91	
										6145.45

Option Valuation Lattice of Strategy A



Deferment Option Model in the Real Options SLS software

Strategy B Option Valuation Lattice

										6311.03
									6305.00	
								6298.98		6298.89
							6292.97		6292.88	
						6286.96		6286.87		6286.78
					6280.96		6280.87		6280.78	
				6274.96		6274.87		6274.78		6274.69
			6268.97		6268.88		6268.79		6268.70	
		6262.98		6262.89		6262.80		6262.71		6262.62
	6257.00		6256.91		6256.82		6256.73		6256.65	
6251.03		6250.94		6250.85		6250.76		6250.67		6250.58
	6244.97		6244.88		6244.79		6244.70		6244.61	
		6238.92		6238.83		6238.74		6238.65		6238.56
			6232.87		6232.78		6232.69		6232.60	
				6226.83		6226.74		6226.65		6226.56
					6220.80		6220.71		6220.62	
						6214.77		6214.68		6214.59
							6208.74		6208.65	
								6202.72		6202.63
									6196.71	
										6190.70

Option Valuation Lattice of Strategy B