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APPLICATION OF REAL OPTIONS THEORY TO SOFTWARE-INTENSIVE SYSTEM ACQUISITIONS

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Application of Real Options Theory to Software-intensive System Acquisitions

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Abstract[1]

In the Department of Defense (DoD), the typical outcome of a software acquisition program has been massive cost escalation, slipping planned delivery dates and making major cuts in the planned software functionality to guarantee program success. To counter this dilemma, the DoD put forth a new weapons acquisition policy in 2003 based on an evolutionary acquisition approach to foster increased efficiency while building flexibility in the acquisition process. However, the evolutionary acquisition approach often relies on the spiral development process, which assumes end-state requirements are known at the inception of the development process, a misrepresentation of reality in the acquisition of DoD software-intensive weapons

[1] This work was supported in part by the NPS Acquisition Research Program—OUSD_08 (Project #:F08-023, JON: RGB58). 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 US Government.

systems. This article presents a framework to address requirements uncertainty as it relates to software acquisition. The framework is based on Real Options theory and aims at mitigating risks associated with requirement volatility based on the technology objectives—constraints as put forth by the customer at the acquisition decision-making level.

1. Introduction

The software acquisition lifecycle, which encapsulates the activities related to its procurement, development, implementation and subsequent maintenance, continues to present challenges to software executives and program managers due to increasingly complex organizational requirements and the ever-increasing role that software plays in US Department of Defense (DoD) weapons systems. Various factors and considerations, most of which are complex in nature, compound the software acquisition process: factors that present themselves in the form of "uncertainties," and which have the potential of introducing risks if the uncertainties are not adequately addressed and or resolved. In this paper, we address the issue of requirements uncertainty and propose a methodology for addressing this issue. Our approach addresses these issues by taking a proactive/preemptive approach to risk management by planning and paying up front for the risks associated with requirements. This is not to say that risk management strategies are not being adopted today; rather, there is a failure of management to take a strategic approach towards risk management. Currently, the status quo is to employ reactive risk management strategies that often result in the reduction of much-needed functionality from the scope of the software investment effort. We therefore propose a more proactive decision-making framework that involves identifying the risks, pricing risk upfront during the planning stages of the acquisition before a decision to commit resources is made.

2. The Requirements Dilemma

In software development, requirements instability has a profound impact on a program's schedule and drives up costs due to increases in Research, Development, Test & Evaluation (RDT&E) costs associated with the requirements changes. The lack of adequately defined requirements is one of the leading problems in the software development effort. Without adequate definition and validation of requirements and design, software engineers could be coding to an incorrect solution, resulting in missing functionality and errors. This dilemma is highlighted in a 2007 interview of the Army's Program Executive Officer (PEO) for Ammunition, in which "the ability to acquire and maintain, safe, reliable supportable and modifiable software systems which met user requirements in an environment of rapid technological advances" was identified as their biggest challenge in software acquisitions (Starrett, 2007). Furthermore, the US Government Accountability Office (GAO), responsible for reviewing weapon systems investments, found consistent problems of cost increases, schedule delays, and performance shortfalls exacerbated by factors such as pressure on program managers to promise more than they could deliver. These concerns infer a resounding theme that continues to resonate within the software acquisition community: *Meeting customer requirements within cost and schedule constraints*.

Balancing the satisfaction of a customer's ever-changing requirements within the realms of meeting both current and future uncertain operational needs against the costs and schedule constraints poses a cumbersome challenge to the software executive, thereby making software-investments a very risky venture. They are risky in the sense that software engineering and investment decisions are plagued by uncertainties that more often than not lead to varying degrees of risk ranging from operational shortfalls to cost and schedule overruns.

Ever-changing requirements continue to impact software acquisition efforts, and more often than not, force managers to choose between requirements, i.e., which requirements to accept and which requirements to reject with the full understanding that ignoring changes in requirements results in the delivered product failing to meet the customers needs while accepting changes in requirements has the potential of impacting costs and schedule.

Furthermore, changes in requirements while a software acquisition effort is under way poses the risk of introducing unwanted, unanticipated or unknown impact on existing requirements, not to mention associated costs and scheduled delays depending on the phase of the investment or software development process experiencing significant requirements changes. While the standard practice has been to "freeze" requirements prior to the commencement of any development activities, frequently, this does not work and is not representational of the DoD doctrine to support the flexible development and rapid delivery of products to meet the warfighters needs in an ever-changing environment in response to operational needs.

The inefficiencies of current management techniques as shown in Table 1 highlight the needs of new management approaches that proactively plan for and factor uncertainty into their acquisition strategy. This is because the acquisition of software, its development and the operational use of the software are dominated by human action, human judgment, decision-making and, inevitably, human error. The outcome is, therefore, often uncertain and unpredictable and leads to unavoidable uncertainties that introduce and drive risk (Starrett, 2007).

Table 1. Program Management Failures of Top Three Major Weapons Systems[2]

Program	Initial Investment	Initial Quantity	Latest Investment	Latest Quantity	% Unit Cost Increase	% Quantity Decrease
Joint Strike Fighter	$189.8 billion	2,866 aircraft	$206.3 billion	2,459 aircraft	26.7	14.2
Future Combat Systems	$92 billion	18 System	$163.7 billion	14 systems	54.4	77.7
F-22A Raptor	$81.1 billion	648 aircraft	$65.4 billion	181 aircraft	188.7	72.1

We must, however, emphasize that uncertainty should not be confused with risk as there is an important distinction between the two. Risk is something one bears and is the outcome of uncertainty, as uncertainty is either resolved through the passage of action or left unattended due to inaction (Mun, 2006). The risks associated with the acquisition of the software need to be identified and analyzed very early in the decision-making process, and an approach to mitigate the high-priority risks must be incorporated into a software acquisition plan.

Therefore, in order to accurately estimate requirements volatility and its impact on the future value of a software-intensive-system under consideration for acquisition, the risk of

[2] Numbers were complied from various GAO reports and were current as of 2007.

requirements changes must be quantified, and it must also be specifically predicted and quantified based on the phase in the software development process in which the changes are more likely to occur. Hence, the need arises for an approach that would explicitly acknowledge the probability of occurrence based on previous objective estimates also in addition to the possibility of occurrence based on subject expert opinions (Delphi Method) that acknowledges either the degree of belief or ignorance in the objective probability estimates. (See Section 4 for details.)

3. The Real Options Approach

The Real Options approach is based on the concepts of financial options theory, and it builds on several tried-and-proven approaches of management. The study conducted by Olagbemiro (2008), showed how the Real Options approach could be used as a proactive risk management tool within a strategic decision-making level (executive level) pre-acquisition context—further complementing the spiral development approach at the "tactical level." It was also demonstrated using the US Army Future Combat Systems program as an example of how the traditional Real Options methodology, when enhanced and properly formulated around a proposed or existing software-investment, could provide a framework for guiding software acquisition decision-making by highlighting the strategic importance of managerial flexibility. This flexibility offers management the ability to balance the satisfaction of a customer's requirements within the realms of the associated cost and schedule constraints by developing the appropriate options during the acquisition decision-making phase and executing the options when optimal. However, the Real Options approach calls for the existence or satisfaction of certain pre-conditions before it can be applied. These pre-conditions, which correlate directly to the various activities associated with software related capital investments, are outlined in Mun (2006) as follows:

1. The existence of a basic financial model used to evaluate the costs and benefits of the underlying software asset (e.g., Net Present Value (NPV) as the Real Options approach builds on the existing tried-and-tested approaches of current financial modeling techniques.

2. The existence of uncertainties during the software-related capital investment decision-making process, otherwise the Real Options analysis becomes useless as everything is assumed to be certain and known.

3. The uncertainties surrounding the software-related capital investment decision-making process must introduce risks that directly impact the decision-making process. Real Options could then be used to hedge the downside risk and take advantage of the upside uncertainties.

4. Management must have the flexibility or option to make mid-course corrections when actively managing the project.

5. Management must be smart enough to execute the Real Options when it becomes optimal to do so.

3.1 Real Options Valuation

Real options valuation originated from research performed to price financial option contracts in the field of financial derivatives. The underlying premise of its suitability and applicability to software engineering is based on the recognition that strategic flexibility in software acquisitions decisions can be valued as a portfolio of options or choices in real "assets," akin to options on financial securities that have real economic value under uncertainty (Dixit & Pindyck, 1995). In contrast to financial options, real options valuation centers on real or non-financial assets and is valuable because it enables the option holder (i.e., software program manager) to take advantage of potential upside benefits while controlling and hedging risks. When extended to a real "asset," such as software, real options could be used as a decision-making tool in a dynamic and uncertain environment. An option gives its holder the *rights but without the obligations*, to acquire or dispose of a risky asset at a set *price* within a specified time period (Erdogmus, 1999). If the market conditions are favorable before the option expires, the holder exercises this right, thus making a profit—otherwise, the holder lets the option expire.

A necessary and key tenet of the real options approach is a requirement for the presence of uncertainties, a constraint that is widely characteristic of software acquisitions decision-making. Software acquisitions encapsulate the activities related to software procurement, development, implementation, and subsequent maintenance. The uncertainties that surround these activities are compounded by increasingly complex requirements demanded by the warfighter and present themselves in various forms: changing or incomplete requirements, insufficient knowledge of the problem domain, decisions related to the future growth, technology maturation, and evolution of the software.

To tackle the issue, we developed a formal and distinct uncertainty elicitation task as part of the software investment decision-making process (Figure 1) to obtain information on the relevant uncertainties from a strategic point of view. While this task would not include members of a typical requirements team, they would work in tandem with the requirements team to identify and document uncertainties as they are revealed from an independent point of view. Implementing an explicit uncertainty elicitation task would facilitate the identification of uncertainties very early in the acquisition process, so that the necessary steps could be taken to either refine the requirements to address the uncertainties or identify strategic options to mitigate the risks posed by the uncertainties.

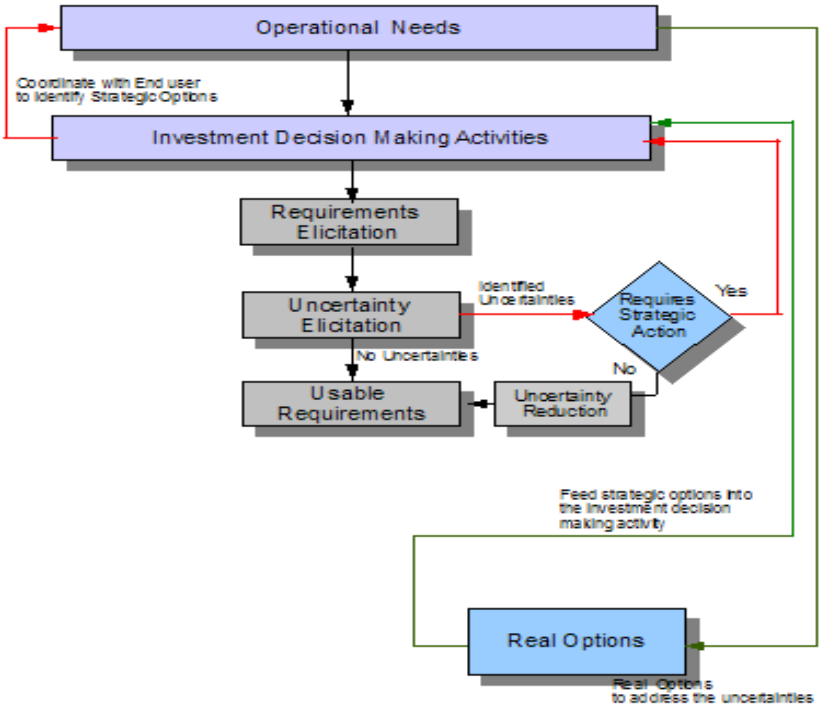

Figure 1. Uncertainty Elicitation Model

In the uncertainty elicitation step in the model, uncertainties are captured from two perspectives (the managerial and technical perspective) using what we call the "2 **T**" approach as illustrated in Figure 2. Managerial uncertainties of people, time, functionality, budget, and resources contribute to both estimation and schedule uncertainties that are considered to be pragmatic uncertainties. Technical uncertainties of incomplete requirements, ambitious, ambiguous, changing or unstable requirements contribute to software specification uncertainties. Such uncertainties lead to software design and implementation, software validation and software evolution uncertainties all of which can be categorized as exhibiting both Heisenberg-type and Gödel-like uncertainties.

If uncertainty cannot be resolved, strategic real options could be developed to address the risks posed by the uncertainty, providing management the flexibility to address the risks posed by the uncertainties when they become revealed at a later date during the acquisition effort.

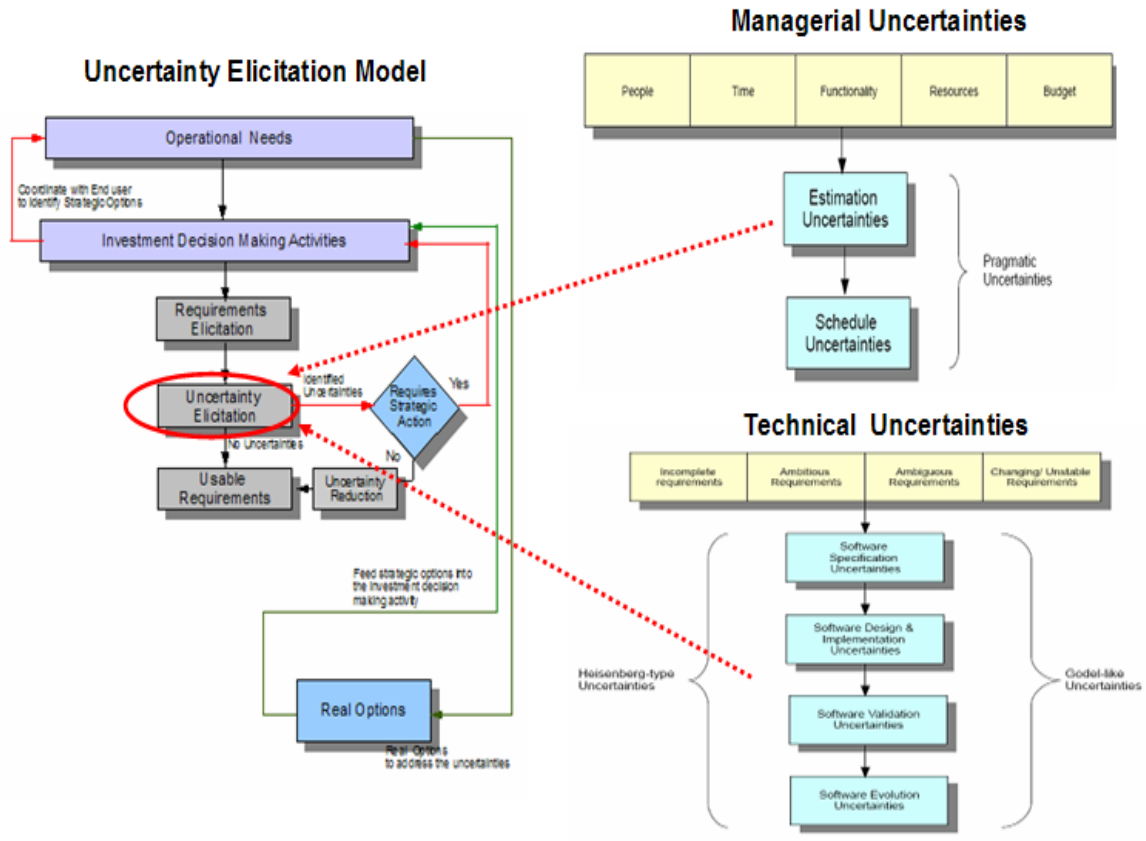

Figure 2. Expanded View of Uncertainty Elicitation Model

3.2 The Real Options Framework

To develop the appropriate options to hedge against the risks due to the uncertainties surrounding a software acquisition effort, we develop a generalized Real Options Framework (Figure 3) in line with the five preconditions outlined in Mun (2006). This proposed framework consists of the following four phases, each of which explicitly addresses and establishes compliance with the preconditions.

1. Study Phase
2. Data Collection and Preparation Phase
3. Analysis Phase
4. Execution Phase

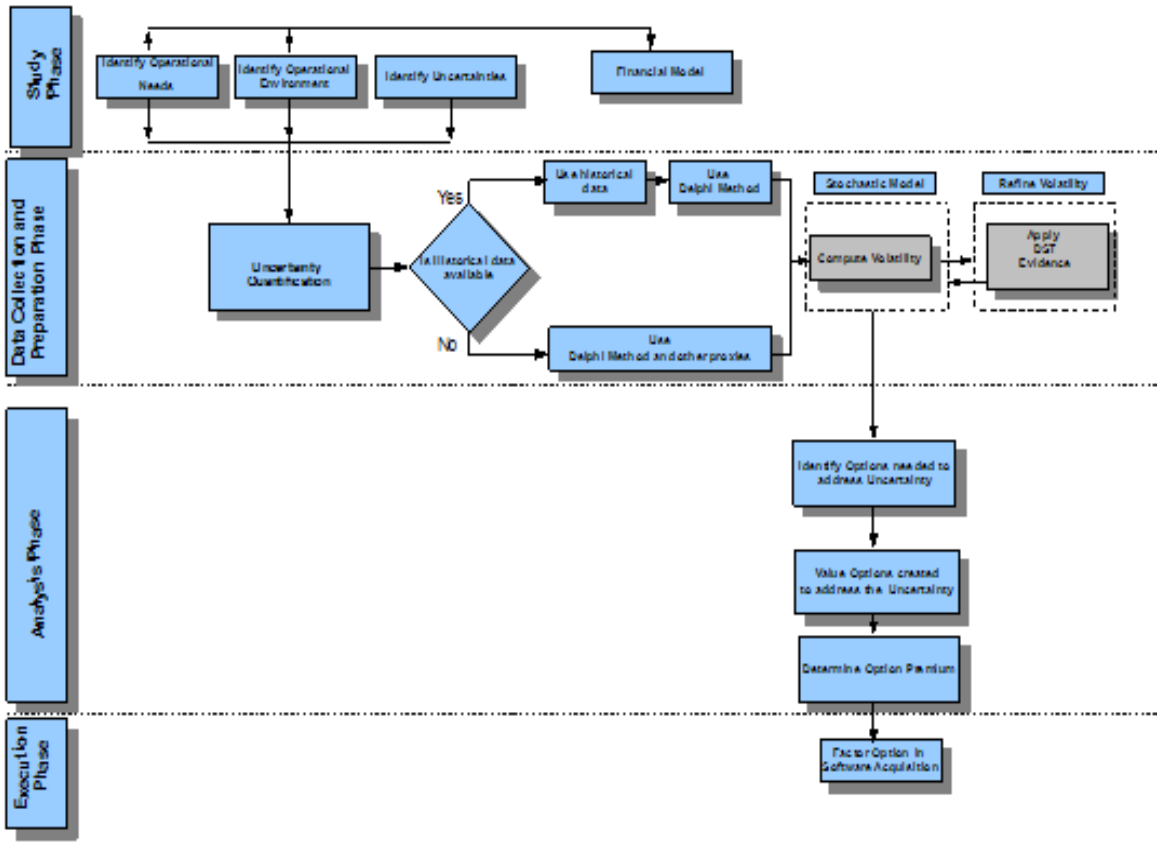

Figure 3. Real Options Framework

4. Addressing Uncertainty

Uncertainties permeate virtually every phase of the software acquisition process—ranging from procurement decision-making, requirements specification, software development and implementation, to the eventual evolution of the software. These uncertainties could be broadly categorized into the categories shown in Figure 4.

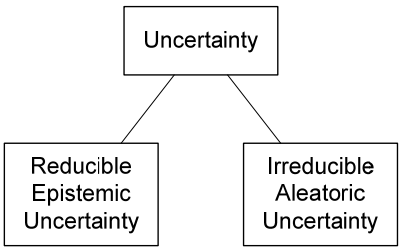

Figure 4. Taxonomy of Uncertainty

Epistemic uncertainties are reducible, and they deal with our lack of knowledge, lack of information and our own and others' subjectivity concerning an issue. Aleatoric uncertainties, on the other hand, are irreducible and they deal with the randomness (or predictability) of an event due to variability of input or model parameters when the

characterization of the variability is available (Wojtkiewicz, Eldred, Field, Urbina, & Red-Horse, 2001). In other words, an aleatoric uncertainty is an inherent variation associated with the physical system or the environment. Both epistemic and aleotoric uncertainties are interwoven and form the general framework of uncertainties that plague software acquisition efforts from a requirements uncertainty perspective.

Since requirements uncertainty implies risk, consequently, uncertainty must be duly quantified as a risk factor to gauge the magnitude of its impact on the underlying asset. The process of translating or equating software engineering uncertainties into a quantifiable property begins with quantifying the identified requirements uncertainties, computing the impact of uncertainties and ultimately developing a risk analysis framework in which the associated risks are identified, predicted and modeled using simulation and the results analyzed and costs factored into the software acquisition as appropriate.

4.1 Estimating Requirements Volatility

While volatility is just one of the parameters needed for Real Options analysis, it is the most difficult of all the parameters to estimate. Given the impact that requirements instability has on costs, we attempt to determine the rate of requirement change or the volatility of requirements. We will then use volatility to quantify the risk of requirements changes in the proposed software acquisition effort.

In order to estimate the volatility of the returns associated with our current software investment effort, we attempt to gather evidence to help derive our estimates. Historically, gathering of evidence using previously completed software-related capital investments as a proxy is a difficult task for the following reasons:

1. The current software investment effort under consideration might be the first of its kind with no known comparables.
2. Information is rarely or actively collected and managed in a disciplined fashion.
3. Even when information is collected, accessibility by third parties is usually difficult due to the proprietary nature of the information.

Thus, more often than not, the software executive is faced with identifying alternate sources of information to either assert or dispute their initial volatility estimates. In our study, we propose to use either historical data (i.e., objective approach) or expert opinions obtained using the Delphi method (i.e., subjective approach). We choose to use both methods because we believe intuition and judgment (subjective approach) should supplement quantitative analysis (objective approach). More often than not, past success and failures serve as key indicators of the future. Historical data can be used to predict and explore “what-if” scenarios on future projects based on the use of forecasting and analytical analysis.

The Delphi Method is a technique first introduced by the RAND Corporation in the 1940’s as 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. It places emphasis on an iterative, systematic, disciplined and interactive process of individual interviews (usually conducted using questionnaires) and the outcome is based on the Hegelian Principle of achieving consensus through a three-step process of thesis, antithesis, and synthesis (Stuter, 1996). In the thesis and antithesis steps, the team of experts present their opinion or views on the given subject, establishing views and opposing views, and consensus is ultimately reached

during the synthesis phase as opposing views are brought together to form the new thesis. Widely used as an estimating tool, the Delphi Method has been used to estimate values for factors (e.g., cost estimation) that appear in software estimation models such (Boehm, Abts, & Chulani, 2000) and risk estimation. Furthermore, it is one of the approved techniques published in February 2001 by the US Army Cost and Economic Analysis Center for preparing or reviewing economic analyses in support of the decision-making process.

In the event that there is no historical data available, the customer should resort to obtaining the required information using the Delphi Method. In the case that we do have historical data but are unable to find projects meeting any or all of the criteria above, we proceed to "fit" the data to as close as possible to mimic our current software investment effort by employing interpolation techniques to understand and forecast our project based on the trends depicted in the historical data.

To determine the rate of volatility, we employ the Caper Jones' approach, which is a transposition from the financial industry (Kulk & Verhoef, 2008). Jones asserts that existing methods of average percentage of change of the overall requirements volume lacks information because it does not give any information on the time in which the change occurred—a key factor in determining software engineering since requirements changes become more expensive to implement the farther we are into the software development process.

Jones therefore uses the compound monthly requirements volatility rate to express the time aspect. Calculating monthly requirements volatility rates, as defined by Jones, is a transposition from the financial world. The time value or future value of money is well-known in the field of accounting as compound interest or CAGR, short for compound annual growth rate. By transposing from compound growth rate in finance, we assume that requirements are compounded within a project (Kulk & Verhoef, 2008). The basic financial equation is given as follows:

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

which translates to

$$r = \left(\sqrt[t]{\frac{SLOCAtEnd}{SLOCAtStart}} - 1 \right) \times 100 \qquad (2)$$

where *t* is the time period in years during which the estimates were observed.

However, SLOC is not a suitable proxy for measuring requirements volatility because it is often dependent on the type of programming language being used and does not take COTS into consideration. In light of this finding, we proposed an alternative proxy: Function Points, which is a better metric for the size of the software requirements irrespective of how the software will be developed.

$$r = \left(\sqrt[t]{\frac{FuncPointAtEnd}{FuncPointAtStart}} - 1 \right) \times 100 \qquad (3)$$

4.2 Refining Volatility Estimates

Volatility refinement based on the Dempster-Shafer Theory on Evidence was a key aspect of the framework proposed in Olagbemiro (2008). Since volatility is a key input parameter needed for Real Options analysis, we attempt to overcome the complexity of volatility estimation by proposing the use of Dempster-Shafer Theory on Evidence, a technique first proposed for application in the domain of *sensor fusion.* It is a mathematical theory of evidence based on *belief functions* and *plausible reasoning*, which is used to combine separate pieces of information (evidence) to calculate the probability of an event. We posit that it could be used to address both aleotoric and epistemic uncertainties inherent in software-related capital investments by "*fusing*" and reducing uncertainties to the maximum extent as they become revealed, thereby facilitating a more accurate estimate of the risks propagated by uncertainty and allowing us to develop the appropriate option in response based on a more accurate volatility measure.

We choose to use DST because while Bayesian inference requires all unknowns to be represented by probability distributions, which awkwardly implies the probability of an event for which we are completely ignorant, DST takes over by introducing belief functions to distinguish ignorance and randomness by assigning probability mass to subsets of parameter space, so that randomness is represented by the probability distribution and uncertainty is represented by large subsets (Gelman, 2006). In other words, while Bayesian theory requires probabilities for each uncertainty of interest, the theory of belief functions provides a non-Bayesian way of using mathematical probability to quantify subjective judgments (Shafer, 1996). It measures degrees of belief (or confidence) for one uncertainty on the probabilities for a related uncertainty.

The premise behind DST is it can be interpreted as a generalization of probability theory where probabilities are assigned to sets as opposed to mutually exclusive singletons. In the case that there is sufficient evidence to permit the assignment of probabilities to single events, the Dempster-Shafer model collapses to the traditional probabilistic formulation in which evidence is associated with only one possible event (Sentz & Ferson, 2002). DST relies on three basic functions: the basic probability assignment function, a primitive of evidence theory that does not refer to probability in the classical sense, and two non-additive continuous measures called *Belief* and *Plausibility* that are used to combine separate pieces of information (evidence) to calculate the probability of an event, while simultaneously defining the upper and lower bounds, respectively, of an interval that contains the precise probability of a set of interest.

Since evidence can be associated with multiple possible events (i.e., sets of events) the evidence in DST can be meaningful at a higher level of abstraction—a key benefit needed at the strategic decision-making level that eliminates resorting to assumptions about the events within the evidential set. Furthermore, the DST model can be used to cope with varying levels of precision regarding information with no further assumptions needed to represent the information, as demonstrated during a study in addressing uncertainties in systems (Sentz & Ferson, 2002). We posit that the demonstrated approach also allows for the direct representation of uncertainties associated with software-related capital investments since we can characterize vague inputs as sets or intervals with the resulting output being a set or an interval.

DST is a theory about two things: 1) Degrees of belief and 2) Weights of evidence. A key benefit of DST is the ability to represent ignorance in the face of uncertainty, especially when there is no information so far. In probability theory, uniform distributions are used to represent ignorance; however, the problem with this approach is that we represent the space of possibilities affected by the probabilities we get. The theory of belief functions is based on two ideas:

1. The idea of obtaining degrees of belief for one question from subjective probabilities of a related question, and
2. Dumpster's rule for combining such degrees of belief when they are based on independent items of evidence. Degrees of belief obtained in this way differ from probabilities in that they may fail to add to 100%.

Both ideas are consistent with the Real Options pre-conditions as the degrees of belief are established on a frame of discernment meant to address uncertainty. DST assumes a Universe of Discourse Θ, otherwise known as the Frame of Discernment, which is a set of mutually exclusive alternatives. Thus a frame of discernment A of a set of mutually exclusive alternatives or possibilities can be represented as

$$\Theta = \{A_1 \ldots\ldots\ldots A_n\} \quad (4)$$

where A_1 through A_n represents the set of possibilities or mutually exclusive alternatives.

A key stipulation of DST is that it should only be used to combine belief functions that represent independent items of evidence. The independence required is simply probabilistic independence applied to the questions for which we have probabilities, rather than directly to the question of interest. In other words, it means that the sources of information (or at least their current properties as sources of information) are selected independently from well-defined populations.

Combining information or evidence from multiple sources (historical data and Delphi method) in the form of belief assignments aggregates the information with respect to its constituent parts. Dempster proposed a standard combination rule that can be represented as:

$$m_{12}(A) = \sum_{B \cap C = A} \frac{m_1(B) m_2(C)}{1 - K} \text{ when } A \neq \emptyset \quad (5)$$

where $K = \sum_{B \cap C = \emptyset} m1(B) m2(C)$

This rule is computed by summing the products of the belief probability assignments (bpa's) of all sets where the intersection is null, and represents basic probability mass associated with conflict. In addition, $m_{12}(A)$ is calculated from the aggregation of two bpa's m_1 and m_2.

Assuming we have two pieces of evidence, based on historical data and expert judgment (Delphi Method), we combine the pieces of evidence using the Dempster's combination rules by computing the orthogonal sum of both. First, we determine the pairs of sets whose intersection is A for a given set A such that $A_1 \bigcap A_2 = A$. We then add the products of the basic probability assignments $m_1(A_1)$ and $m_2(A_2)$, giving us

$$\sum_{A_1 \cap A_2 = A} m_1(A_1) m_2(A_2) \qquad (6)$$

The orthogonal sum of m_1 and m_2 defined by $m = m_1 \oplus m_2$ could then be given as $m(\emptyset) = 0$ and is demonstrated in the matrix below (Table 2), in which we compute the orthogonal sum of three hypothetical risk factors (Risk1, Risk2 and Risk) affecting a software investment program based on two independent expert assessments.

			Independent Expert 1 Subjective estimates on Objective probabilities		
	Risk Factors		{Risk1} m1= 0.80	{Risk1,Risk2} m1= 0.15	{Risk1,Risk2,Risk3} m1 = 0.05
Independent Expert 2 Subjective estimates on 3 Objective probabilities	{Risk1}	m2 =0.70	m1({Risk1})*m2({Risk1})	m1({Risk1,Risk2})*m2({Risk1})	m1({Risk1,Risk2,Risk3})*m2({Risk1})
	{Risk1,Risk 2}	m2 =0.20	m1({Risk1})*m2({Risk1,Risk2})	m1({Risk1,Risk2})*m2({Risk1,Risk2})	m1({Risk1,Risk2,Risk3})*m2({Risk1,Risk2}
	{Risk1,Risk2,Risk3}	m2 =0.10	m1({Risk1})*m2({Risk1,Risk2,Risk3})	m1({Risk1,Risk2})*m2({Risk1,Risk2,Risk3})	m1({Risk1,Risk2,Risk3})*m2({Risk1,Risk2,Risk3})

Table 2. Orthogonal Sum of Basic Probability Assignments

Based on the sample matrix (Table 2), we can obtain the resulting three evidence functions.

$m_1 \oplus m_2$({Risk1})

= m_1({Risk1})*m_2({Risk1)} + m_1({Risk1,Risk2})*m_2({Risk1})

+ m_1({Risk1,Risk2,Risk3})*m_2({Risk1}) + m_1({Risk1})*m_2({Risk1, Risk2}) + m_1({Risk1})*m_2({Risk1, Risk2, Risk3})

$m_1 \oplus m_2$({Risk1,Risk2})

= m_1({Risk1,Risk2})*m_2({Risk1,Risk2})
+ m_1({Risk1, Risk2})*m_2({Risk1, Risk2, Risk3})
+ m_1({Risk1, Risk2, Risk 3})*m_2({Risk1, Risk2})

$m_1 \oplus m_2$({Risk1,Risk2,Risk3})

= m_1({Risk1,Risk2,Risk3})*m_2({Risk1,Risk2,Risk3})

Using on the information derived from the matrix, we can establish joint beliefs. Any variations between inferred probability assignments based on the mass of evidence under this joint belief and our initial volatility estimates based on our modified Caper Jones' equation (Eqn. 3) would reflect inconsistencies. These variations are captured and used to refine the initial probability estimates to reflect the new "findings" that are then modeled using a Monte Carlo simulation to derive new estimates for the requirements volatility and an overall volatility for the software acquisition effort.

5. Applying the Real Options Valuation Framework

In an attempt to validate our proposed approach, we applied the framework to the software component FCSN (Future Combat Systems Network) of US Army Future Combat System (FCS). The decision to select this case study as a validation mechanism was based on the recent nature of the project, the high-risks associated with software development due to the advanced technologies involved, the challenge of networking the FCS subsystems so that FCS-equipped units can function as intended, and the associated outcome had a Real Options approach been applied. This section summarizes our study. Readers can refer to Olagbemiro (2008) for the details of the study.

5.1 Development of a Business Case

We used a traditional discounted cash flow model to obtain a net present value (NPV) in terms of five high-level determinants (Erdogmus & Vandergraaf, 1999):

$$NPV = \sum \frac{(C_t - M_t)}{(1+r)^t} - I$$

where ***I*** is the (initial) *development cost of the FCSN*
t is the (initial) *development time* or time to deploy the FCSN.
C is the *asset value of the FCSN* over time *t*
M is the *operation cost* of the FCSN over time *t*
r is the rate at which all future cash flows are to be discounted (the *discount rate*).

A NPV of $6.4 trillion[3] was computed for the FCSN using estimated values based on key assumptions in Olagbemiro (2008).

5.2 Identification of Uncertainties and Risk Quantification

Using publicly available information (GAO, 2008), we determined that requirements uncertainty fostered by technology maturation issues plagued the FCSN program and resulted in the following uncertainties:

1. Requirements uncertainties
2. Integration uncertainties
3. Performance uncertainties
4. Estimation uncertainties (size and cost of the software)
5. Scheduling uncertainties.

In response, we developed Real Options to mitigate the risk due to requirements change. Due to the lack of publicly available historical data for the FCSN program, data from the Joint Strike Fighter program was fitted and utilized as a source of historical information for comparative purposes. The risk of requirements changes in the FCSN program was estimated

[3] NPV of $6.4 trillion is computed based on (1) Value of the FCSN program, (future value less operating costs, i.e., sum of (C – M), = $10 trillion), (2) Initial development cost I = $163.7 billion, (3) r = 3%, and (4) Time t to develop the FCSN = 13 years.

to be 12% (as oppose to 0.28% for the JSF program, which is 1/5 the size of the FCSN program) using Equation 1.[4]

We used requirements volatility to quantify the risk effect as variations in the returns associated with the investment. We ran Monte Carlo simulation of the risk model using the Risk Simulator software, taking into account interdependencies between the risk variables to emulate all potential combinations and permutations of outcomes. The analysis indicated that requirements volatility introduced an overall volatility of 0.0866% in the FCSN program. The volatility of 0.0866% resulted in a reduction in the NPV of the FCSN program from $6.4 trillion to $6.1 trillion. This reduction in NPV is a result of the potential increased costs in light of the risks facing the FCSN program, which ultimately reduces the value of the investment effort from a financial point of view.

To improve the accuracy of the volatility estimates, we chose to refine the volatility using the DST. This is accomplished by establishing "belief functions" that reflect the "degrees of belief" between our NPV estimates in light of the risks posed by requirements uncertainty and the FCSN cost estimates provided by two independent sources: the Cost Analysis Improvement Group (CAIG) and the Institute of Defense Analysis (IDA). The independent belief functions based on the CAIG and IDA, which inferred basic probability assignments associated with each of the FCSN risk factors (i.e., requirements, integration, estimation risk, etc) were combined using an orthogonal matrix to determine the most probable beliefs for the set of risk factors. Where the combined functions reflected "belief" in our estimates, the latter were considered valid and were left untouched. When the combined belief functions reflected conflict with our estimates, our estimates were revised accordingly. 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. Details of the computation can be found in Olagbemiro (2008).

5.3 Options Development

The FCS software effort has been decomposed into six components: Combat Identification, Battle Command and Mission Execution, Network Management System, Small Unmanned Ground Vehicle, Training Common Component, and Systems-of-Systems Common Operating Environment. 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. We proceeded and developed two options to address this scenario: (1) Compound Option and (2) Deferment Option.

[4] The requirements volatility of 12% was computed based on start and ending SLOC for the FCSN program. SLOC is used for demonstration purposes only. A more suitable metric, such as function points, is recommended.

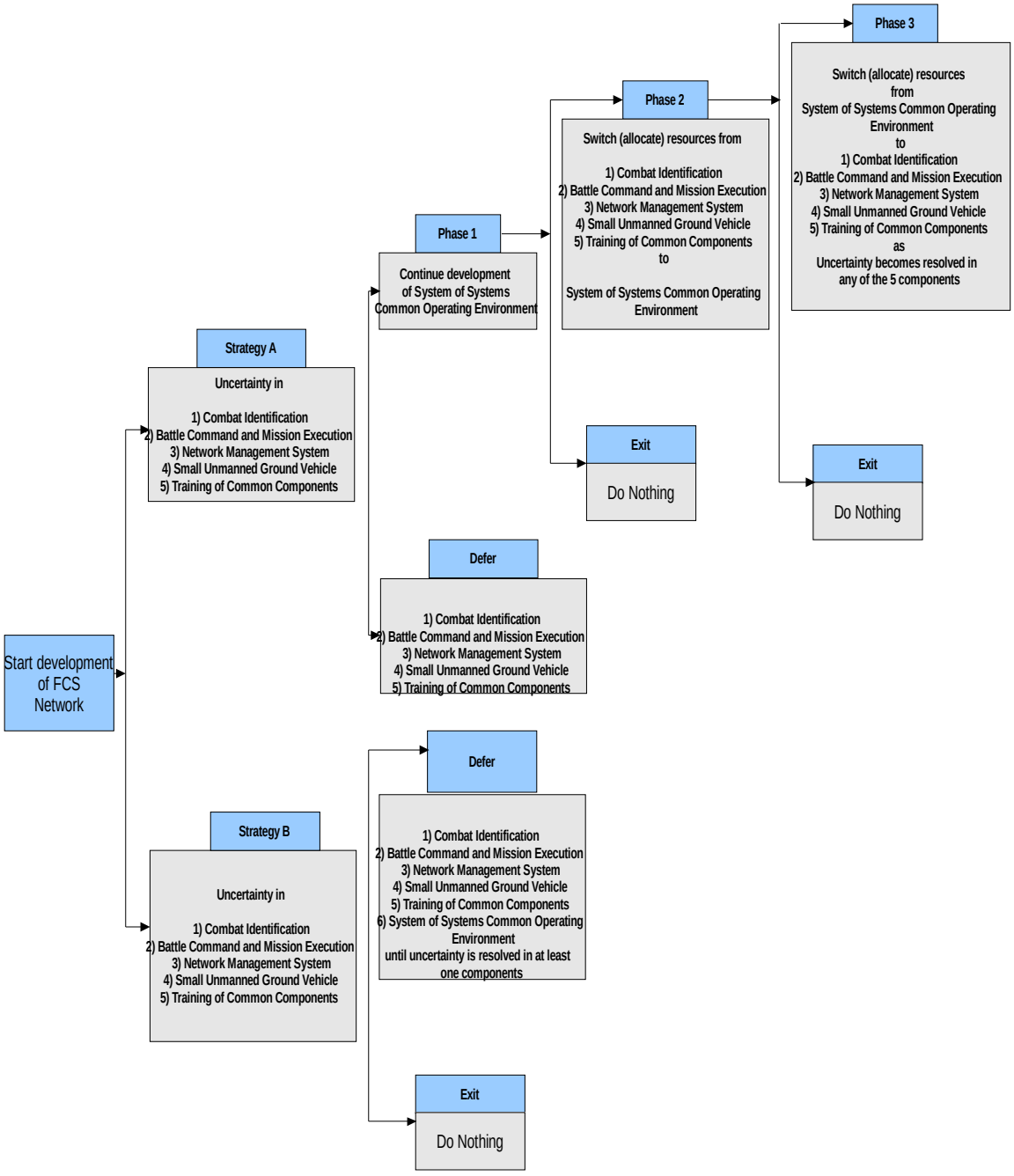

Figure 5. FCS Strategy Tree Depicting Strategy A and B for Given Scenario

(1) Strategy A—The Compound Option

In the event that at least one of the software components is not facing requirements uncertainty, with all the others facing requirements uncertainty, an option could be developed to scale down the resources/staff allocated to the software components facing requirements uncertainty. The staff could then be switched to work on the software component that is not

facing requirements uncertainty, while the uncertainties in the other components are addressed using our uncertainty elicitation model.[5] We, therefore, frame the real options in this case as an *Option to Contract and Scale Down* from an uncertain system, *Option to Switch* resources to another system, *Optios to Expand and Scale Up* staff assigned to the development of a system not facing uncertainty (shown as Strategy A in Figure 5). Essentially, this is a compound option—an option whose "exercise" is contingent on the execution of the preceding option.

(2) Strategy B—The Deferment Option

In the event that five out of the six software components are facing requirements uncertainty, then an option could be developed to stop and defer all development to include the development of the software component that is not facing requirements uncertainty for a specified period until uncertainty is resolved (shown as Strategy B in Figure 5). This is an *Option to Wait and Defer*.

5.4. Options Valuation

We utilize the Real Options Super Lattice Solver (SLS) 3.0 software developed by Real Options Valuation, Inc., for the task.

(1) Strategy A

The Real Options SLS software was populated based on the following underlying values:

(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 option under Strategy A returned a value of $6.27 trillion.

(2) Strategy B

In Strategy B, which calls for a "defer and wait approach," an assumption is made that the duration for deferment option would be three years. We set up our model using the same assumptions used in strategy A, but we set the duration of the Deferment Option to three years. The value of the underlying asset was computed as $6.4 trillion, and the option analysis returned a value of $6.25 trillion.

[5] Note: The assumption with this approach is that the software component development effort, which the staff engineers are being reallocated to work on, is not behind schedule and, therefore, does not violate Brooks Law.

5.5. Investment Valuation

Given the option value of $6.27 trillion under Strategy A, the intrinsic value of the compound option is determined to be $6.4 trillion—$6.27 trillion = $130 billion. Under Strategy B, the intrinsic value of the deferment option is determined to be $6.4 trillion—$6.25 trillion = $150 billion. This implies that under both Strategies A and B, the software executive should be willing to pay no more than (and hopefully less than) the option premium of $130 billion and $150 billion, respectively, in addition to the initial investment cost of $163.7 billion to increase the chances of receiving the initially projected NPV of $6.4 trillion for the FCSN as opposed to the current $5.7 trillion in light of the risks caused by the uncertainties in five of the six software components. This premium would also include the administrative costs associated with exercising an option from an integrated logistics support point of view (i.e., costs associated with contractual agreements, software development retooling costs, and costs associated with infrastructure setup of the infrastructure).

In analyzing both strategies, Strategy A is more attractive than Strategy B. Instead of waiting another three years at an additional potential cost of $150 billion (after which uncertainty would hopefully have been resolved) and then proceeding to spend $163.7 billion at once to develop all six software components, the staged-phase approach in Strategy A calls for spending up to $130 billion for the option up front plus some of the $163.7 billion for the Systems-of-Systems Common Operating Environment component, and then investing more over time as the requirements are firmed up for the other five components. Therefore, under these conditions, Strategy A—which employs the compound sequential options—is the optimal approach.

6. Conclusion

Uncertainties associated with software-related capital investments lead to unnecessary and sometimes preventable risks. As the DoD often sets optimistic requirements for weapons programs that require new and unproven technologies, the application of the real options valuation methodology would be beneficial to enable the DoD to incorporate the appropriate *strategic options* into the acquisition contracts. The options would serve as a contract between the software executive and the contractor—in the case of a government acquisition—to buy or sell a specific capability known as the options on the underlying project. The proposed real options valuation approach is able to overcome the limitations of traditional valuation techniques by utilizing the best features of traditional approaches and extending their capabilities under the auspices of managerial flexibility. The explicit uncertainty elicitation task, the development of options to hedge against the risk, and the timely execution of the options as they appear will allow decision-makers to better balance customer requirements as dictated by operational needs within financial viability and schedule constraints and manage risks proactively.

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