Sub-Corporate Finance:
New Sources of Data for Real Options Analysis

Sub-Corporate Finance:
New Sources of Data for Real Options Analysis

> *If [we] have seen further it is because [we] have stood on the shoulders of giants.*
>
> Isaac Newton to Robert Hooke (1676)

Introduction

There appear to be four interlocking issues in the real options research area that require resolution to move the theory a new level of rigor as well as practical application. These issues are alluded or discussed directly to in much of the real options literature and were the main points of a keynote address by Dr. Steward Myers at the June 2004 8th Annual Real Options Conference in Montreal, Canada. They are:

(1) problems related to developing fundamental inputs for the models;

(2) a low level of computational transparency for average users, leading to difficulties in creating consistent structure and repeatability of RO problems and solutions;

(3) no standardized method by which to check projected results against reality;

(4) the need to more effectively "commercialize" the practice of real options analysis.

In this paper, we will address these issues by presenting an theory that provides a new source of raw data for use in real options. This analytic theory is based on the idea that organizational outputs can be described in thermodynamic terms using complexity theoretic concept of a unit of complexity. The underlying syllogism is: Given that an organization takes inputs and changes them into outputs, the value added by the organization is proportionate to the amount of changes it makes in the inputs to produce the outputs. A unit of change is can be described as a unit of complexity. This provides a means to describe all organizational outputs in terms of *common units of change*, that is, units of complexity.

This theory was originally created as a means to count the amount of change in entropy (described in terms of corporate knowledge) required to make the changes needed to produce an organization's outputs. The approach was designed to provide management with a verifiable method by which to assign benefit streams and costs to the sub-organizational outputs produced by the organization's knowledge assets (such as people, processes, capabilities, and information technology). This, in turn, was intended to shift management's investment focus from some variation of cost containment to value creation. After over fifteen years of use, the fundamental theory, known as Knowledge Valuation Analysis (KVA), has been the focus of academic research and numerous consulting interventions covering a wide range of for-profit, not-for-profit, and government organizations.

Knowledge Valuation Analysis (KVA) functions much like accounting in terms of its historical orientation, the kinds of data it produces (i.e. described in common units), the simplicity by which the data can be monetized, and the ways in which the data is gathered (i.e., using verifiable observation) and analyzed (i.e., using common performance and profitability ratio analysis). For these reasons, KVA results can also be utilized in corporate finance and valuation problems with beneficial outcomes. Such outcomes suggest a number of useful resolutions to the troublesome limitations of current approaches to real options analysis.

The first section of this paper will present a summary of KVA theory to provide the context for our approach to real options analysis. Section Two reviews the statement of the problem and supporting literature in conjunction with suggested complexity theoretic solutions. Section Three will contain a recent case study using KVA and real options analysis together to solve a research problem. The final section will present conclusions, limitations and avenues for future research.

I. Knowledge Valuation Analysis (KVA)

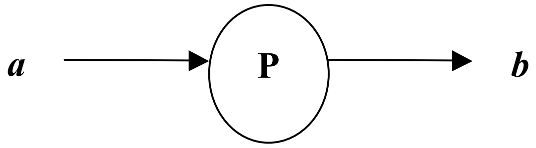
Knowledge Valuation Analysis (KVA) is the seminal work of Dr. Tom Housel (Naval Postgraduate School) and Dr. Valery Kanevsky (Agilent Labs). It is an explanatory theory within the complexity paradigm, using a methodology that is analytic and tautological, and provides a means to count the outputs of an organization in common units using a knowledge metaphor. In this metaphor, the amount of corporate knowledge, in equivalent units, that is resident in the final outputs of the organization (i.e. products and services) is used in core processes to generate these outputs. The following summary has been abstracted from the most current iteration of the theory (see Housel & Nelson, 2004: in press).

In the KVA model, measurement is in common units of output at the level of Kolmogorov Complexity. These common units allow us to directly assign revenue streams to an organization's core processes. They also allow us to assign costs to core processes with greater clarity than allowed by standard cost accounting or ABC methods. Whether a process approach, a matrix approach, or a function approach is used to "slice up" the company for valuation or costing purposes, the common units of measurement provided by KVA will remain the same and be equally applicable.

Two underlying assumptions of the theory are that: (a) Humans and technology in organizations take inputs and change them into outputs through core processes; and (b) by historically describing all process outputs in common units of change, it is possible to assign revenue, as well as cost, to those units at any given point in time.

The outputs of all processes can be standardized by describing them in terms of the number of units of change (complexity) required to produce them, given the existing state of the technology used in the processes.

The rationale for this is that processes with predetermined outputs (i.e., the outputs are always the same, given the same inputs) are more or less isomorphic with computer algorithms. Therefore, process changes are virtually identical to computing. This fundamental parallelism between the structural change of substances (inputs into outputs) and information processing allows us to describe the amount of knowledge required to produce process outputs and determine the value added by the process (Kanevsky & Housel, 1998). A diagram of this value-adding cycle is found in Figure 1 following.



Process ***P*** is a business process.
If input ***a*** is equal to output ***b***, no value has been added by process ***P***.
If input ***a*** is changed by process ***P*** into output ***b***, value has been added and is ≈ change.
Change can be measured by the amount of knowledge required to make the change.
This knowledge ≈ the amount of time it takes for an average learner to acquire the knowledge.
So, value added by process ≈ change ≈ knowledge required to produce the outputs ≈ $\mathbf{K}_\mu$

Housel, T. & Kanevsky, V. (1995) "Reengineering Business Processes: A Complexity Theory Approach to Value Added," INFOR **33(**4): 251.

Figure 1: The KVA Value-Adding Cycle

The amount of change generated by a process can be discussed in any descriptive language, provided that the language used produces reliable value estimates stated in roughly equivalent units of measure. For this reason, there have been many languages used within KVA theory to describe units of change, e.g. tasks, process instructions, Haye knowledge points, Shannon bits, Jackson structural diagram decision points, units of knowledge.

Although the term *bits* has been used to describe units of complexity (i.e., change) at the most granular level, it is currently an impractical operationalization. Therefore, we have chosen to discuss units of change in terms of the knowledge required to reproduce the change, because the operational metaphor, "knowledge," is easy to understand and rapidly apply to generate estimates of change. This metaphor provides the added benefit of allowing us to describe intangible outputs such as those associated with the use of intellectual capital.

These units are less precise than bits, but more practical to estimate. We define them in terms of the time required by an "average" learner to learn how to produce process outputs and name them Knowledge Units (K_μ). In KVA theory, the K_μ unit is proportionate to an information bit which is proportionate to a unit of Kolmogorov complexity which is proportionate to a unit of change. Thus, the K_μ is the descriptive language for change within the knowledge metaphor.

Knowledge is embedded in process assets such as IT, employees, training manuals, etc. and all processes can be described in terms of knowledge units. A process must execute once to produce a single unit of output, represented by a given number of knowledge units. Additional levels of detail in process descriptions provide additional levels of accuracy in the estimation of the number of knowledge units comprising those processes.

The value of outputs, such as products and services, is derived from their inherent characteristics. The corporate knowledge needed to produce the organization's products and services has these characteristics embedded in it. Processes, outputs, and related corporate knowledge fit very generally within three categories, based on these characteristics. Since KVA is a kind of "value" accounting, we have chosen to use accounting terminology to describe these categories, as follows.

Variable Processes, Generating Variable K_μ*:* Variable Knowledge units describe outputs from the variable processes and sub-processes of the organization. Like variable cost, they vary in quantity with the number of employees and/or amount of technology executing a process and with the number of process executions.

If the output will always be the same, given the same input, then we describe the output as *predetermined*. Variable Processes imply predetermined outputs that are identical in name and in characteristics. They are associated with continuous process flows, unspecialized non-managers, and day-to-day operations. Primarily the product of manufacturing and other mature, highly standardized industries and operational processes, they involve tangible outputs.

Semi-Fixed Processes, Generating Semi-Fixed K_μ*:* Semi-Fixed Knowledge units describe outputs from the semi-fixed processes and sub-processes of the organization. Like Variable Knowledge units, they vary in quantity with the number of employees and/or amount of technology executing a process and with the number of process executions. Similar to Variable Knowledge units, Semi-Fixed Knowledge units imply predetermined outputs that are identical in name. Like semi-fixed costs, they are generated by infrastructure and/or ongoing operations but, like variable costs, vary with the organization's outputs.

Unlike Variable Process outputs, Semi-Fixed Process outputs may vary in characteristics from one to another. In addition, they are associated with event-driven (custom) process flows, line managers and specialist non-managers, and day-to-day operations. Primarily outputs from knowledge/professional service industries and specialized operational processes, they can be found in both tangible and intangible outputs. Semi-Fixed Knowledge units have a large component related to long-term experience and expertise.

Meta Processes, Generating Fixed K_μ*:* Fixed Knowledge units describe the Meta Process outputs of the company. Although elements of Fixed Knowledge exist throughout the organization within Semi-Fixed Knowledge unit outputs, we have chosen to define Fixed Knowledge units as the descriptor for the organization's management and "creative" Meta Process outputs. Like fixed costs, they do not vary with the organization's outputs, i.e. number of products or services produced. They are assigned by spreading them over the outputs of the entire organization since they are generated by Meta Processes.

We have also chosen to define Meta Processes as prospective, non-divisible, synergistic, and universally influential throughout the organization. They are prospective and non-divisible because they are the base of control from which all the activities of the firm will flow over a sample period and their influence is prospective, not historical. The management and "creative" personnel who are present at the start of the sample period will execute Meta Processes described by Fixed Knowledge units and influence the organization throughout the sample period going forward.

They are non-divisible because we are not able to identify separate segments of Fixed Knowledge in the outputs of the organization in a clearly defined way. For example, it is almost impossible to say where the effects of senior management, marketing, or research begin and end when we examine the outputs of the organization.

They are synergistic with Variable and Semi-Fixed Processes rather than additive to them. They are the "strategic engine" that drives, coordinates and empowers the core processes of the organization. Since Meta Processes exert universal influence throughout the organization, we assume that they only executes in conjunction with Variable and Semi-Fixed Processes, never by themselves. If, at some future time, we are able to more precisely identify and estimate the effects and Fixed Knowledge outputs of Meta Processes, we will do so.

There are several additional assumption sets necessary to understand and apply KVA consistently. They are presented following. Again, they have the “look and feel” of traditional accounting.

The Treatment of Non-Systems Infrastructure: For most KVA purposes, we assume that non-systems infrastructure (electricity, physical plant, etc.) is predictable, standardized, and does not generate change/entropy, i.e. provides no leverage or value-added to the company. We, therefore, also assume that we do not need to count knowledge units it contributes. Instead non-systems infrastructure provides the condition in the Kolmogorov Complexity equation defined as “given the state of the system.”

Under these circumstances, non-systems infrastructure becomes part of the value equation as fixed costs. If production increases to the point where fixed costs become Semi-Fixed from a cost accounting standpoint, we adjust our denominator accordingly.

In situations where non-systems infrastructure is an integral part of the transformation process (e.g., sewage treatment plants, chemical processing operations, refineries), we count the knowledge units it contributes and assign revenues and costs accordingly.

The Treatment of Information Technology (Automation): For the KVA model, we define Information Technology (Automation) as programs and software. We classify hardware and the infrastructure that supports it as part of the *Infostructure Systems Management* core process, not the Information Technology of the company.

IT (automation) contributes knowledge units to most or all the processes of a company. It can: Automate 100% of all executions of a process by replacing all employees (and their knowledge); automate 100% of a given number of executions of a process as a replacement for x% of the total employees that execute the process; or assist an individual employee by automating x% of each execution of a process.

There are a number of sampling processes KVA can use to estimate the contribution IT makes to processes. One of the more precise methods is to set up analysis scenarios in which subject matter experts are asked to assume that the company IT has failed and the company must produce outputs without it. The experts are then asked to estimate how long it would take an average employee to learn how to produce these outputs without the assistance of IT.

A less precise method is to ask managers to describe the role of IT in a given process (per the choices above) and provide a reasonable estimate of the % automation for that process. Since we are gathering data very close to the source of observations rather than at the organizational level far away from the source of observations, the loss of precision is not material enough to disqualify the analysis.

In order to conduct the analysis initially, we assume that the process is optimized. Once KVA data is gathered and analyzed, it will become clear which processes are, in actuality, not optimized and need reengineering.

Measuring K_μ: There are at least three measures that can be used as proxies for the number of Knowledge units representing process outputs. Each of these measures assumes process efficiency maximization as a baseline, that is, the shortest learning time per average "learner," the least number of process instructions, or the shortest sequence of binary questions required to obtain the outputs. The following describes these measures briefly:

1) <u>The time required to learn the process</u>: Learning time is proportionate to the amount of knowledge embedded in the process description. It can be described as the amount of

time necessary for an average person ("learner," for common reference point) to learn how to complete a process correctly.

Just as flawed or inefficient processes will result in higher execution times and costs to execute, so process innovation will result in lower learning times, execution times, and costs to execute. Estimating the learning time for an average "learner" sets a baseline for the process. However, inefficiencies or higher efficiencies will be revealed as KVA data is collected and analyzed.

2) The number of process instructions: The number of process instructions required to generate the process output successfully can serve as the proxy for the knowledge content of the process. The level of the language used must be consistent across all instructions (e.g., Cobol cannot be used for one process and Java for another).

3) The length of the sequence of binary questions (i.e., bits) required to complete the process: In the language of computers, since computer code is a reasonable proxy for a process description, it can also serve as a proxy for the amount of knowledge embedded in the process.

Ideally, at least two proxies should be used during any given analysis of a process to provide a reliability check for the estimates of knowledge content. This ensures that all reliability checks are derived directly from the same theoretical basis and the same source of data, rather than through triangulation and the concurrent validity of several theoretical bases and sources of data. We have chosen the "Time to Learn" proxy as our primary approach.

There are several assumptions that provide a foundation for using Time to Learn to estimate K_{μ}:

Assumption 1: On average, all the human resources of the company are in positions that match their experience and education.

Assumption 2: “Time to Learn” is defined, for the purposes of estimating Variable and Semi-Fixed Knowledge, as the time it takes for an *average* employee (i.e., common point of reference, “learner”) to learn a given process. It is a mix of formal training and on-the-job training. It can be stated in actual units of time or normalized as an estimated percentage (%) of 100 months.

We acknowledge that, in the real world, “time to learn” involves a learning curve that begins slowly and increases speed over time. However, KVA focuses on the *total time from start to finish of a learning cycle* rather than on the change in learning velocity throughout the learning cycle. The *learning cycle ratio* is the KVA factor that represents the learning curve on a uniform-velocity basis.

Assumption 3: “Time to Learn” is defined, for the purposes of estimating Fixed Knowledge, as the time it takes for an *average* “qualifying individual” to become an expert in his/her given field. We chose as a proxy the findings of psychology and behavioral finance that state that a person attains “expert” status after practicing in a field for 10 years. (Simon,1983)

Assumption 4: Every employee producing Variable Knowledge units starts at 0% knowledge of a process on the date of hire. S/he does not carry forward years of experience from prior employers. Since “Time to Learn” is a surrogate for desired output and experienced employees should produce outputs faster than inexperienced ones, “years of experience” will be reflected in increased number of process executions (higher productivity).

Assumption 5: Employees producing Semi-Fixed Knowledge units carry forward “years of experience” from prior companies. They do not start at 0% knowledge on the date of hire because their experience cannot be captured in increased numbers of process executions and is captured instead in higher quality or complexity of outputs.

Assumption 6: Individuals executing Meta Processes carry forward "years of experience" from prior companies. They do not start at 0% knowledge on the date of hire because their experience becomes a part of all the organization's processes and outputs but cannot be observed or counted in discrete units.

Assumption 7: At the outset of a KVA, we assume that each process utilizes the optimal number and skill mix of employees. Once the KVA data has been gathered and analyzed, we can then identify processes that have not been optimized in this way.

Data Gathering Techniques: As will be noted from the prior discussion, our method of gathering data by which to measure knowledge units involves extensive use of subject matter experts and management. There is a large body of academic research that justifies this choice of methodology. The following presents a summary of this research. (King and Zeithaml. 2003; Housel and Nelson. 2005 in press)

(1) Organizational knowledge is enacted through the perspective of multiple 'knowers' in a firm (Tsoukas, 1996; Glazer, 1998; Orlikowski, 2002). Therefore, it is not appropriate to attempt to measure knowledge from one individual's viewpoint.

(2) Knowledge is acquired in two stages (e.g., Anderson, 1976; Singley and Anderson, 1989), the *declarative* and the *procedural*. The declarative stage involves conscious, general knowledge that can be verbalized. The procedural stage involves practice, growing recognition of patterns, improved abilities, and lower requirements for cognitive involvement (Newell and Simon, 1972; Simon, 1974; Anderson, 1995; Gobet and Simon, 1996). Procedural knowledge is rich, embedded, specific, and embodied in actions and skills (Singley and Anderson, 1989:31).

(3) Organizational knowledge resources are predominantly procedural (Nelson and Winter, 1982). However, to measure organizational knowledge requires declarative knowledge.

(4) “Managers routinely are required to communicate and transform procedural knowledge into declarative knowledge as they negotiate organizational priorities and make strategic decisions. Although it is impossible to articulate all that one knows about organizational knowledge (Leonard and Sensiper, 1998), we suggest that experienced top- and middle-level managers are particularly adept at recognizing and articulating organizational knowledge. Tapping their knowledge about the organization . . can provide a new and valuable way to measure organizational knowledge.” (King and Zeithaml, 2003: 2, 3)

The algorithms and the application of the KVA methodology will be demonstrated in Section Three.

II. Sub-Corporate Finance

As stated earlier, the field of real options analysis appears to be grappling with four interlocking issues: 1) Intractable problems related to developing fundamental inputs for the models; 2) a low level of computational transparency for average users, leading to difficulties in creating consistent structure and repeatability of RO problems and solutions; 3) no standardized method by which to check projected results against reality; 4) the need to more effectively “commercialize” the practice of real options analysis.

Although we can demonstrate how KVA will assist in addressing Issues 2-4, we choose to focus on Issue 1 in this paper because it is foundational to not only real options but the whole practice of corporate finance. It is our belief that much of the work presented here is new so reference to the academic literature will be made where it is relevant and possible.

Intractable Problems in Developing Model Inputs: The following is a list of problems related to developing RO model inputs. They have been commonly stated in finance and real option literature and were clearly defined during panel discussions, presentations, and the keynote speech by Dr. Stewart Myers at the June 2004 Real Options Conference.

1) Various parties are using different languages and thought processes to develop model inputs and evaluate model outputs for corporate finance.

a. Real options are driven by value creation while finance and engineering are driven by risk management, creating difficulties in discussing and developing inputs (de Neufville, Presenter, 2004 RO Conference).

b. Corporations are measured by the markets on predictable growth, while real options analysis (ROAn) estimates value under uncertainty, i.e. the value of strategic flexibility. This means that the client (investor, market) will be looking for one kind of data and value estimate while the supplier (RO analyst) will be providing another (Thursday Panel Discussion, 2004 RO Conference: Antikarov, Monitor Group; Brosch, Boston Consulting; Eapen, Decision Options; Matthews, Boeing; Vardan, ROG, ex General Motors).

c. Currently, corporations are tracking performance in excruciating detail on a virtually real-time basis, but not within a strategic context. "We were looking in the rear view mirror. Now we can see through the floorboard. But we still need to look through the windshield" (Audience, Thursday Panel Discussion, 2004 RO Conference: Antikarov, Monitor Group; Brosch, Boston Consulting; Eapen, Decision Options; Matthews, Boeing; Vardan, ROG, ex General Motors).

d. ROAn needs to be positioned within the context of normal capital budgeting language, such as IRR and PBP (Alesii, Presenter, 2004 RO Conference).

2) There are "quality of data" issues with which to contend.

a. "Any techniques would be welcomed that will deal better with assessing and collecting data to correct the 'garbage in-garbage out' effect" (Closing Panel Discussion, 2004 RO Conference: Sick, Boyer, Brennan, Kamrad, Lambrecht, Myers, Trigeorgis).

b. RO needs performance measures at the portfolio level (and at the project level). Without these, it is difficult to estimate the value of staged, growth, compound and other complex options (Thursday Panel Discussion, 2004 RO Conference: Antikarov, Monitor Group; Brosch, Boston Consulting; Eapen, Decision Options; Matthews, Boeing; Vardan, ROG, ex General Motors).

c. "If we could find a way to define the real portfolio position of a firm, then we could investigate new positions effectively" (Kassar & Lasserre, Presenters, 2004 RO Conference).

d. There is a need to develop methods to measure benefits as well as costs for model inputs (Closing Panel Discussion, 2004 RO Conference: Sick, Boyer, Brennan, Kamrad, Lambrecht, Myers, Trigeorgis).

3) Valuation of the underlying asset is extremely difficult.

a. It is difficult or impossible to replicate the underlying asset for real options analysis by using a market portfolio (Myers, Keynote, 2004 RO Conference).

b. It is difficult to develop appropriate estimates of the net present value of cash flows of the underlying assets. Examples: Assets that currently produces little or no cash flow; the changing nature of an organization's weighted average cost of capital (WACC) over time; difficulties in estimating an asset's economic life; forecast errors in estimating future cash flows, due to uncertainty, riskiness, and project complexity; no unambiguous cash flows that can be assigned to a project; diversification, interdependencies, synergies that are hard to identify or quantify but affect value; no means to measure intangible factors, which are often mission critical (Myers, Keynote, 2004 RO Conference; Mun, 2002; Nelson, 2004).

c. It is difficult to develop an appropriate and defensible rate by which to discount the expected cash flows of the underlying asset for the base case. This requires subjective assessment of various risk factors (maturity risk, inflation risk, size risk, non-marketability risk, and so forth) and invites massaging to suitable levels (Myers, Keynote, 2004 RO Conference; Mun, 2002; Nelson, 2004).

4) Capturing the volatility (risk) of projects is extremely difficult. For example, the risk profiles for the organization and project or asset may differ from each other and also from original estimates over time (Mun, 2005).

5) It is difficult to determine how to modify traditional theoretical assumptions to fit real options settings and/or fit real options analysis to traditional theoretical assumptions.

a. The underlying assets of real options do not follow prescribed stochastic processes required for options theory to operate, making discrete event simulation more appropriate (Mun, 2005).

b. The theoretical assumptions fundamental to portfolio and options theory are all violated by real options – marketability, tradability, infinite borrowing and lending, no taxes, no transaction costs, a perfectly risk-free asset, a hedge-able and arbitrage-free portfolio (Mun, 2005).

What becomes apparent from reviewing this laundry list is that most or all of the issues can be traced back a single fatal flaw, our inability to assign benefit streams directly to sub-

organizational activities and assets. This problem is stated by Marr (2005: 58), “To value any asset, we need to specify an income stream clearly identified with that asset.”

In the defense of real options, the field has inherited this inability from Discounted Cash Flow Analysis as a precursor to real options analysis, not created it, and has found numerous useful methods by which to attempt to overcome it. But the problem remains, as does its corollary. *All troublesome estimations of cash flows, discount rates, volatilities, and the like stem from a fundamental disability, i.e., that we are forced to rely on data that is drawn from exogenous sources at the highest levels of aggregation (i.e., the “market” and/or audited SEC financial reporting for publicly held companies) to evaluate company-specific endogenous investments, activities, and assets.* Together this inability and disability have affected the practice of real options analysis, the valuation of intellectual capital in its many forms, the valuation of privately held companies, and innumerable other investing activities.

We suggest that until Information Age theoretical constructs (e.g., complexity and information theory) were available to apply to wide-ranging business problems *at the sub-organizational level*, we did not have a defensible means by which to solve the problem. We have attempted to develop the conceptual framework for these constructs (i.e., assigning benefit-value streams at the sub-corporate level of analysis) using the KVA methodology..

Let us, therefore, assume for the time being that the analytic tautology proposed by KVA is valid and verifiable and that complexity theory can be applied to corporate finance, using the K_μ as the fundamental unit of measure for a new “value” accounting. How would this change the way we view and estimate the value of organizations, projects, or intellectual assets?

To answer that question, we will revisit a number of cornerstones of finance from a complexity theoretic-KVA perspective.

Change, Risk, and Uncertainty: The universal activity of humans is changing inputs into outputs. This is true of investing as well as all other human activities.

Complexity theory indicates that change creates Kolmogorov Complexity (and its equivalent, information), where Kolmogorov Complexity is the "universal product," a universal measure of changes in the form of matter, and a universal property of matter as well (Housel and Kanevsky, 1998:6).

Entropy is the term that describes the reduction of energy to a state of maximum disorder in which each individual movement (activity) is neutralized by statistical laws. Left to itself, an isolated system tends toward a state of maximum disorder, i.e. higher probability. Boltzmann stated, "In an isolated system, the system will evolve to its most probable state, that is, the one with the most homogeneous probability distribution," (e.g. the Law of Large Numbers). In a state of homogeneity (or, highest entropy or uncertainty), we have no indication at all to assume that one state is more probable than another.

Information is a probabilistic measure of reduction in uncertainty (entropy). The following formula, developed by Claude Shannon, expresses the probabilistic relationship between entropy and information, for all possible states 1 . . . n :

$$\mathrm{H}(x) = -\sum_{i=1}^{n} p(i)\log_2 p(i)$$

Where:
H = Entropy
x = A discrete random event
p = Probability distribution
i = Outcome

H is maximized if all states are equi-probable (a state of homogeneity), since when there is no pattern, there is no information and entropy and information are opposites. H is 0 if $p(i) = 1$, since the system is in a state of maximum certainty or complete information.

Randomness, entropy, probability, and uncertainty are equivalent terms. Their opposites are pattern, complexity, information, and certainty which are also equivalent terms.

Since the most basic activity of humans, technology, organizations, and industries is change, companies and other organizations can be viewed as open systems that can: (1) Exchange raw inputs (substance, information, or energy) with the environment; and (2) change the structure of raw inputs into outputs (final products/services). This structural change is described in terms of the way process "*P*" structures input "*a*" to be output "*b*."

In investing activities, we could call process *P* a "transaction" that structures input *Asset A* into output *Asset B*. The structural change that occurs during transaction process *TP* involves a change in uncertainty (entropy, Kolmogorov complexity) as *Asset A* undergoes a state transformation to become *Asset B*. The monetization of this change in uncertainty from *Asset A* to A*sset B* is what we call "return on investment." It is also the "value added" by *TP*.

Traditional finance states, "There are several accepted risk and return models in finance, and they all share some common views about risk. First, they all define risk in terms of *variance in actual returns around an expected return*; thus, an investment is riskless when the actual return is always equal to the expected return.

"Second, they all argue that risk has to be measured from the perspective of the marginal investor in an asset and that this marginal investor is well diversified. Therefore, the argument goes, it is only the risk that an investment adds to a diversified portfolio that should be measured and compensated. In fact, it is this view of risk that leads risk models to break the risk in any investment into two components: a firm-specific component that measures risk that relates only to that investment or to a few investments like it, and a market component that contains risk that affects a large subset of or all investments. It is the latter risk that is not diversifiable and should be rewarded" (Damodaran, 2001:55).

We propose a simple modification to this definition. In terms of complexity theory, *risk* is a descriptor for the *change in uncertainty* (ΔΦ) related to the state transformation of *Asset A* into *Asset B* via *TP*. As such, it is a rate and is composed of two elements: (1) *volatility*, the magnitude of change in uncertainty; and (2) *growth, or, drift*, the direction of change in uncertainty. The "expected return" (i.e., expected ΔΦ) for *Asset A* remains the baseline against which to estimate the risk (i.e., actual ΔΦ) related to *Asset B* regarding the state transformation taking place via *TP*.

Using this approach, risk is no longer interchangeable with uncertainty, though commonly discussed this way currently (e.g., Mun, 2002). However, many of the common assumptions concerning uncertainty still hold true. For instance, "the higher the volatility, the higher the range of uncertainty," and "operating, technological, market, and other factors are subject to uncertainty and change so that uncertainty drives project value" (Mun, 2002:149, 150). In addition, uncertainty increases over time, creating a "cone of uncertainty," while the risk (ΔΦ) assigned to time steps may remain the same over the whole period (Mun, 2002:151).

Thus, when we adjust cash flows for *risk* we are providing an estimate of the ΔΦ that will be assigned to those cash flows as they undergo a state transformation via *TP*.

Since ΔΦ is also a descriptor for "returns," we now have a complexity theoretic way of describing the relationship between risk and return, e.g. they are equivalent, just as they are in traditional finance. Risk is actual ΔΦ and return is expected ΔΦ, which enables us to use the traditional notion of matching actual risk with expected return.

So far, complexity theory and traditional finance say the same things in slightly different ways. Where they begin to diverge is that if we apply the proportionalities we described in KVA in which ΔE (change in entropy) ≈ $K(y|x)$ (conditional Kolmogorov complexity) ≈ bits ≈ K_μ, and we agree that risk is a change in uncertainty (ΔΦ), we find we are talking about the same common units of measure. This suggests that measuring the process outputs of the organization in common units, K_μ, is equivalent to measuring risk. This in turn ties risk measurement *directly* to the knowledge assets of the organization and only indirectly to the movements of "the market" and competitors.

Risk-Neutrality and the Risk-Free Rate: What do risk neutrality and the risk-free rate mean in this suggested context? Risk-neutrality is currently described from several angles: (1) "A risk-neutral world means that a certain variable is stripped of its risks" (Mun, 2002:163); "Risk-neutral probabilities are calculated based on a constant volatility" (Mun, 2002:244); "[R]*isk-neutral probability* [is] the probability that would prevail in a risk-neutral world where investors are indifferent to risk" (Trigeorgis, 1996:75); and "[A]ny contingent claim on an asset, whether traded or not, can be priced in a world with systematic risk by replacing its actual growth rate with a certainty equivalent rate, by simply subtracting a risk premium that would be appropriate in market equilibrium and then behaving as if the world were risk-neutral. Intuitively, since in a risk-neutral world all assets would be expected to earn just the risk-free return (i.e., risk premia would not be offered), equilibrium expected growth rates would therefore be less in the risk-neutral world than they actually are in our risk-averse world" (Trigeorgis, 1996:103). The risk-free rate is the rate of return at which the expected return on an investment exactly matches the actual return on that investment.

If we apply our complexity theoretic approach to these concepts, it appears that a risk-neutral world based on risk-free rates of return is one in which no change in uncertainty, no structural state transformation, occurs in *Asset A* to get *Asset B*. No value is being added. The level of uncertainty before and after the transaction remains the same. The risk-free rate indicates a static state. Would such a world exist in which agents of change (investors) were indifferent to the level of value added (uncertainty resolved) during state transformations and prefer a static state?

We suggest that a simple change in definition would resolve this. A risk-free rate of return might better be described as a benchmark value for risk, i.e., a “certainty-equivalent risk.” Since this benchmark has been observed to be 99% certain over a prescribed period of time (for example in the rate of return on zero coupon government securities), risk has not disappeared. It will, however, experience very little change in uncertainty during the state transformation from *asset a* to *asset b* because almost all information about it is already known. Risk-neutral probabilities might then offer a similar benchmark for “certainty-equivalent risk” by simulating enough state transformations that most of the uncertainty has been captured in the “information” of a probability distribution. If this is the case, we might call them “certainty-equivalent” probabilities rather than risk-neutral, since risk-neutrality implies neutralization of risk (i.e. no risk).

“The Market,” Efficient Markets, and Diversification: “The Market” is a term that covers a wide range of concepts from the whole universe of available investments to the public stock markets to specific market indexes such as the Dow Jones Industrial Average or the

Standard & Poors 500. The following are some of the commonly used definitions and assumptions about the market.

A "complete" market is one in which all trades can be made using available securities. An "incomplete" market is one in which some trades cannot be made using available securities. Market prices are determined by real people making real trades. Market equilibrium is the state in which all investors have chosen some combination of a market portfolio plus borrowing or lending and face only one source of risk – the performance of the market as a whole. The market portfolio should contain all forms of capital – human, intangible, tangible, and financial. But it does not because it is still too difficult to value anything but tangible and financial capital. Market risk is the risk related to the overall size of the pie, while private (non-market) risk is related to the size of individual pieces of that pie. Non-market (diversifiable, unsystematic) risk is not rewarded with higher expected returns because it can be eliminated by diversification of the market portfolio (Sharpe, 2004 website).

An efficient market is one in which ". . . there are large numbers of rational, profit-maximizers actively competing, with each trying to predict future market values of individual securities, and where important current information is almost freely available to all participants. In an efficient market, competition among the many intelligent participants leads to a situation where, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that have already occurred and on events which, as of now, the market expects to take place in the future. In other words, in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value" (Fama, 1965).

We propose to extend our complexity theoretic approach to a discussion of The Market so that we can eventually return to our discussion of risk an uncertainty. For ease of discussion, we will split The Market into three levels: The Universal Market (UM) composed of all investments everywhere, highly abstracted in order to allow for global principals and insights; the Corporate Investment Markets (CIMs), composed of the many organizations and people whose actions and interactions create them; and the Sub-Corporate Investment Markets (SCIMs) composed of the tangible and knowledge assets (people, processes, capabilities, and information technology) of individual firms. This division approximates current practice.

The Universal Market is built on timeless global insights and constructs such as the efficient market, the Capital Asset Pricing Model (CAPM), Arbitrage Pricing Theory (APT), and the Black-Scholes Option Pricing Model, to name a few. The UM is bounded by normative theory and highly abstracted universal rules and assumptions such as those for the CAPM and the Black-Scholes option pricing model.

It appears that currently the UM is treated as a closed system, perfectly efficient and complete. All the information available about its parts exists everywhere within it. All of its parts are in equilibrium or near-equilibrium and they are fully diversified, meaning that all of their risk-creating actions or interactions cancel each other out. The only risk (i.e., $\Delta\Phi$) that remains is that which the UM can generate itself, which we call systematic risk. Systematic risk is produced primarily by the actions of governments and regulators and takes the form of inflation, budget deficits and the like.

We suggest there may be some difficulties with this view of the UM. First of all, the UM is not capable of effecting change of any kind or creating or adding value. Its parts do that. Governments and regulators are actors within (parts of) the UM, but are not the UM. Their actions and interactions affect all the other parts but, once absorbed by the other parts, are effectively cancelled out by diversification, that is, how one company manages the effects of systemic change will cancel out how another company manages it. Systematic risk, as we know it, would disappear. In addition, as a closed system, the UM would steadily be moving toward a state of complete probability (uncertainty) or homogeneity, in which all parts and their actions and interactions would be equally probable, no information would be available by which to make choices, and risk (i.e., $\Delta\Phi$) would reach 0%. Under such conditions, the UM would stagnate and die.

If, on the other hand, the UM is viewed as an open system, it will have characteristics more in line with what we know to be actual market conditions. It will be in a constantly fluctuating state of efficiency because there will be information flowing in and out of it, creating constantly changing levels of uncertainty (i.e. risk). The UM will become like the porous membrane of a cell. Like the UM in a closed system, it will not be capable of effecting change of any kind or creating or adding value.

The UM will be filled with information and risk (i.e., $\Delta\Phi$) that do not "cancel each other out," though they exhibit a kind of equilibrium. The actions and interactions of governments and regulators are just one more form of risk. This kind of risk is low (i.e., has a low $\Delta\Phi$) and mundane but it affects all the UM parts alike. However, since it is slow taking effect and can be planned for far in advance, the other parts of the UM absorb it as part of their total risk profile and nothing more. Dying firms, new entrepreneurial entrants, and acts of God (such as September 11) will change the structure of the UM regularly.

As an open system, the UM will be steadily maintaining a state of homeostasis – one of the most remarkable and typical properties of highly complex open systems. A homeostatic system (a firm, an organization, a cell) is an open system that maintains its structure and functions by means of a multiplicity of dynamic equilibriums rigorously controlled by interdependent regulation mechanisms. Such a system reacts to every change in the environment, or to every random disturbance, through a series of modifications of equal size and opposite direction to those that created the disturbance. The goal of these modifications is to maintain the internal balances. In a sense, the UM, as an open system in homeostasis, will be in a state of 100% risk ($\Delta\Phi$).

Why does this discussion matter? It matters because it will help us revisit traditional algorithms for rates of return in a new light. This may, in turn, assist us in overcoming some of the intractable problems in finance.

The CAPM and Beta: In the last two sections, we have suggested that risk is really a measure of change in uncertainty and can be directly counted in common units of change, described in KVA as K_μ. Based on this, we have slightly redefined the risk-free rate as a rate for "certainty-equivalent risk." We have suggested that "risk-neutral" probabilities are just another means of arriving at that benchmark rate and that they are better called "certainty-equivalent" probabilities. We have demonstrated the UM should be considered an open system in which all risk is unsystematic (idiosyncratic) and cannot be diversified away because that would halt change and bring about the death of the organism. Instead, the UM should remain in homeostasis, in which the risks and information flows maintain internal balances.

These proposed changes in approach do not have to alter the use of valuable tools such as the CAPM and the concept of beta. They will, however, give us a different picture of what CAPM and beta tell us.

At the level of the CIMs, we can agree to use a "certainty-equivalent risk" rate based on the yields for long-term government securities. We can also agree to aggregate the actions and interactions of selected groups of CIM players into indexes which we can analyze for trends and movements, using rules and assumptions we select to provide clarity and ease of use.

We can analyze the returns on these indexes over selected periods of time and construct an average picture of their volatility and drift (i.e., risk, $\Delta\Phi$) that we can use as an "equity risk premium" (ERP) benchmark, just as we do now. Since we are not constrained to discuss risk in terms of UM-level systematic and non-systematic risk, we might also choose to describe the ERP in terms of the index from which it was drawn – which would be helpful to investors.

And we can build betas for individual company performance, using the same techniques we use today. The messiness of building the betas will remain the same. The insights that beta presents might change. Currently, beta indicates how sensitive a particular company's equity price is to a 1% change in the average equity price of "The Market Portfolio." It is considered a measure of company-specific risk against market risk. If, however, all risk is company specific, then beta might tell us something very important.

In an open system in homeostasis, when we average the equity prices of a selected index (the market portfolio), we are actually creating a picture of the risk ($\Delta\Phi$) related to the "average" company with "average" characteristics. All unique characteristics disappear. Since beta is company-specific, we are comparing not only the characteristics that make it like the "average" company, but also the unique characteristics that cause it to exhibit change differently from the "average." Simply put, beta has become a high level indicator of the effect of a company's *intangible assets (uniqueness)* once its "average" characteristics have been accounted for.

This is in keeping with our finding that we can measure risk in terms of common units of output, K_μ, and thereby link it directly with the knowledge assets of the firm. It also means that we are already a lot further along toward measuring the effect of intangible assets on company performance than we thought.

However, there are still "many problems with using any of these traditional approaches. For instance, if the company is not publicly traded, there are no stock returns to calculate the β coefficient. The firm may also have projects that are not highly diversified, meaning that using the diversified market as a proxy for the risks inherent in a single project is unjustified. For instance, a large firm (e.g., IBM or Microsoft) may have hundreds of small projects, business units, and investments in its corporate portfolio, and saying that the risk inherent in one of its projects can be wholly explained by the fluctuations of its stock prices in the market (stock price returns are used to calculate β) is very dangerous. Not to mention stock prices change every few minutes, meaning that β changes every few minutes, and is relatively unstable over different time horizons. Also, stock prices fluctuate in the market due to investor overreaction, advent of news and events, economic conditions, and many other factors which are not attributable directly to the risk of the single project being analyzed" (Mun, 2003).

Two noted academics have attempted to overcome these traditional problems by suggesting alternative ways of estimating beta. Both approaches use *sub-corporate data* to populate their models.

Estimating a Bottom-Up Beta: "To develop this alternative approach, we need to introduce an additional feature that betas possess and that proves invaluable. The beta of two assets put together is a weighted average of the individual betas, with the weights based on market value. Consequently, the beta for a firm is a weighted average of the betas of all of the different businesses the firm is in" (Damodaran, 2001:78). The methodology includes: (1) Identifying the business or businesses that make up the firm; (2) estimating the unlevered beta(s) for those business or businesses, looking at operating and financial leverage, and take their weighted average; (3) calculate the leverage for the firm; (4) and re-lever the beta estimated in Step 2. This approach produces a superior beta because: (1) averaging regression betas reduces the standard errors in the estimate; (2) the beta reflects the firm as it exists today based on current weights for different businesses; and (3) the final re-levered beta is based on the current financial leverage of the firm (Damodaran, 2001:78, 79).

Estimating an Internal Beta: This approach uses Monte Carlo simulation and real options analysis. The β coefficient is calculated as the covariance of the asset and the market's returns $cov(r_i, r_m)$, divided by the variance of the market returns $var(r_m)$. "Further, covariance can be broken down into the products of correlation $\rho_{i,m}$, and the standard deviations of the asset (σ_i) and the market (σ_m) or

$$\beta = \frac{\text{cov}(r_i, r_m)}{\text{var}(r_m)} = \frac{\rho_{i,m}\sigma_i\,\sigma_m}{\sigma_m^2}$$

"Using this underlying theory, we can estimate a project's discount rate through Monte Carlo simulation and Real Options Analysis to obtain the correlation between, and the volatilities of the project and an internal corporate portfolio.

"Monte Carlo simulation can be applied to variables that are uncertain and risky, such as price, volume, market share, competition, and technical success. These variables can also be correlated to each other to obtain a closer relationship to reality. These simulated inputs are then linked to a DCF model and the resulting project's volatility of the cash flow returns is obtained.

"Then, all other projects in the firm are combined to create the company's cumulative portfolio DCF. Sometimes, the company's cash flows from an annual report are used (as the company is made up of a portfolio of different projects, business units, and so forth, the total cash flows to a company is the project's internal market comparable). In other cases, a set of comparable internal projects can be selected as the market benchmark. This portfolio is used as the market comparable portfolio for the project. The correlation between the net cash flows of the project and portfolio are obtained using a non-parametric Spearman rank-based correlation coefficient.[1]

"Using the newly calculated "internal beta" β^*, a revised discount rate can be calculated using:

$$DR = WACC + Max\left[(\beta^* - 1)(WACC - R_{rf}),0\right]$$

This means that the discount rate has a minimum value of WACC or hurdle rate if the β coefficient is less than or equal to 1.0. A coefficient less than or equal to 1.0 indicates that the risk of the specific project is less than or equal to the risk of the company's portfolio of projects (the internal market comparable). Under these circumstances, the WACC should be used. For riskier projects (β exceeding 1.0 means that the project has a higher risk than the overall internal portfolio of projects), the excess risk above 1.0 should be compensated at the rate differential between WACC and the risk-free rate.

"To summarize, instead of using an external market-based beta coefficient which may not fully represent the risk of a specific project, an internal beta can be constructed based on the firm's portfolio of projects" (Mun, 2003:8-10).

Estimating k-Beta and the KAPM Discount Rate: We suggest that we can estimate an even more accurate beta if we consider the SCIM as a proxy for the "market" and use KVA data (i.e. K_μ) gathered from the firm's knowledge assets (people, processes, capabilities, and IT) to populate either of the above beta-estimation models, with modifications for our complexity theoretic approach. Since this beta will be related to knowledge assets, we call it a *k-beta.*

Once we have developed *k-beta(s)* for a SCIM, we can use it/them to build a KAPM (Knowledge Asset Pricing Model) discount rate, with relaxed CAPM assumptions that better fit the realities of the CIM and SCIM and match the requirements of our complexity theoretic approach.

Is the SCIM a Legitimate Market? We propose that it is, using the follow reasoning substantiated by what we know about theories of the firm and real companies. In the context of sub-corporate finance, the term "firm" is synonymous with the term "organization" and includes profit-making, not-for-profit, and government entities.

There are many theories of the firm and they are divided up using a number of different classification systems. For example, R.L. Marris (1964) divides theories of the firm into three main categories: Discretionary, growth-oriented, and bureaucratic. Foss (1997) divides them into two categories: Evolutionary and contractual. Kaplan, Schenkel, von Krogh, and Weber (2001) provide an overview of a classifications: (1) Orthodox economic – The firm is a simple production function; (2) contractual rights – The firm as a bundle of property rights (Coase, 1937); (3) behavioral – The firm is a repository for information processing, organizational structure, and resource allocation decision-making processes (Cyert & March, 1963; Cyert & Williams, 1993); (4) attention-based – The firm as performance outcomes guided by decision-maker focus on issues and decisions (Ocasio, 1997); (5) transaction-cost based – The firm as an effective intermediary to mediate and manage contractual rights and transaction costs (Williamson, 1975, 1999); (6) resource-based – The firm as a portfolio of resources (physical, financial, human, organizational, knowledge) (Penrose, 1959; Wernerfelt, 1984; Barney, 1991); (7) resource and capability based – The firm as a portfolio of resources and also the repository of the capabilities needed to transform these resources (Barney, 1991; Foss and Eriksen, 1995); (8)

knowledge-based – An emerging set of theories regarding the role of knowledge in providing firm competitive advantage (Kogut & Zander, 1992; Nonaka, 1994; Spender & Grant, 1996; von Krogh, Roos & Slocum, 1994; Kaplan, Schenkel, von Krogh & Weber, 2001).

Sudarsanam, Sorwar and Marr (2003:8-9) further describe the resource-based view as focusing on firms as heterogeous entities characterized by their unique resource bases (Nelson and Winter, 1982) and with different distinctive competencies (Selznick, 1957) They go on to discuss the knowledge-based view in more depth as well. It is grounded in the idea that all organizational capabilities are based on knowledge (Marr and Schiuma, 2001; Winter, 1987) and that knowledge forms the foundation of a company's capabilities. Since the ownership of specific knowledge provides companies with specific capabilities (Leonard-Barton, 1992; Prahalad and Hamel, 1990), companies should pursue continuous development of their knowledge assets. (Senge, 1990)

In addition, there is the *real options-based* concept of the firm as a portfolio of real options (Trigeorgis, 1996; Smit and Tregeorgis, 2004; Roemer, 2004). We feel we have much in common with the resource-based, knowledge-based, and real options-based views of the firm.

Coming from a complexity theoretic view, we submit that the firm is a "market" of knowledge assets (people, processes, capabilities, and IT) that functions as a microcosm of UM-CIM. We call this market a Sub-Corporate Investment Market (SCIM). If "options are the Lego blocks of finance" (Copeland and Antikarov, 2001:11), then real options are the Lego blocks of the SCIM.

Similar to the UM-CIM, a SCIM is an open system, a permeable membrane, containing parts that dynamically combine and recombine into portfolios, while also competing for scarce resources (financial assets and infrastructure) and interacting with the outside world of stakeholders and competitors. Also similar to the UM-CIM, SCIM assets are affected by the risk and uncertainty, the availability of resources and information, the property rights, the transaction costs, and the real investment options available to the SCIM and to each other.

SCIM parts are focused on producing and delivering outputs, similar to the parts in the UM-CIM. Securities are the proxy for the production outputs of the CIMs, and they are monetized (Sharpe, 2004 website). K_{μ} are the proxy for the production outputs of the SCIM, and they are commonly monetized. This enables the SCIM to offer observable, verifiable, defensible sub-corporate level benefit streams for use in real option analysis and competitive strategy.

III. Case Example of Real Options Analysis Using KVA Data

We will use the work we have done on a research study conducted for OFT by Booz Allen Hamilton on the Mission Support Center used by the Special Operations Forces (SOF) within the Naval Special Warfare Group One (NSWG1) to demonstrate how KVA and ROAn can be used effectively together. We selected this particular example as the most extreme case that might face any organization.

The Special Operations Forces are key players in a market space we call the global battlespace (Housel, Mun, Nelson, 2005). This market space is highly turbulent, beyond Internet time, creates the continuous-time need for changes in tempo and improvisation, relies on information technology infrastructures for critical information feeds, and within which failure bears ultimate consequences. Its private sector equivalent might be medical emergency or fire department and rescue services.

The Mission Support Center was an innovation developed by NSWG-1 to meet its needs during Operation Enduring Freedom and Operation Iraqi Freedom. A “reach-back” component located in San Diego, CA, it is described as follows: “The MSC is the conduit that facilitates enhanced collaboration among and between forward and rear units. . . . The MSC is ultimately responsible for enhancements in shared situational awareness that enable war planners and war fighters to plan and execute successful missions" (BAH, 2004:9).

The purpose of the KVA analysis was to assist strategic planners in understanding the levels of value contributed to the MSC by people, processes, and information technology so that they could increase MSC performance in the present and plan for deployment of additional MSCs in the future. Once we developed raw data using KVA, we used the data in common ratio analysis and as inputs into a ROAn model.

The following is a highly simplified synopsis of the steps in using the KVA computation once basic data has been gathered. The first four steps utilize *sample* numeric data. The remaining steps utilize actual case data. A brief analysis of results follows.

We chose to focus on the NSWG-1 Mission Planning Process and the Mission Feasibility Assessment Cycle within it. To further simplify, we analyzed just two of the Mission Feasibility Assessment sub-processes: SFP2 and SFP3.

KVA Algorithms: The following are some of the algorithms we used in doing the KVA for the MSC.

(1) Total Variable Knowledge in Use for Process with Observable Executions and *without Automation*

$$K_{\mu Vna} = K_{\mu V} * Ex_o$$

Where:

$K_{\mu Vna}$ = Total Variable Knowledge Units in Use for one process *without automation*

$K_{\mu V}$ = # of Variable Knowledge Units in Use for one unit of process output *without automation*

Ex_o = # of observable executions of one process

(2) Total Semi-Fixed Knowledge in Use for Process with Observable Executions and *without Automation*

$$K_{\mu SFna} = K_{\mu SF} * Ex_o$$

Where:

$K_{\mu SFna}$ = Total Semi-Fixed Knowledge Units in Use for one process *without automation*

$K_{\mu SF}$ = # of Semi-Fixed Knowledge Units in Use for one unit of process output *without automation*

Ex_o = # of observable executions of one process

(3) Total Variable Knowledge in Use for Process – Attributable to Automation (IT)

$$K_{\mu VIT} = K_{\mu Vna} * a$$

Where:

$K_{\mu VIT}$ = Total Variable Knowledge Units in Use for one process – *attributable to automation (IT)*

$K_{\mu Vna}$ = Total Variable Knowledge Units in Use for one process *without automation*

a = % automation

(4) Total Variable Knowledge in Use for Core Process *Including Automation* (IT)

$$K_{\mu VP} = K_{\mu Vna} + K_{\mu VIT}$$

Where:

$K_{\mu VP}$ = Total Variable Knowledge Units in Use for one core process *including automation*

$K_{\mu Vna}$ = Total Variable Knowledge Units in Use for one process *without automation*

$K_{\mu VIT}$ = Total Variable Knowledge Units in Use for one process – *attributable to automation (IT)*

(5) Total Semi-Fixed Knowledge in Use for Process – Attributable to Automation (IT)

$$K_{\mu \mathrm{SFIT}} = K_{\mu \mathrm{SFna}} * a$$

Where:

$K_{\mu \mathrm{SFIT}}$ = Total Semi-Fixed Knowledge Units in Use for one process – *attributable to automation (IT)*

$K_{\mu \mathrm{SFna}}$ = Total Semi-Fixed Knowledge Units in Use for one process *without automation*

a = % automation

(6) Total Semi-Fixed Knowledge in Use for Core Process *Including Automation* (IT)

$$K_{\mu \mathrm{SF}P} = K_{\mu \mathrm{SFna}} + K_{\mu \mathrm{SFIT}}$$

Where:

$K_{\mu \mathrm{SF}P}$ = Total Semi-Fixed Knowledge Units in Use for one core process *including automation*

$K_{\mu \mathrm{SFna}}$ = Total Semi-Fixed Knowledge Units in Use for one process *without automation*

$K_{\mu \mathrm{SFIT}}$ = Total Semi-Fixed Knowledge Units in Use for one process – *attributable to automation (IT)*

(7) Fixed Knowledge Allocation Factor

$$k_{\mathrm{f}} = \frac{K_{\mu \mathrm{Fi}}}{\underbrace{\left(K_{\mu P\mathrm{i}} + K_{\mu \mathrm{Fi}}\right)}_{\substack{\text{Total Knowledge in Inventory for All Processes} \\ \text{Start of Current Sample Period}}}}$$

Where:

k_{f} = Fixed Knowledge Allocation Factor

$K_{\mu \mathrm{Fi}}$ = Total Fixed Knowledge Units in Inventory for all individuals executing meta processes *including automation* – ***start of current sample period***

$K_{\mu P\mathrm{i}}$ = Total Knowledge Units in Inventory for all core processes *including automation*– ***end of prior sample period***

Step One: Estimate Time to Learn: First, we estimated the time it takes an average MSC analyst to learn one whole sub-process. This represents the amount of knowledge required to produce a single sub-process output, as presented in Table I.

	Time to Learn	K_μ for 1 Output
SFP2	7.0 years	7.0
SFP3	7.0 years	7.0

Table I: Time to Learn Estimates

Steps Two, Three, and Four: Find the Total K_μ for Each Sub-Process: We counted the number of times each sub-process executes during 1 year to give us the number of outputs produced by 1 analyst, as presented in Table II. [*Step Three:* Columns (B) x (A) = (C); *Step Four:* Columns (C) x (D) = (E)]

	(A) K_μ for 1 Output	(B) # of Sub-Process Executions per Analyst	(C) K_μ for All Outputs per Analyst	(D) # of Analysts Executing Sub-Process	(E) Total K_μ for the Sub-Process
SFP2	7.0	34/yr	238.0	2	476.0
SFP3	7.0	34/yr	238.0	3	714.0

Table II: Total K_μ for Each Sub-Process

Step Five: Calculate the K_μ Contribution by Information Technology (IT): In Steps 5-8, we used actual case data instead of generalized example data. First we calculated the K_μ without IT (automation) and then this result was multiplied by the % automation to get the contribution by IT, as presented in Table III. [Columns (A) x (B) = (C)]

	(A) Total K_μ for Sub-Process without Automation	(B) % Automation (IT) for Sub-Process	(C) Total K_μ Contributed by IT
SFP2	186.69	60.0%	104.96
SFP3	228.10	10.0%	22.81

Table III: Total K_μ Contributed by IT

Step Six: Develop the Value Equation Numerator by Assigning Revenue Streams to Sub-Processes: We developed a ratio of single sub-process Kμ to Total Kμ for all sub-processes. Example: [(Kμ for SFP2) ÷ (Total Kμ for all sub-processes)]. Then, we assigned revenues to sub-processes, people, and IT, per Table IV. [Columns (A) x (B) = (C)]

	(A) Total Kμ for Sub-Process ÷ Total Kμ for all Sub-Processes	(B) Total Annual Revenue for MSC	(C) Revenue Assigned to Sub-Process	(D) Revenue Assigned to Human Contribution	(E) Revenue Assigned to IT Contribution
SFP2	.1238	$ 2,808,550	$ 347,741	$ 227,233	$ 120,508
SFP3	.1113	$ 2,808,550	$ 312,472	$ 286,278	$ 26,194

Table IV: Sub-Process Revenue Streams

Step Seven: Develop the Value Equation Denominator by Assigning Costs to Sub-Processes: We used the % of a year allocated to executing each sub-process to assign cost to sub-processes, people, and IT, per Table V. [Columns (A) X (B) = (C)]

	(A) Time to Execute as % of 1 Yr	(B) Total Annual Cost for MSC	(C) Cost Assigned to Sub-Process	(D) Cost Assigned to Human Contribution	(E) Cost Assigned to IT Contribution
SFP2	7.665%	$ 2,289,000	$ 175,452	$ 165,871	$ 9,581
SFP3	19.163%	$ 2,289,000	$ 438,630	$ 414,677	$ 23,953

Table V: Sub-Process Costs

Step Eight: Calculate the Value Equation (ROI): We used the revenues and costs assigned to sub-processes, people, and IT to calculate ROIs, as presented in Table VI. We utilized three common ratios and renamed them as follows: ROK – Return on Knowledge, a productivity ratio; ROKA – Return on Knowledge Assets, a profitability ratio; ROKI – Return on Knowledge Investment, the value equation.

	ROKI for Sub-Process	ROKI for Human Contribution	ROKI for IT Contribution
SFP2	98.2%	37.0%	1157.7%
SFP3	(28.8)%	(31.0)%	9.4%

Table VI: Value Equations

Analysis of Results: KVA quantifies the contributions of MSC Information Technology (software and infrastructure) and human assets to the efficiency (productivity) and effectiveness (profitability) of the Mission Feasibility Assessment Cycle. Although process profitability is not a goal for the non-profit DoD, profitability ratios demonstrate whether the MSC IT and human contributions to processes are using budget dollars effectively.

Assuming for this discussion that the data is representative and accurate, MSC leaders might begin a discussion of why some of the sub-processes are more productive and profitable than others. For example: What makes **SF*P*2** such a high performer with a ROKI of 98.2%? What has produced a ROKI of (28.8)% for **SF*P*3**? Or, are the results for SF*P*3 to be expected, given the highly human-experience intensive nature of process and the inability to automate it more than a small amount? Is the MSC getting optimal leverage from human and IT assets? If not, what other configurations would produce more value for the Mission Feasibility Assessment cycle? These are the kinds of questions Command and DoD strategic planners can now ask, using quantitative data, in preparation for building decision options for future deployments of the MSC.

Real Options Analysis Proposed Problem: The following was the proposed problem for use in the MSC ROAn.

The Department of Defense has decided that the NSWG-1 Mission Support Center, as utilized in Operation Iraqi Freedom, improved mission success and tempo considerably. It has decided that it needs several more MSCs to assist Joint Force Special Operations in their warfighting missions. However, the DoD does not know the most effective personnel mix to use to staff the MSCs and whether the supporting IT should be built, bought, or outsourced. Uncertainties related to acquiring the right MSC analysts and IT, and budgetary constraints are significant. (in what follows, we should refer to any or all of the problems explicitly that we cited as a reason for this article in the appropriate places in the ROA area below)

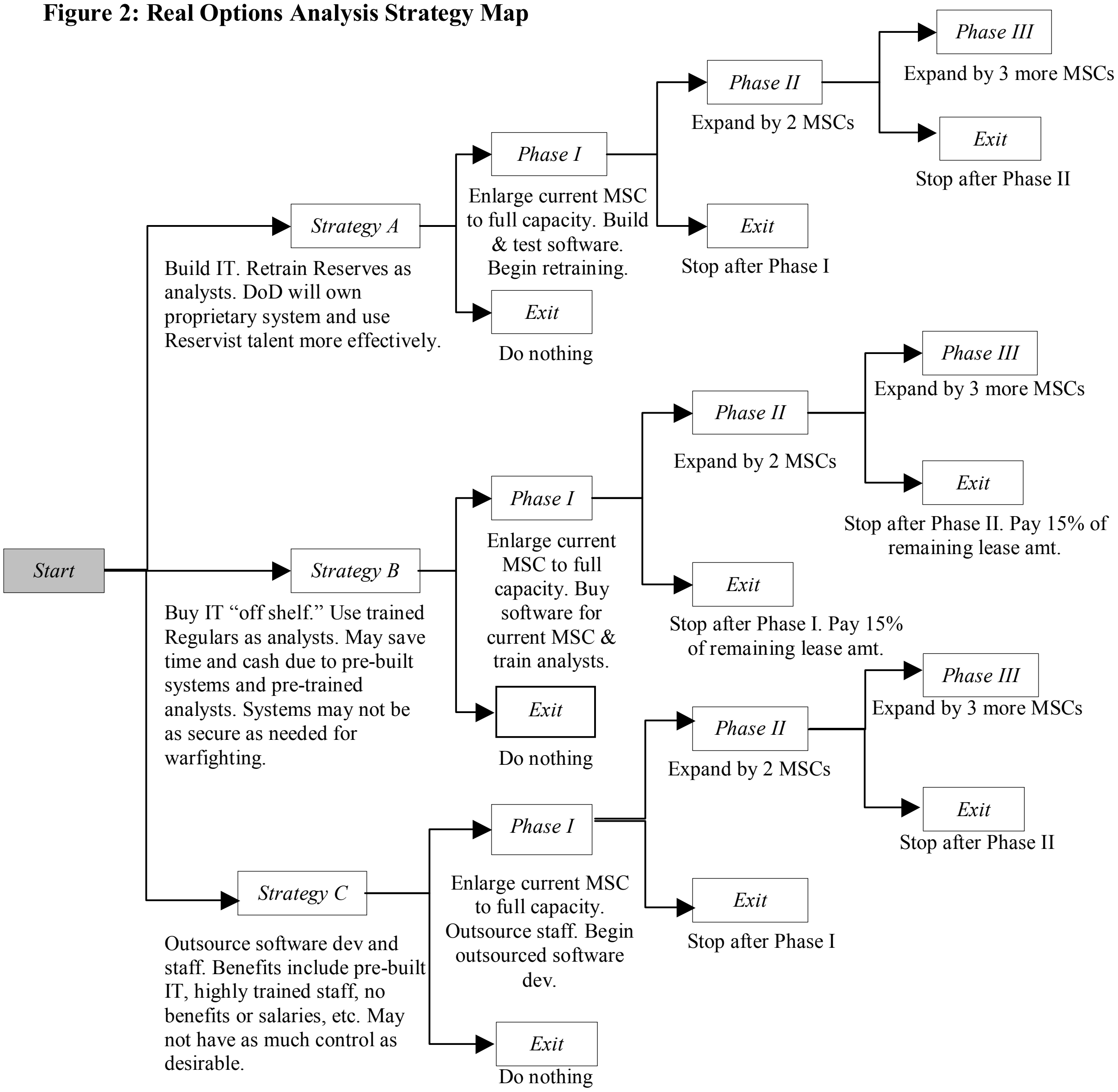
Real Options Analysis Proposed Solution Strategies: To address the problem, we constructed three scenarios for the future of the Mission Support Center that seemed reasonable and feasible. *Strategy A* was to bring the current MSC up to full capacity in Year One, "as is." Then, build the technology for further MSCs and staff with re-trained US Military Reservists. *Strategy B* was to bring the current MSC up to full capacity in Year One, "as is." Then, buy the technology for further MSCs and staff with already-trained US Military "Regulars." *Strategy C* was to bring the current MSC up to full capacity in Year One, "as is." Then, outsource whole MSC function, including both analysts and IT, housing them in properties currently held by the DoD.

We made one single critical assumption to enable us to do the ROAn for the MSC using the data that was available to us. It is as follows: *The Mission Feasibility Assessment Cycle is the*

only *segment of the Mission Planning Process in which the MSC participates and the remainder of the Mission Planning Process occurs in the field.* This assumption allowed us to utilize the total costs and proxy revenues for the MFA cycle as identical to the costs and proxy revenues for the MSC. As a result, we could also use the net cash flows of the MFA cycle as those for the MSC in DCF and ROAn model inputs.

For the sake of brevity, we will provide the following strategy map (Figure 2) instead of a detailed description of each strategy. Detailed model inputs are provided in Exhibit A at the end of this paper.

Figure 2: Real Options Analysis Strategy Map



First, we modeled the results from the KVA approach into a set of discounted cash flows for the three strategies, resulting in expected net present values (NPVs) *without flexibility* for each. In calculating the base case NPV we assumed that all future net cash flows are known with certainty and therefore there is zero volatility around input values.

However, in modeling the future net cash flows related to the MSC project strategies we developed a probabilistic range of NPV values for our analysis, rather than on a single-point estimate of value uncertainty. Since we pegged proxy revenues to budgeted salaries, proxy revenue fluctuation would be correlated to the volatility of salaries. In addition, the rate of inflation, modeled in the base case as 4.5%, might fluctuate (i.e., exhibit volatility), as might the risk free rate used to discount future net cash flows.

These probabilistic value distributions were generated by using Monte Carlo simulation, using *Crystal Ball* decision support software and running the inputs into the model through 1,000 trials. Table VII contains the Expected NPVs and Statistical Confidence Ranges of the three strategies.

	Expected NPV	**90% Statistical Confidence Range**
Strategy A	$24.37M	$23.60M – $25.13M
Strategy B	$26.63M	$26.24M – $27.02M
Strategy C	$24.75M	$24.02M – $25.51M

Table VII: **Expected NPVs and Statistical Confidence Ranges**

These results indicated that, using the base case NPV approach, Strategy B is the optimal decision to pursue. However, the base case NPV probability distributions do not tell us what volatility parameters we should apply to inputs into a *staged* MSC implementation. Ordinarily, to get these we could go out to the public markets and make estimates based on our informed professional judgment, or use extrapolations of endogenous historical data to help us build our estimates.

However, the KVA approach produces an internally generated historical ratio, Return on Knowledge Investment (ROKI), which can be used in a Monte Carlo simulation to generate a volatility parameter. This volatility parameter is a statistical value representing the distilled, integrated effects of all the volatilities and uncertainties that are inherent in the forecasted values for each MSC strategy stage.

Although there are many methods used to calculate volatility, we chose to use the Logarithmic Present Value Approach (LPVA) as it was the most robust method for this purpose and we could utilize Monte Carlo simulation to provide a higher level of precision. When implied ROKI volatilities were simulated using the LPVA, they produced the following volatility parameters, found in Table VIII.

	Volatility Parameter for ROKI
Strategy A	92%
Strategy B	86%
Strategy C	92%

Table VIII: **Volatility Parameters Related to Strategy ROKIs**

Using these volatility parameters as well as the other inputs associated with each stage of each strategy, we ran real options analyses using binomial lattices and simulation pathways generated by Geometric Brownian Motion with fixed volatilities (see Table VIII). Table IX summarizes the total strategic value and the value of the options built into the staged models for our three strategies. Again, *Crystal Ball* software was used to do the actual calculations.

	(A) Base Case NPVs	(B) Option Values	(C) Total Strategic Values
Strategy A	$24.37M	$9.42M	$33.79M
Strategy B	$26.63M	$8.37M	$35.00M
Strategy C	$24.75M	$14.17M	$38.92M

Table IX: **Base Case, Option, and Total Strategic Values**

Once the real options analysis is completed for all strategies, we were able to compare total strategic values with base case NPVs under varying levels of volatility, to identify the optimal strategy to execute. Table X following presents the results of this statistical comparison. In this table, Strategy B is labeled "2" and Strategy C is labeled "3."

Strategy Selection	Volatility (10.00%)	Volatility (20.00%)	Volatility (30.00%)	Volatility (40.00%)	Volatility (50.00%)	Volatility (60.00%)	Volatility (70.00%)	Volatility (80.00%)	Volatility (90.00%)	Volatility (100.00%)	Volatility (110.00%)	Volatility (120.00%)	Volatility (130.00%)	Volatility (140.00%)	Volatility (150.00%)
Total Strategic Value	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3
Traditional NPV	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table X: Reversion of Optimal Strategy under Different Volatilities

An interesting result emerges. When volatilities are low, Strategy B (Strategy 2) is optimal. However, when the volatility is high, the total strategic value (NPV plus real options value) indicate that Strategy C (Strategy 3) is optimal. Because the analysis of each strategy involved a relatively high volatility for ROKIs (92%, 86%, and 92%), the optimal strategy is C. Hence, when accounting for the strategic flexibility of the MSC implementations, Strategy C should be undertaken.

IV. Conclusions, Limitations, Directions for Further Research

Conclusions: The Mission Support Center case example provides a simple but clear picture of how KVA can be used to identify and measure the outputs of people, IT, and a core process and then monetize those outputs and use them to generate common, useful ratios. When the KVA historical Return on Knowledge Investment (ROKI) is used to generate a volatility parameter for the MSC's one process, the Mission Feasibility Assessment Cycle, and standard accounting data for cost and revenue (here, proxy revenue) are plugged into real options analysis software, the results of the analysis are reasonable and useable. Furthermore, if the results had made us uncomfortable, we could have gone back to the original KVA data and validate it by using other approaches to KVA, still based on direct observation and discussions with subject matter experts.

In addition, we have the option to collect KVA data over time on a particular MSC real option implementation. Since KVA data collection methods are highly cost-and-time effective, and in mid-2005 there will be software that can provide the power and scalability to capture and analyze enormous amounts of KVA data, we will have the means by which to *track projected results against reality. (Issue 3)*

If we so choose, we can use the same software, coupled with available real options software, to collect data, create benchmarks, and begin to *develop consistently structured, repeatable real options problems and solutions. (Issue 2)*

Finally, we have offered complexity analytic insights into issues like risk, uncertainty, discount rates, betas, and an open-system structure of the markets, all of which can be utilized within real options practices and algorithms. And, we have provided the real options community with *a practical methodology by which to assign benefit streams to knowledge assets. (Issue 1)*

Limitations: Since incipience, there have been a number of limitations to KVA theory and practice, all of which have been or are currently being addressed (Housel and Nelson, 2005). They are:

(1) The need to standardize KVA theory and migrate it into the languages of accounting and finance where it can be adopted more widely and easily. This has been accomplished in 2004.

(2) The need to capture non-directly-observable Meta Processes and the contribution of management and creative staff to the organization within KVA algorithms, instead of simply adding the cost of these components of value into the total cost of overhead. This was initially addressed in 2004 and is continuing to be researched and refined.

(3) The need to fully standardize our data-gathering methods. Although much data has been collected, we do not yet have a database of comparable historical KVA information from which to begin to benchmark future work or provide broader-scale insights for current work. This will be addressed once we have software that can manage the data.

(4) The need to embed KVA in a solid, useable, flexible software product that will provide the analytic power and storage capacity to undertake large-scale, complex KVA research and practical applications. This is being addressed by *GaussSoft* in a software application by mid-2005. However, it would be beneficial to the finance, valuation and real options communities if we had a menu of software options from which they could choose, including software that did simulation, real options analysis, and KVA in the same package.

(5) The need to use KVA data and sub-corporate finance in a broad enough array of real options (and other) problems to understand in more depth its limitations and contributions to the field. This is our goal for 2005 and beyond.

Areas for Further Research: This paper only touches the surface of areas in which further research can be done. At the top of the list is our need to use KVA data and sub-corporate finance in a broad array of real options problems. For instance, our intuition is that Merton's

(1987) model and definition of the shadow costs of incomplete information may become of central importance in future calculations of KAPM, the Knowledge Asset Pricing Model. In addition, *k-beta* derivations will need to be further explored and refined.

Although we have begun work on issues of investor behavior, based on our sub-corporate finance approach, there is much work to be done in that area. Relaxed rules and assumptions to fit open market systems in homeostasis will need to be carefully reviewed and new or different rules and assumptions will need to be developed.

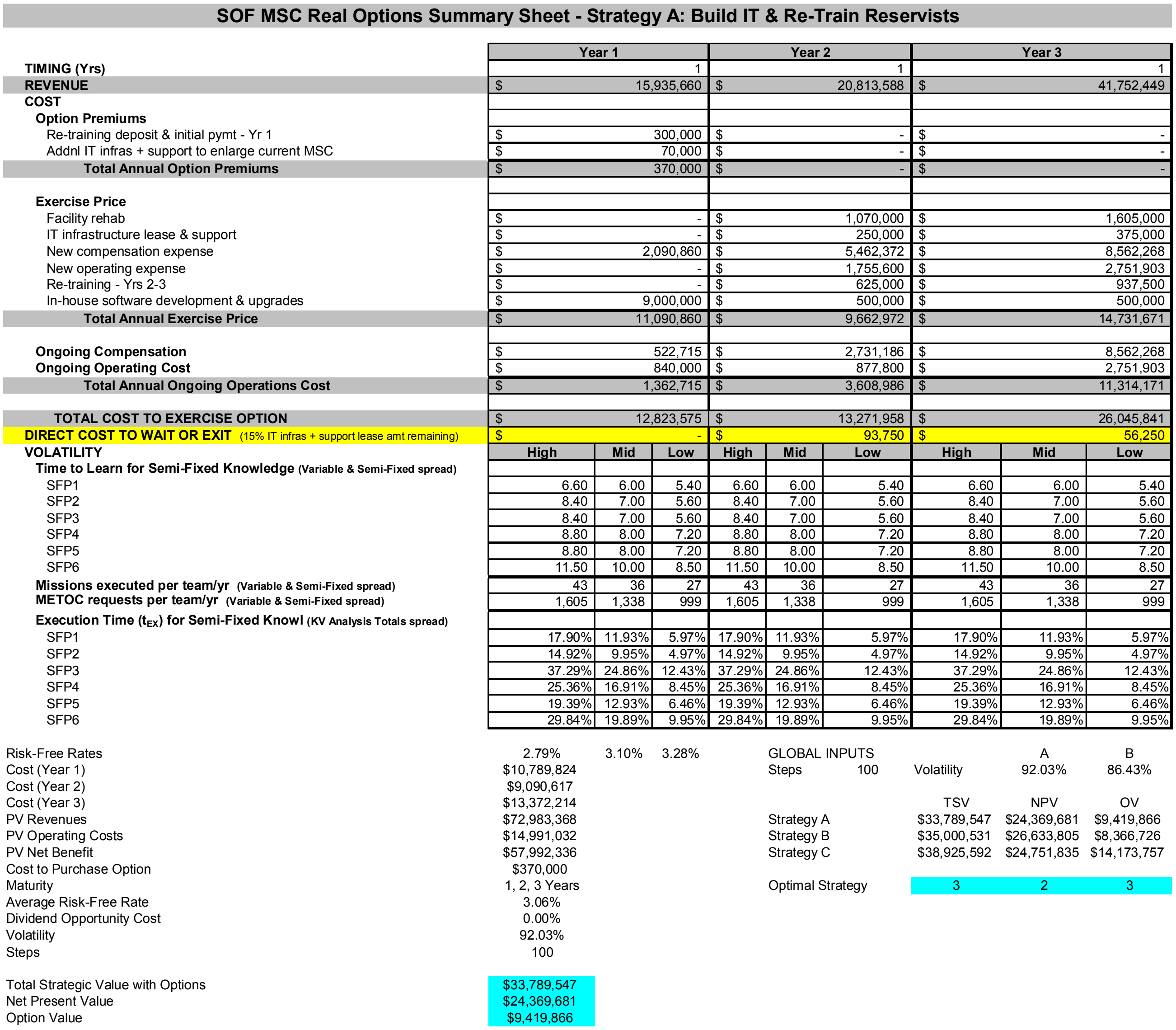
The rich field of strategic investment using real options and games, introduced by Smit and Trigeorgis, may be a good fit for the application of sub-corporate finance concepts.

The use of stochastic integer programming to value the real options "in" projects (Tang and de Neufville, 2004) will be a key area of inquiry for us on behalf of the Department of Defense, since their real options problems are at such a huge scale and level of complexity.

And last, but certainly not least, we have begun work with key market players in a major Latin American country to develop the concept and limited application of a sub-corporate equities market (Kendall and Housel, 2004; Cook and Housel, 2005; Housel and Nelson, 2005). This endeavor, made possible by the KVA ability to assign revenue at the sub-corporate level and value sub-corporate knowledge assets, could bring an array of useful and exciting applications across all industries and CIM markets.

Exhibit A

The following Tables (EX-1 through EX-3) present the summary valuations for each strategy.



SOF MSC Real Options Summary Sheet - Strategy A: Build IT & Re-Train Reservists

	Year 1			Year 2			Year 3		
TIMING (Yrs)	1			1			1		
REVENUE	$ 15,935,660			$ 20,813,588			$ 41,752,449		
COST									
Option Premiums									
Re-training deposit & initial pymt - Yr 1	$ 300,000			$ -			$ -		
Addnl IT infras + support to enlarge current MSC	$ 70,000			$ -			$ -		
Total Annual Option Premiums	$ 370,000			$ -			$ -		
Exercise Price									
Facility rehab	$ -			$ 1,070,000			$ 1,605,000		
IT infrastructure lease & support	$ -			$ 250,000			$ 375,000		
New compensation expense	$ 2,090,860			$ 5,462,372			$ 8,562,268		
New operating expense	$ -			$ 1,755,600			$ 2,751,903		
Re-training - Yrs 2-3	$ -			$ 625,000			$ 937,500		
In-house software development & upgrades	$ 9,000,000			$ 500,000			$ 500,000		
Total Annual Exercise Price	$ 11,090,860			$ 9,662,972			$ 14,731,671		
Ongoing Compensation	$ 522,715			$ 2,731,186			$ 8,562,268		
Ongoing Operating Cost	$ 840,000			$ 877,800			$ 2,751,903		
Total Annual Ongoing Operations Cost	$ 1,362,715			$ 3,608,986			$ 11,314,171		
TOTAL COST TO EXERCISE OPTION	$ 12,823,575			$ 13,271,958			$ 26,045,841		
DIRECT COST TO WAIT OR EXIT (15% IT infras + support lease amt remaining)	$ -			$ 93,750			$ 56,250		
VOLATILITY	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**
Time to Learn for Semi-Fixed Knowledge (Variable & Semi-Fixed spread)									
SFP1	6.60	6.00	5.40	6.60	6.00	5.40	6.60	6.00	5.40
SFP2	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP3	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP4	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP5	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP6	11.50	10.00	8.50	11.50	10.00	8.50	11.50	10.00	8.50
Missions executed per team/yr (Variable & Semi-Fixed spread)	43	36	27	43	36	27	43	36	27
METOC requests per team/yr (Variable & Semi-Fixed spread)	1,605	1,338	999	1,605	1,338	999	1,605	1,338	999
Execution Time (t_{EX}) for Semi-Fixed Knowl (KV Analysis Totals spread)									
SFP1	17.90%	11.93%	5.97%	17.90%	11.93%	5.97%	17.90%	11.93%	5.97%
SFP2	14.92%	9.95%	4.97%	14.92%	9.95%	4.97%	14.92%	9.95%	4.97%
SFP3	37.29%	24.86%	12.43%	37.29%	24.86%	12.43%	37.29%	24.86%	12.43%
SFP4	25.36%	16.91%	8.45%	25.36%	16.91%	8.45%	25.36%	16.91%	8.45%
SFP5	19.39%	12.93%	6.46%	19.39%	12.93%	6.46%	19.39%	12.93%	6.46%
SFP6	29.84%	19.89%	9.95%	29.84%	19.89%	9.95%	29.84%	19.89%	9.95%

Risk-Free Rates	2.79%	3.10%	3.28%	GLOBAL INPUTS			A	B
Cost (Year 1)	$10,789,824			Steps	100	Volatility	92.03%	86.43%
Cost (Year 2)	$9,090,617							
Cost (Year 3)	$13,372,214					TSV	NPV	OV
PV Revenues	$72,983,368			Strategy A		$33,789,547	$24,369,681	$9,419,866
PV Operating Costs	$14,991,032			Strategy B		$35,000,531	$26,633,805	$8,366,726
PV Net Benefit	$57,992,336			Strategy C		$38,925,592	$24,751,835	$14,173,757
Cost to Purchase Option	$370,000							
Maturity	1, 2, 3 Years			Optimal Strategy		3	2	3
Average Risk-Free Rate	3.06%							
Dividend Opportunity Cost	0.00%							
Volatility	92.03%							
Steps	100							
Total Strategic Value with Options	$33,789,547							
Net Present Value	$24,369,681							
Option Value	$9,419,866							

Table EX-1: Summary Valuation for Strategy A

SOF MSC Real Options Summary Sheet - Strategy B: Buy IT Off Self & Use Regulars

	Year 1			Year 2			Year 3		
TIMING (Yrs)	1			1			1		
REVENUE	$ 6,792,973			$ 21,908,853			$ 46,832,207		
COST									
Option Premiums									
Year 1 software purchase + support	$ 302,500			$ -			$ -		
Year 2 downpayment on software upgrades	$ -			$ 250,000			$ -		
Total Annual Option Premiums	$ 302,500			$ 250,000			$ -		
Exercise Price									
Facility rehab	$ -			$ 1,070,000			$ 1,605,000		
IT infrastructure lease & support	$ -			$ 250,000			$ 375,000		
Addnl hardware to enlarge current MSC	$ 70,000			$ -			$ -		
New compensation expense	$ 2,242,460			$ 5,699,953			$ 8,934,676		
New operating expense	$ -			$ 1,755,600			$ 2,751,903		
Yrs 2-3 software purchase + support	$ -			$ 703,500			$ 3,500,519		
Software training	$ 20,000			$ 52,500			$ 82,688		
Total Annual Exercise Price	$ 2,332,460			$ 9,531,553			$ 17,249,785		
Ongoing Compensation	$ 560,615			$ 2,849,976			$ 8,934,676		
Ongoing Operating Cost (incl ongoing software suppt)	$ 840,000			$ 877,800			$ 2,966,891		
Total Annual Ongoing Operations Cost	$ 1,400,615			$ 3,727,776			$ 11,901,566		
TOTAL COST TO EXERCISE OPTION	$ 4,035,575			$ 13,509,329			$ 29,151,351		
DIRECT COST TO WAIT OR EXIT (15% IT infras + support lease amt remaining)	$ -			$ 93,750			$ 56,250		
VOLATILITY	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**
Time to Learn for Semi-Fixed Knowledge (Variable & Semi-Fixed spread)									
SFP1	6.60	6.00	5.40	6.60	6.00	5.40	6.60	6.00	5.40
SFP2	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP3	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP4	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP5	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP6	11.50	10.00	8.50	11.50	10.00	8.50	11.50	10.00	8.50
Missions executed per team/yr (Variable & Semi-Fixed spread)	43	36	27	43	36	27	43	36	27
METOC requests per team/yr (Variable & Semi-Fixed spread)	1,605	1,338	999	1,605	1,338	999	1,605	1,338	999
Execution Time (t_{EX}) for Semi-Fixed Knowl (KV Analysis Totals spread)									
SFP1	17.69%	11.79%	5.90%	17.69%	11.79%	5.90%	17.69%	11.79%	5.90%
SFP2	14.74%	9.83%	4.91%	14.74%	9.83%	4.91%	14.74%	9.83%	4.91%
SFP3	36.85%	24.57%	12.28%	36.85%	24.57%	12.28%	36.85%	24.57%	12.28%
SFP4	25.06%	16.70%	8.35%	25.06%	16.70%	8.35%	25.06%	16.70%	8.35%
SFP5	19.16%	12.77%	6.39%	19.16%	12.77%	6.39%	19.16%	12.77%	6.39%
SFP6	29.48%	19.65%	9.83%	29.48%	19.65%	9.83%	29.48%	19.65%	9.83%

Risk-Free Rates	2.79%	3.10%	3.28%
Cost (Year 1)	$2,269,151		
Cost (Year 2)	$8,966,982		
Cost (Year 3)	$15,657,953		
PV Revenues	$69,730,220		
PV Operating Costs	$15,672,847		
PV Net Benefit	$54,057,373		
Cost to Purchase Option	$529,481		
Maturity	1, 2, 3 Years		
Average Risk-Free Rate	3.06%		
Dividend Opportunity Cost	0.00%		
Volatility	86.43%		
Steps	100		
Total Strategic Value with Options	$35,000,531		
Net Present Value	$26,633,805		
Option Value	$8,366,726		

Table EX-2 Summary Valuation for Strategy B

SOF MSC Real Options Summary Sheet - Strategy C: Outsource MSC Function

	Year 1			Year 2			Year 3		
TIMING (Yrs)	$ 1			$ 1			$ 1		
REVENUE	$ 12,300,877			$ 25,313,211			$ 49,797,546		
COST									
Option Premiums									
Downpayment for facilities and IT infrastructure construction	$ 785,000			$ -			$ -		
Downpayment on software development	$ 1,250,000			$ -			o		
Total Annual Option Premiums	$ 2,035,000			$ -			$ -		
Exercise Price									
Facility rehab & IT infrastructure	$ -			$ 2,500,000			$ 6,250,000		
Addnl hardware to enlarge current MSC	$ 140,000			$ -			$ -		
New compensation expense	$ 2,254,218			$ 5,697,497			$ 8,930,826		
New operating expense	$ -			$ 1,755,600			$ 2,875,739		
Software development	$ 3,750,000			$ 3,750,000			$ 3,750,000		
Total Annual Exercise Price	$ 6,144,218			$ 13,703,097			$ 21,806,565		
Ongoing Compensation	$ 563,554			$ 2,848,748			$ 8,930,826		
Ongoing Operating Cost	$ 840,000			$ 877,800			$ 2,875,739		
Total Annual Ongoing Operations Cost	$ 1,403,554			$ 3,726,548			$ 11,806,565		
TOTAL COST TO EXERCISE OPTION	$ 9,582,772			$ 17,429,645			$ 33,613,130		
DIRECT COST TO WAIT OR EXIT									
VOLATILITY	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**	**High**	**Mid**	**Low**
Time to Learn for Semi-Fixed Knowledge **(Variable & Semi-Fixed spread)**									
SFP1	6.60	6.00	5.40	6.60	6.00	5.40	6.60	6.00	5.40
SFP2	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP3	8.40	7.00	5.60	8.40	7.00	5.60	8.40	7.00	5.60
SFP4	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP5	8.80	8.00	7.20	8.80	8.00	7.20	8.80	8.00	7.20
SFP6	11.50	10.00	8.50	11.50	10.00	8.50	11.50	10.00	8.50
Missions executed per team/yr **(Variable & Semi-Fixed spread)**	43	36	27	43	36	27	43	36	27
METOC requests per team/yr **(Variable & Semi-Fixed spread)**	1,605	1,338	999	1,605	1,338	999	1,605	1,338	999
Execution Time (t_{EX}) for Semi-Fixed Knowl **(KV Analysis Totals spread)**									
SFP1	16.25%	10.83%	5.42%	16.25%	10.83%	5.42%	16.25%	10.83%	5.42%
SFP2	13.54%	9.03%	4.51%	13.54%	9.03%	4.51%	13.54%	9.03%	4.51%
SFP3	33.85%	22.56%	11.28%	33.85%	22.56%	11.28%	33.85%	22.56%	11.28%
SFP4	23.01%	15.34%	7.67%	23.01%	15.34%	7.67%	23.01%	15.34%	7.67%
SFP5	17.60%	11.73%	5.87%	17.60%	11.73%	5.87%	17.60%	11.73%	5.87%
SFP6	27.08%	18.05%	9.03%	27.08%	18.05%	9.03%	27.08%	18.05%	9.03%

Risk-Free Rates	2.79%	3.10%	3.28%
Cost (Year 1)	$5,977,447		
Cost (Year 2)	$12,891,439		
Cost (Year 3)	$19,794,228		
PV Revenues	$80,983,031		
PV Operating Costs	$15,588,317		
PV Net Benefit	$65,394,714		
Cost to Purchase Option	$1,979,765		
Maturity	1, 2, 3 Years		
Average Risk-Free Rate	3.06%		
Dividend Opportunity Cost	0.00%		
Volatility	92.03%		
Steps	100		
Total Strategic Value with Options	$38,925,592		
Net Present Value	$24,751,835		
Option Value	$14,173,757		

Table EX-3: Summary Valuation for Strategy C

References

Alesii, G. (2003) "Rules of Thumb in Real Options Analysis." Universitá degli Studi – L'Aquila, Facoltá di Economia, Dip. Di Sistemi ed Istituzioni per l'Economia. JEL: G13, G31. Paper presented at 8th Annual Real Options Conference, June 2004.

Anderson JR. (1976) Memory, Language, and Thought. Erlbaum: Hillsdale, NJ.

Anderson JR. (1995) Learning and Memory: An Integrated Approach. New York: Wiley.

Arnott, R. D. and Bernstein, P. L. (2002) "What Risk Premium is 'Normal'?" Financial Analysts Journal. March/April 2002. Downloaded from the Social Science Research Network Electronic Paper Collection: http://papers.ssrn.com/abstract=296854.

Bellalah, M. (2004) "Real Options Valuation within Information Uncertainty: Some Extensions and New Results." University de Cergy. JEL: G12, G20, G31. Paper presented at 8th Annual Real Options Conference, June 2004.

Booz Allen Hamilton (2004) "Network Centric Operations Case Study: Naval Special Warfare Group One (NSWG-1)." Research presented to Department of Defense, Office of Force Transformation.

Burton, J. (1998) "Revisiting the Capital Asset Pricing Model." Dow Jones Asset Manager. May/June. Pp. 20-28. From http://wwwstanford.edu/~wfsharpe/art/djam/djam.htm

Campbell, J. and Knoess, C. (2002) "How to Build a Future Wealth Company, Ernst and Young's Point of View on Value in the New Economy." Study by Ernst & Young. http://www.ey.com/GLOBAL.

Cook, G. & Housel, T. (in press) "Where to Invest in Information Systems: A CRM Case Study." Naval Postgraduate School. Paper for HICS conference, January 2005.

Copeland, T. and Antikarov, V. (2001) Real Options: A Practitioner's Guide. Texere: New York and London. pp. 28-30. From Rogers, E. (1995) Diffusion of Innovations, 4th edition. Free Press.

Damodaran, A. (2001) The Dark Side of Valuation. Prentice-Hall, Inc.: New Jersey.

Davis, G. A. (2002) "The Impact of Volatility on Firms Holding Growth Options." Division of Economics and Business, Colorado School of Mines. JEL classification: A23; C61; G13.

Dixit, A. K. and Pindyck, R. S. (1998, working paper 6373) "Expandability, Reversibility, and Optimal Capacity Choice." National Bureau of Economic Research. Cambridge, MA.

Fama, E.F. (1965) "Random Walks in Stock Market Prices." *Financial Analysts Journal*, September/October. (reprinted January-February 1995).

Fama, E. F. (1997 working paper for comment only) "Market Efficiency, Long-Term Returns, and Behavioral Finance." Graduate School of Business, University of Chicago.

Foss, N.J. (1997) "On the Relations Between Evolutionary and Contractual Theories of the Firm." Department of Industrial Economics and Strategy, Copenhagen Business School. Revised draft.

Glazer R. (1998) "Measuring the knower: toward a theory of knowledge equity." California Management Review. **40**(30): 175–194.

Gobet F, Simon HA. (1996) “Recall of random and distorted chess positions: implications for the theory of expertise.” Memory and Recognition. **24**(4): 493–503.

Housel, T. and Bell, A. (2001) Measuring and Managing Knowledge. McGraw Hill/Irwin: New York.

Housel, T. and Kanevsky, V. (1995) “Reengineering Business Processes: A Complexity Theory Approach to Value Added,” INFOR **33**(4): 251.

Housel, T. and Nelson, S. (2005, in press) “Knowledge Valuation Analysis: Applications for Organizational Intellectual Capital”

Housel, T. and Nelson, S. (2004) Knowledge Valuation and Portfolio Management for Capabilities-Based Planning. Office of Force Transformation, Department of Defense: Washington D.C.

Kaplan, S., Schenkel, A., von Krogh, G., Weber, C. (2001) “Knowledge-Based Theories of the Firm in Strategic Management: A Review and Extension.” Paper submitted to Academy of Management Review.

Kendall, A. and Housel, T. (2004) “Resolving the ROI on IT Issue.” Naval Postgraduate School. Paper presented at SCI Conference 2004.

Kanevsky, V. & Housel, T. (1998) “The Learning-Knowledge-Value Cycle” in von Krogh, G. Roos, J. & Kleine, D. (Eds) Knowing in Firms: Understanding, Managing and Measuring Knowledge, Sage Publications: London, pp. 269-284.

King, A. W. & Zeithaml, C. (2003) “Research Notes and Commentaries: Measuring Organizational Knowledge: A Conceptual and Methodological Framework,” Strategic Management Journal. John Wiley & Sons, Ltd. Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/smj.333.

Lambrecht, B. M. and Myers, S. C. (2004) “A Theory of Takeovers and Disinvestment.” Lancaster University Management School and MIT Sloan School of Management. Paper presented at 8th Annual Real Options Conference, June 2004. JEL: G34, C72, G13. Paper presented at 8th Annual Real Options Conference, June 2004.

Leonard D, Sensiper S. (1998) “The role of tacit knowledge in group innovation.” California Management Review. **40**(3): 112–132.

Marr, B. (Ed) (2005) Perspectives on Intellectual Capital: Multidisciplinary Insights into Management, Measurement, and Reporting. Elsevier: Boston, MA.

Marris, R.L. (1964) “Managerial Theories of the Firm.” From http://pioneer.netserv.chula.ac.th/~ckieatvi/Managerial%20theories%20of%20the%20firm.htm

Maya, C. (2004) “In Search of the True Value of a Start-Up Firm: Creative Destruction and Real Options Approach (CD_ROA).” Department of Finance, School of Business, Universidad EAFIT. Paper presented at 8th Annual Real Options Conference, June 2004.

Mun, Johnathan C. (2002) Real Options Analysis. John Wiley & Sons, Inc.: New Jersey.

Mun, Johnathan C. (2003, in press) “An Alternative Discount Rate Determination Using Monte Carlo Simulation and Real Options Analysis.” Whitepaper.

Murto, P. (2004) “Valuing Options to Learn: Optimal Timing of Information.” Helinski School of Economics. Paper for 8th Real Options Annual International Conference, June 2004.

Nelson RR, Winter SG. (1982) The Evolutionary Theory of Economic Change. Belknap Press of Harvard University Press: Cambridge, MA.

Newell A, Simon HA. (1972) Human Problem Solving. Prentice-Hall: Englewood Cliffs, NJ.

Orlikowski WJ. (2002) “Knowing in practice: enacting a collective capability in distributed organizing.” Organization Science. **13**(3): 249–273.

Robichek, A. A. and Myers, S. C. (1966) “Conceptual Problems in the Use of Risk-Adjusted Discount Rates.” The Journal of Finance. Vol. 21, No. 4 (December) 727-730.

Rodgers, W. and Housel, T. (2004) “The Knowledge Transfre Effect on Users’ Decision Making.” University of California, Riverside and Naval Postgraduate School. Paper presented at European International Business Academy 30th Annual Conference, December 2004.

Roemer, E. (2004) “Real Options and the Theory of the Firm.” University of Bradford, School of Management, Marketing Group. Paper presented at 8th Annual Real Options Conference, June 2004.

Sharpe, W.F. website. www.wsharpe.com (permission not given to quote or cite certain documents.)

Simon, H.A. (1974) “How big is a chunk?” Science. **183**(4124): 482–488.

Simon, H.A. (1983) “Alternate visions of rationality.” Chapter from *Reason in Human Affairs*, Stanford University Press. 7-35.

Singley MK, Anderson JR. (1989) The Transfer of Cognitive Skill. Harvard University Press: Cambridge, MA.

Smit, H.T.J. and Trigeorgis, L. (2004) “Quantifying the Strategic Options Value of Technology Investments.” Erasmus University, The Netherlands, University of Cyprus, and University of Chicago. JEL: G31, L63, D81. Paper presented at 8th Annual Real Options Conference, June 2004.

Smit, H.T.J. and Trigeorgis, L. (2004) Strategic Investment: Real Options and Games. Princeton University Press: New Jersey.

Smith, J.E. (1996, draft) “Fisher Separation and Project Valuation in Partially Complete Markets.” Fuqua School of Business. Duke University.

Sudarsanam, S., Sorwar, G., Marr, B. (2003) “Valuation of Intellectual Capital and Real Options Models.” Paper presented to PMA Intellectual Capital Symposium, October 2003, at Cranfield University.

Trigeorgis, L. (1996) Real Options: Managerial Flexibility and Strategy in Resource Allocation. The MIT Press: Cambridge, Massachusetts and London, England.

Tsoukas H. (1996) “The firm as a distributed knowledge system: a constructionist approach.” Strategic Management Journal. Winter Special Issue **17**: 11–26.

Wang, T. and de Neufville, R. (2004) "Building Real Options into Physical Systems with Stochastic Mixed-Integer Programming." Massachusetts Institute of Technology. Paper for 8th Real Options Annual International Conference, June 2004.

End Notes

---

[1] A non-parametric Spearman rank-based correlation is used instead of the regular parametric Pearson's R because the underlying distribution of the cash flows is probably non-normal. Also, the number of cash flow periods in the model may be less than 30, and normality cannot be automatically assumed. Finally, Pearson's correlation coefficient measures a linear relationship between two variables. The simulated cash flows may fluctuate extensively such that non-linear relationships may exist, relationships that cannot be captured with the Pearson's R.