3 Valuation of Software Initiatives under Uncertainty: Concepts, Issues, and Techniques

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Abstract: State-of-the-practice in software engineering economics often focuses exclusively on cost issues and technical considerations for decision-making. Value-based software engineering (VBSE) expands the cost focus by also considering benefits, opportunities, and risks. Of central importance in this context is valuation, the process for determining the economic value of a product, service, or a process. Uncertainty is a major challenge in the valuation of software assets and projects. This chapter first introduces uncertainty along with other significant issues and concepts in valuation, and surveys the relevant literature. Then it discusses decision-tree and options-based techniques to demonstrate how valuation can help with dynamic decision making under uncertainty in software development projects.

Keywords: software economics, valuation, net present value, discounted cash flow, uncertainty, decision tree, real options

3.1 Introduction

Technological and economic factors put enormous competitive pressures on organizations producing software and providing services and products that rely on software. As a result, software professionals and managers at all levels have to make decisions in complex situations under uncertainty and conflicting goals. They have to take many variables into consideration. Academic research and industrial practice have by and large tackled decision making in software development by focusing on the cost side, for example by looking for more efficient ways to develop software or by evaluating new software initiatives only in terms of development effort. However, determining the value of a new initiative requires other important dimensions, benefits and uncertainty, to be accounted for as well. Without these dimensions, the consequences of product or process decisions cannot be properly evaluated.

Several authors have explicitly promoted value, as opposed to cost alone, as a basis for decision making in software engineering (Favaro, 1996, Favaro et al., 1998, Favaro, 1999, Biffl and Halling, 2001, Boehm and Sullivan, 1999, Port et al., 2002, Boehm 2003). Chapter 1 (Boehm) identifies seven key elements for value-based software engineering (VBSE). Among these elements, valuation specifically addresses *Business Case Analysis*, *Continuous Risk and Opportunity Management*, and *Change as Opportunity*. Focusing on these elements naturally positions valuation more as a management activity than as a tool for technical decision making, although valuation concepts are relevant and have been applied to technical decisions in software engineering as well (Sullivan et al., 1999). This chapter addresses valuation from a management perspective in terms of its ability to help with decisions at the project level. The aim is to orient the reader and illustrate how economic value can be leveraged to make project-level decisions, rather than describe a specific valuation process or provide a self-contained exposition of the topic.

The chapter is organized as follows. Section 2 draws attention to the main issues that make valuation difficult and provides pointers to the relevant literature. Sections 3 and 4 focus on the treatment of uncertainty and dynamic decisions. Section 3 first discusses a decision-theoretic approach through an illustrative example and introduces the notion of an *option*. Section 4 then builds on this approach to explain how projects with growth opportunities and abandonment strategies can be analyzed using *real options* theory.

It is impossible to cover a topic as diverse as valuation with its rich theoretical foundations and multiplicity of underlying techniques in a single chapter. However we hope to provide a glimpse by focusing on the most thorny issues and on the techniques that we deem most illustrative and promising. For the reader who desires a deeper investigation, Section 6 provides many references for further reading. Finally, Section 7 gives a summary and discusses the difficulties regarding the adoption of the various techniques mentioned.

3.2 Issues in Valuation

Valuation is the process of determining the economic value of an asset, be it a product, service, or a process. In simple terms, *value* is defined as the net worth, or the difference between the benefits and the costs of the asset, all adjusted appropriately for risk, at a given point in time. When the costs are disregarded, implicit, or have been incurred before the point at which an asset is evaluated then value may refer to future benefits or the remaining worth of the asset at that point. Several factors make valuation a difficult endeavor:

- Costs and benefits might occur at different points in time and need to be downward adjusted, or *discounted*, to account for *time value of money*: the fundamental principle that money is worth more today than in the future under ordinary economic conditions. Discounted Cash Flow and related techniques handle time value of money. These are illustrated in the earlier parts of Section 1.3.
- Not all determinants of value are known at the time of the valuation due to uncertainty inherent in the environment. Modeling uncertainty is more often an art than a science. Section 1.3 shows how decision-tree and options-based approaches can help address uncertainty.
- The appropriate discount rate to use depends on the risk carried by a project and the return expected on alternative initiatives. These factors must be analyzed to determine the discount rate. Chapter 5 (Harrison) tackles this topic.

- Sometimes intangible benefits such as learning, growth opportunities, and embedded flexibility are the dominant sources of value under uncertainty. These benefits are hard to quantify and requires more advanced techniques such as decision trees and real options analysis that are designed to deal with uncertainty. While later parts of Section 1.3 introduce decision trees, Section 4 discusses real options.
- Value is to a certain extent in the eye of the beholder: risk preferences of stakeholders who make resource decisions influence it. Section 1.2. 3 briefly talks about the techniques for taking into account risk preferences in valuation.
- When assets are interdependent, it may be more appropriate to treat them as parts of a whole. This calls for a portfolio-based approach. Section 1.2.4 provides a short discussion on project portfolios.
- When stakeholders have clashing incentives and different information, value can be destroyed or become hard to judge. While these effects are unavoidable, incorporating them into valuation may lead to more objective results. Section 1.2.5 touches upon how they can affect value creation.

The remainder of this section draws attention to these issues and provides pointers for tackling them. It's impossible to do justice to all of these issues in the space allocated. Therefore, Sections 3 and 4 focus on the basic valuation concepts as well as the treatment of uncertainty, covered by the first four bullets above. The treatment of uncertainty is especially important from the VBSE perspective because uncertainty is prevalent in software development and can be a significant source of value creation or destruction depending on how it's managed.

The different techniques and approaches discussed in the chapter are summarized in Table 3 at the end of the chapter.

Beyond Cost-Benefit Analysis

The valuation of software assets and projects depends on a detailed analysis of underlying costs and benefits. A prerequisite for cost-benefit analysis is the identification of the relevant value and cost drivers. While models for software development costs are well established, comprehensive definitions of individual value drivers (e.g., performance variables that support decision-making and prioritization) and frameworks for value creation in software engineering have been missing.

Models exist in economic theory for the analysis of value creation. The most prominent is the model of Porter (Porter, 1985, Porter and Millar, 1985), based on value chain analysis. The core idea behind this model is the definition of value as "the amount buyers are willing to pay for what a supplier provides them". The application of Porter's model to software projects would involve definition of strategic goals, identification of critical activities, definition of product properties, and analysis of the value of these activities and properties. The buyer perspective of value gives rise to a single-dimensional, external measure, which is more objective and easier to reason about than those given rise by multi-dimensional, internal perspectives.

A special challenge for cost-benefit analysis in software engineering is the assessment of intangible or soft benefits, the influence of time on the value of these benefits and costs, and the consideration of uncertainty. However these situations are not unique to software development. Comparable situations can be found in the valuation of public goods and social investments; see Layard and Glaister (1994) for an example.

Intangible benefits should in the long run lead to an improvement in monetary terms (Powell, 1992). These benefits include flexibility and learning, which can generate significant long-term value in software development. Traditional cost-oriented techniques (Boehm, 1984, Boehm, 2000) address only tangible benefits such as direct savings due to reduced effort. Real options analysis is a promising approach that can address this gap. Sections 3 and 4 will discuss this approach and the underlying theory.

Modeling Uncertainty

In addition to benefits and costs, the valuation process must consider uncertainty. Uncertainty arises from different sources. Natural uncertainty directly relates to variations in the environment variables (e.g., the variation in the number of defects in a software product). Parameter uncertainty relates to the estimation of parameters (e.g., the reliability of the average number of defects). Model uncertainty relates to the validity of specific models used (e.g., the suitability of a certain distribution to model the defects). Kitchenham and Linkman (1997) provide a taxonomy of uncertainty for software engineering that includes additional sources such as scope error and assumption error.

The traditional approach of handling uncertainty is by defining probability distributions for the underlying quantities, allowing the application of a standard calculus. Other approaches based on fuzzy measures or Bayesian networks (Klir et al., 1998) consider different types of prior knowledge. Srivastava and Mock (2002) have successfully applied these approaches to analyze business decisions.

Main financial theories, such as the traditional portfolio theory (Markowitz, 1952, Lintner, 1965) and the Capital Asset Pricing Model (CAPM) (Sharpe, 1964, Mossin, 1966), consider both expected returns and borne risks in order to value alternative trading strategies. This means that uncertainty and resulting risks can also be seen from an opportunistic perspective. If appropriately rewarded, taking risks are warranted depending on the investors' risk attitudes, but an appropriate risk premium is expected for additional risk borne when uncertainty increases. The reason behind this argument is that risk, as measured by the standard deviation of expected returns, includes both positive and negative variability. The determination of this risk premium and the resulting *risk-adjusted discount rate* are central to valuation, especially in discounted cash flow models (Myers, 1974, Black, 1988). These are briefly discussed in the beginning of Section 3, but elaborated in more detail in Chapter 5 (Harrison).

Attitudes of Decision Makers

When stakeholders take on decision-making roles about allocation of limited resources, their decisions are to an extent driven by their attitudes toward risk and how they tend to respond to uncertainty. These attitudes are reflected in the decision maker's assessment of value derived from the underlying resource allocation activity. The main modeling concept here is utility. Although in software engineering economics, utility functions are often introduced to avoid assigning monetary value to benefits and costs, the concept of utility in finance has a different foundation.

Utility functions in finance mainly model investors' risk aversion. While according to traditional portfolio theory, investors directly care about the mean (expected returns) and variance (risk or volatility) of asset returns, utility functions defined over wealth offer more flexibility to account for risk. The shape of the utility function determines the intensity of the investor's risk aversion, that is, how the decision maker's attitude toward risk distorts the losses and gains of varying amounts. For example, the magnitude of the negative utility a risk-averse person would assign to a *loss* of a certain amount would be higher than the magnitude of the positive utility he would assign to a *gain* of an equivalent amount.

Furthermore, one can distinguish between absolute and relative risk aversion. Absolute risk aversion is a measure of an investor's reaction to uncertainty relating to absolute changes in wealth. Absolute risk aversion decreases with wealth, implying that a billionaire would be relatively unconcerned with a risk that might worry a poor person. Absolute risk aversion is measured by the relative change in the slope of the utility function at a particular level of wealth. Relative risk aversion in contrast is a measure of an investor's reaction to uncertainty relating to percentage changes in wealth. Absolute and relative risk aversion are connected. For example, constant relative risk aversion, a common assumption, implies diminishing absolute risk aversion (i.e., investors become less risk averse as their wealth increases).

Utility functions can be employed in a similar way to model organizational and individual attitudes toward risk in the valuation of non-financial assets as they are used in finance to model investors' risk aversion. They have also proven to be a key factor in the integration of the decision tree and real options approaches described later in this chapter (Smith and Nau, 1995).

Campbell and Viceira (Campbell and Viceira, 2001) provide a detailed discussion of utility. Chapter 4 (Vetschera) discusses its use in the context of multi-attribute decision making. While Chapter 4 (Vetschera) also surveys several other techniques that address value from a multi-dimensional perspective, in this chapter, we consider value only from a single-dimensional, economic perspective. Economics are considered most important in making business decisions, and as such form the basis of valuation. The multi-attribute perspective is of interest when aspects of value that cannot be reduced to monetary terms are important for the underlying decisions, but valuation is not concerned with non-monetary definitions of value.

Project Portfolios

Interactions among multiple projects often affect value. For accurate reasoning, the valuation model must consider these interactions. This implies the use of a portfolio-based approach. In a portfolio-based approach, assets are not valued in isolation. The value of a portfolio of assets is not simply the sum of its parts.

An important concept here is diversification. Diversification refers to an investor's ability to limit the net effect of uncertainty on the value of an investment by spreading the investment over multiple risky assets. The resulting reduction in overall risk impacts the value of the portfolio. In order to quantify the risk reduction, one must know the correlation between the investment opportunities. The impact of diversification is largest if the different investment opportunities are negatively correlated and it is smallest if they are positively correlated.

While calculating correlations is straightforward for financial assets with observable prices, it is not so for a group of software projects. Projects in a portfolio can have different types of dependencies, due to shared infrastructure and resources, that are hard to identify and measure. The type of dependency determines applicable valuation methods. This represents an important difference from financial portfolio theory where one-dimensional correlation structures with respect to observed prices are sufficient. Therefore existing financial methods (Markowitz, 1952) must be adapted to the software engineering context before they can be applied to relevant decision problems. Böckle et al. (2004) discuss the economics of software product lines from a portfolio perspective based on shared costs and infrastructure, but do not address the risk implications.

Seemingly disparate projects may also have structural dependencies that are deliberate or accidental. For example, successful completion of a pilot project can trigger a much larger project. Conversely, a failed project in an unproven technology can impede parallel initiatives. In these cases, again, the individual components cannot be valued in isolation. Such interactions can sometimes be modeled as a portfolio of options, and analyzed using real options techniques discussed in Sections 3 and 4.

Agency Conflicts and Information Asymmetries

It is also important to be aware of the factors that negatively affect value. Agency conflicts are concerned with misalignment of stakeholder interests, and are a potential source of value destruction at the organizational level. Measures of value at the organizational level are agreed upon by the principal stakeholders, such as the private owners, public shareholders, or the community served by the organization. Information asymmetries lead to differing stakeholder perspectives, which in turn may cause undesirable behavior that negatively affects these measures.

Problems of agency conflicts and closely related information asymmetries play a dominant role in areas such as corporate finance and microeconomics. In corporate finance, corporate governance (Shleifer and Vishny, 1997, Hirschey et al., 2003) addresses resolution of agency conflicts that arise due to the separation of ownership and management. Adam Smith more than 200 years ago concluded that "people tend to look after their own affairs with more care than they use in looking after the affairs of others". Generally speaking, agency conflicts occur if project stakeholders have private incentives that differ from the common project goals. These conflicts are exacerbated by information asymmetries, where certain stakeholders have superior or private information, that is, information more accurate than that available to others or information not available to others at all.

If different stakeholders in a software project (e.g., developers, managers, tester, clients) have different incentives and different access to information, the assessment of value on a department or company level becomes more difficult. In valuation, game theoretic techniques can be used to model these effects and highlight their impact. Sang-Pok Ko et al. (2004) use such a technique to analyze the decision to collect data from software developers given that it takes additional effort and the data might be used to evaluate the same stakeholders who provide the data. They define different strategies and find that if every developer strives to maximize own utility, the result of the group will not be pareto-optimal (the best that could be achieved without disadvantaging at least one stakeholder) although a pareto-optimal solution exists.

An example of agency effects in real options analysis concerns the exercise of abandonment options. Abandonment options that are supposed to kill non-performing projects midstream are sometimes not optimally exercised due to conflicts between short-term interests of managers and long-term corporate goals. These conflicts can be taken into account in valuation through simulation, game-theoretic techniques and augmenting the uncertainty models.

Chapter 7 (Biffl and Grünbacher) addresses agency conflicts and information asymmetries in the context of requirements negotiation.

3.3 Valuation of Uncertain Projects with Decision Trees

When information on benefits, costs and the future states of the world is available, valuation techniques of varying sophistication can exploit the available information in different ways. However, most techniques rely on a foundational method called *Discounted Cash Flow* (DCF) and the fundamental concept of *Net Present Value* to which this method gives rise.

The premise of DCF valuation is to render costs and benefits that occur at different points in the future comparable by adjusting them with an appropriate *discount rate*. The discount rate captures the risk borne the cash flow associated with the future benefit or cost. It is applied to the cash flow just like a compound interest rate, but in reverse, to express the cash flow in *present value* terms. Then a Net Present Value (NPV) can be computed by summing the present value of all estimated cash flows. The NPV tells us the project's *net* worth in today's currency.

We assume that the appropriate discount rates are provided since their determination is beyond the scope of this chapter. Chapter 4 (Harrison) discusses this topic and provides a specific technique that can be used in software projects. Further resources are mentioned in Section 5.

In spite of the universal acceptance of DCF and NPV, managers have often hesitated to use them in practice, citing an inability to integrate the techniques into the strategic planning process. Whereas these techniques are essentially static in nature, reflecting their origins in the valuation of financial instruments, strategic planning is a dynamic process, whereby management must constantly evaluate alternatives and make decisions that condition future scenarios under uncertainty. The need to bring techniques for modeling *active management* into the valuation process has motivated the recent interest in the discipline of real options, which aims to create such a bridge between finance and strategy. We will exploit this relationship by a progression of models of increasing complexity, starting with static NPV and gradually expanding it to handle dynamic decisions and flexibility, first through a decision theoretic approach in this section and then through real options theory in the next.

An Uncertain Project with no Flexibility

As a means of getting acquainted with the principal concepts underlying the real options approach, let us consider the economic analysis of the prospects for a software research and development (R&D) project. R&D projects, by their very nature, have very uncertain prospects. Uncertainty makes the prospects vary over possible states of nature. It is not unusual to have to consider a wide spectrum of such states, or outcomes, ranging from spectacular success to spectacular failure. A value then must be attached to each possible outcome and an expected worth computed by aggregating over all the outcomes. It is not unusual to have to consider a wide spectrum of possible outcomes, ranging from spectacular success to spectacular failure.

Suppose that we are considering an investment of 200 thousand dollars in a software R&D project lasting 5 years. As a first step in an NPV analysis we might characterize the possible economic outcomes of the project as being Best, Normal or Worst, and associate a best estimate and probability with each of them. This effectively models uncertainty.

- 30% probability of a Best economic outcome of 1000K
- 40% probability of a Normal outcome of 500K
- 30% probability of a Worst outcome of 0

We assume that the discount rate associated with the firm's projects is 20% per year ($r_{adr} = 0.2$) and that the risk-free rate of return is 2% her year ($r_f = 0.02$). The rate r_{adr} is referred to as a *risk-adjusted discount rate*; it represents the minimum annual return expected of initiatives of comparable risk. This is the discount rate we use for calculating the present value of the project's future benefits. The rate r_f represents the return expected from an initiative with no systematic risk. This rate can be observed in the markets and given by the return on short-term government bonds. The risk-free rate is used to calculate the present value of future costs that are either certain or whose uncertainty only depends on factors internal or unique to the project.

The NPV of the economic prospects for this project is straightforward to calculate. However, before we proceed, the possible benefits are first weighted by their respective probabilities. Then the weighted benefits are added over all outcomes to calculate an *expected worth*. Having reduced the future benefits to a single cash flow, we are now ready to discount the result. Since the benefits will be realized after 5 years, the expected worth of the benefits is discounted back 5 years using the risk-adjusted rate as a compound interest rate applied in reverse to calculate a present value. The cost of 200K is committed upfront; therefore it does not need to be discounted. Finally the undiscounted cost is deducted from the discounted expected benefit to arrive at an NPV:

$$\mathrm{NPV} = -200 + \frac{1000 \times 30\% + 500 \times 40\% + 0 \times 30\%}{(1+r_{adr})^5} = 0.94\mathrm{K}$$

At NPV of less than a thousand dollars, we should be indifferent about the investment.

Accounting for Staged Outlays

Now we will begin to add some more realism to the scenario. A first step is to be more realistic about the timing of the expenses. Unlike a stock or bond, where the entire investment is made up-front, a project's resources are generally allocated in stages. For example, instead of allocating the entire investment of 200K in one lump sum, we might allocate progressively larger amounts such as:

- 20K in a first stage to develop a nonfunctional prototype to gauge concept feasibility, allocated immediately;
- 80K in a second stage to produce a first release to be beta-tested by users, allocated after one year; and
- 100K in a third stage for full development, allocated after two years.

Not only is this a more realistic allocation scenario, but it also confers an extra advantage: the money for the second and third stages can sit in the bank and earn interest while waiting to be invested in the project. In fact, it would not even be necessary to have all of it available at the beginning of the project. For example, in order to have the 100K dollars available for the second-year investment, it would only be necessary to have
$100/(1 + r_f)^2$ = \$96.12K available at the beginning – the rest would come from the interest earned while waiting. This brings us to a first important observation: an expense incurred later has an economic advantage over the same expense incurred earlier, and the degree of that advantage is linked directly to the risk-free interest rate. With this insight, the new NPV calculation for the example is given in below, where the staged costs are discounted by the risk-free rate, and the benefits at the

end are discounted at the firm's risk-adjusted rate as before. Again, the expected worth is computed for the benefits by aggregating over possible outcomes before proceeding with the NPV calculation. The NPV calculation itself involves discounting the resulting cash flows and summing them.

$$\text{NPV} = -20 + \frac{-80}{\left(1+r_f\right)^1} + \frac{-100}{\left(1+r_f\right)^2} + \frac{1000\times 30\% + 500\times 40\% + 0\times 30\%}{\left(1+r_{adr}\right)^5} = 6.39\text{K}$$

At this point, we can make another observation, concerning the nature of the NPV calculation. Notice that the calculated NPV would have been the same if the corresponding Best, Normal and Worst values had been 600, 500, and 400; or 700, 500, and 300; or even 800, 500, and 200. Why is this? NPV here calculates a single, expected net worth; it throws away any information about how much the different estimates vary from this expected worth. In statistical terms, one could say that NPV calculated based on expected worth of the cash flows preserves the mean, but not the variance. Yet intuitively it seems that a decision maker might want to know something about how far the estimated values vary – if only to have an idea of how uncertain we are about those estimates: if the estimates vary widely, then intuitively this large variation must reflect our degree of uncertainty in our estimates.

One way in which we could retain this information about how far the estimates vary is by switching to a tree-like representation, as in Figure 13. The nodes mark the different funding stages, milestones, or outcomes of the project. The branches denote the state changes.

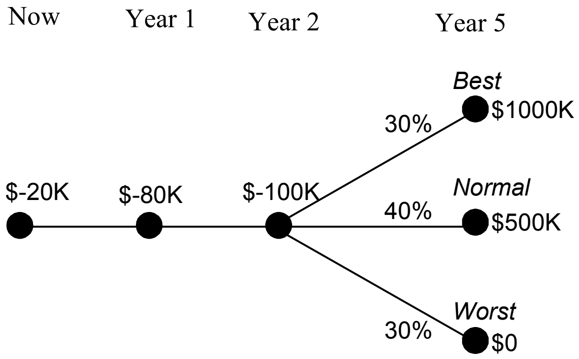

Fig. 13. Representation of uncertainty in the R&D project.

This tree-like representation captures and records visually the differing estimates about the outcome, and so is more useful as an aid to understanding the uncertainty underlying the scenario.

Resolution of Uncertainty

We can further improve the realism of the R&D project scenario. After working for a while on the project – for example, after the end of a first stage – we are more likely to have a better idea of its prospects. By the end of the first stage, we may already be able to judge the prospects as either being *bright* or *dim*. In the optimistic scenario, the probabilities will have remained as we judged in the beginning; whereas in the pessimistic scenario, the probability of a Worst outcome will have increased considerably, at the expense of the probabilities of the Best and Normal outcomes.

The more refined representation in Figure 14 helps us to portray this situation visually, where we have assumed equal probabilities of the future scenario being either bright or dim after the first stage.

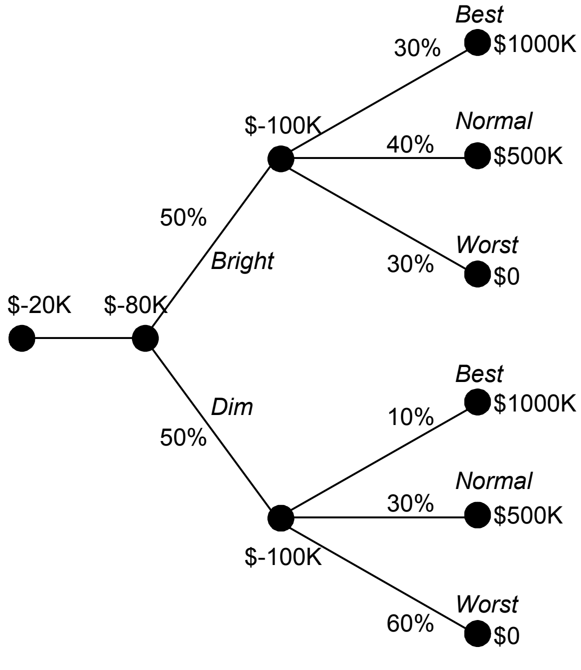

Fig. 14. Refined scenario for the R&D project with Best, Normal, and Worst probabilities conditional on the outcome of the first stage.

Assuming that bright and dim outlooks are equally probable at the end of the first stage, the NPV of the refined scenario now declines significantly below zero, to -43.45K, due to the effects of the *dim* scenario. Yet here again, the NPV calculation doesn't preserve the extra information we have gained from the passage of time, captured in our improved estimates of the relative probabilities of the various outcomes and their variance from the expected worth. Although the passage of time delivers valuable information, traditional NPV still does not incorporate this information in the appropriate way, although our tree-like representation does express it. As a result the NPV now looks worse than ever. More importantly, with the tree-like representation, we can handle the most important element that is still missing from a realistic scenario: the ability to act upon new information. As time passes we do not only acquire information, but we can also act on it: that is, we can make *decisions*.

Incorporating Flexibility through Options

What kind of decision might we take in this scenario? The most obvious would be the decision after each stage concerning whether to continue the project or not. R&D projects notoriously rarely make it to full funding; they are canceled long before, often after the first stage. That is, management has an *option to abandon* the project. We can reflect this decision-making process through a small modification to our tree-like representation, transforming it into a *decision tree*.

Decision trees go beyond NPV by not only representing the occurrence of costs and benefits over time, but by representing the decisions taken by management in reaction to these occurrences. Our original, simple treelike representation is refined by distinguishing different kinds of nodes:

- *Outcome and state change nodes* – similar to those in our original representation, they represent possible outcomes or state changes, with associated probabilities, as we have seen before;
- *Decision nodes* – these nodes represent decision points in the tree, where management can actively intervene;
- *Action nodes* – represent the actions possibly associated with a decision, such as making a further investment outlay.

We now elaborate our scenario further by making explicit the decisions that will be available to management at various stages of project execution. To begin, management has an option to either continue or to stop the project after the first stage depending on the evaluation of the nonfunctional prototype. At that point, management is likely to continue the project only if the prospects are looking bright; if the prospects have turned dim, then the project could be canceled.

Furthermore, we assume that after completion of the second stage, where an initial release of the product is available, we will have accumulated enough information to have a clear idea of what the final outcome of a fully funded project would be – that is, either Best, Normal, or Worst – and be able to put a number on it. At that point, management has another option available to either continue or stop the project. Clearly, the decision will be based on whether the expectation of the final outcome, revealed after the second stage and following the beta-testing on the initial release, will justify the last investment outlay necessary to carry out the project to completion.

The full decision tree capturing this scenario, including all its possible decisions, actions, state changes, and outcomes together with their probabilities, is shown in Figure 15. The leaf nodes represent the final outcomes. The figures inside these nodes represent the associated benefits in present value (already discounted) terms. The corresponding future values (before discounting) are indicated above the nodes. The figures inside the action nodes represent the costs, again in present value terms, associated with the corresponding actions – in this case the additional funding required. The future values of the investment costs are indicated above the action nodes. The bold figures inside the state change and decision nodes are computed as we fold the tree back starting from the leaf nodes.

The fact that the decision tree now includes *options* for decision-making necessitates a change in the way it is evaluated. We must start at the end, and work *backward* through time. At each decision point in the tree, the alternative with the higher assigned worth is chosen as the worth of the project at that decision point.

As an example, consider the $100K funding decision right after the beta testing in Year 2, following an optimistic (bright) evaluation in Year 1. Let's focus on the case where the outlook review in Year 2 after the beta testing predicts a Normal outcome, represented by a benefit estimate of $500K. If the project is fully funded, the remaining net worth of the project after the beta testing will be 201 – 96 = 105K in present value terms. If the project is abandoned at that point, it will be 0. The optimal decision is therefore to proceed, effectively exercising the continuation option. The worth of the project at the decision node consequently equals Max (0, 105) = 105K.

The net worth of the whole decision tree is given by the computed worth of the state change node under Stage 2, minus the seed funding of 20K. The result, 28–20= 8K, represents the dynamic project NPV with the exit options. The project looks much more attractive than it did without the options.

Remarkably, only in the Worst-case scenarios is the project abandoned by exercising the exit option at Stage 3. With the given uncertainty model, the exit option at Stage 2 is never exercised. However a slight increase in the conditional probability of a Worst outcome after a pessimistic (dim) evaluation would trigger the exit option in Stage 2 because the present value of a positive funding decision would be negative.

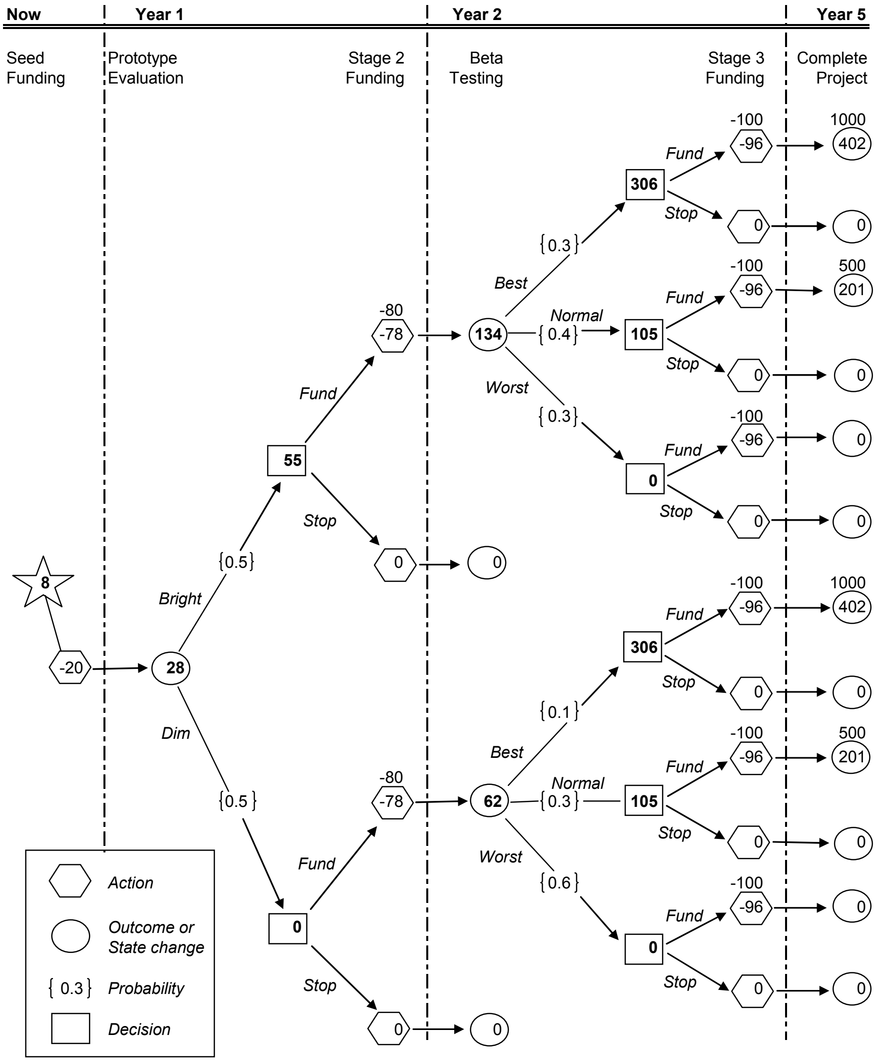

Fig. 15. Full decision tree of the R&D project.

Here what accounts for the more than 50K difference between the static NPV of -43K and the dynamic NPV of 8K is the presence of the options and the ability to exercise them under the right conditions. The exercise of the options prevents the otherwise negative values from propagating toward the root of the decision tree. Consequently, the downside risk is limited, but the upside potential is not affected. The difference between the static and dynamic NPVs is referred to as the *option premium*. This premium represents the additional value, under uncertainty, attributed to managerial flexibility.

3.4 Real Options Theory

The example of the R&D project has highlighted a number of significant points:

- Options for decision-making can be analyzed economically when they are modeled explicitly, as they are in decision trees.
- The passage of time resolves uncertainty and adds more information.
- Less money is needed for the same investment made later in time because of the possibility of earning interest.
- Large variations in possible outcomes make options even more valuable, because the decision maker can choose to exploit the best outcomes and discard the worst outcomes. In contrast, a small variation in possible outcomes makes the decision-making process less important.

We will now see how these points relate to the discipline of *real options*.

Significance of Options

In an environment where uncertainty is high, it is important to have as many options for decision-making as possible, either to exploit opportunities with good prospects or to limit the damage when prospects turn sour. Many of the activities carried out by IT organizations today are in fact targeted at acquiring and exercising strategic flexibility in various forms:

- A firm may have developed or acquired valuable infrastructure technology, such as a set of financial business objects and frameworks giving it the option to enter a new, potentially profitable market of electronic banking (Favaro and Favaro, 1999).
- The human and organizational capabilities developed by a firm may yield strategic options. If it has invested heavily in the recruitment of talented personnel, and invested heavily in training them in component-based development processes, then it may have acquired a strategic option to switch course rapidly in response to changing requirements, improving competitive advantage (Favaro et al., 1998).
- The firm may have created an equally valuable option to get out of an unprofitable market or project by employing IT resources that retain their value even if a project must be stopped. An example would be basing a development project on COTS software that could still be used in another context if the project is halted prematurely. Indeed using COTS components may give rise to a variety of other options of which the firm can take advantage to increase the value of its IT portfolio. COTS components are not only potentially reusable assets, but they also allow upgrading to new technologies at low switching costs (Erdogmus and Vandergraaf, 1999, Erdogmus, 2001).
- When a new technology arrives on the market a firm may decide to wait and see whether the technology matures and is successful in the marketplace before

investing its resources in participating in that market (Favaro, 1999, Erdogmus, 2000).

Each of the scenarios, with their various embedded options, could be modeled with decision tree techniques illustrated, but an alternative theory from the financial community has become available in recent years that more directly supports the analysis of strategic options and their associated flexibility: option pricing theory. One advantage over decision trees of using option pricing theory to analyze dynamically managed decisions is that the analysis can often be represented in a compact, explicit, and more easily understandable form (albeit sometimes at the expense of loss of detail). The theory makes it both possible to classify such decisions conceptually and more straightforward to reason about their behavior. Modeling a dynamic decision explicitly as a specific type of an option improves our understanding of the nature of that decision and how different factors affect its value.

Option Pricing Theory and Real Options

Financial options are special forms of derivative securities—that is, their value depends on the value of an underlying asset. A call option gives the owner the right, but not the obligation, to buy an asset on a specified future expiration date, at a specified strike or exercise price. Similarly, a put option gives the owner the right (but not the obligation) to sell an asset for a specified price on an expiration date in the future. The asset on which an option is defined is called the underlying asset of the option.

Options have been used for nearly three centuries both for speculation and for hedging. Despite their popularity, however, their usefulness was limited by the lack of a rigorous theory of pricing. Such a theory was developed in 1973 by Fisher Black, Myron Scholes, and Robert Merton (winning them the 1997 Nobel Prize in Economics), and led to a new science of financial engineering, whereby derivative instruments are used in many inventive ways to manage risk in investments.

Option pricing theory was first developed for the valuation of income streams from traded financial assets (e.g. stocks). In contrast, real options are intended for the valuation of income streams from projects and other *real assets*. Figure 16 summarizes the parameters associated with financial options, and their mapping to real-world project parameters. Two of the parameters (1 and 4) are familiar from NPV techniques: the estimated present value of the investment's payoffs, and the cost of investment. here

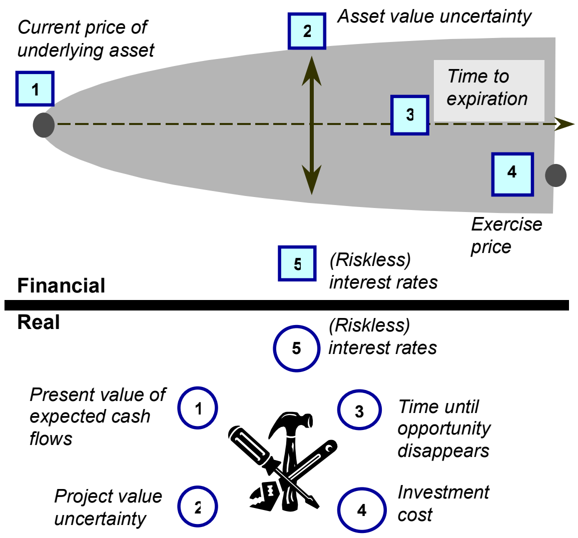

Fig. 16. Financial and Real Option Correspondence.

The remaining three parameters were not as readily identifiable in the decision tree example although they had implicit counterparts:

- The level of uncertainty of the underlying asset, commonly represented by the standard deviation of the asset's return (Parameter 2) – the more variation in an investment's return, the more valuable becomes the option to make decisions concerning that investment.
- The time of the investment decision (Parameter 3) – the passage of time affects the value of an option; the more distant the investment decision from the present time, the higher the uncertainty and the lower the impact of the future investment cost.
- The interest rate (Parameter 5) – the ability to make an investment later in time is like money in the bank, literally, because interest can be earned in the meantime.

Thus, option pricing theory does not *replace* NPV, which remains the point of departure for any serious financial insight, but *augments* it with new reasoning capabilities. The time parameter permits reasoning about when an investment can be made. (NPV implicitly assumes immediate investment.) The standard deviation parameter permits reasoning about the magnitude of the uncertainty of the future evolution of the investment's worth. (NPV permits only calculation of the expected worth of an investment, providing no insight on its variance.) Finally, there is another important characteristic of an option not directly reflected in the parameters: the fact that it is a contingent investment, whereby a decision point is included.

Growth Options

Consider the *growth option*, which is closely related to the option in the decision tree example, where a smaller investment may yield an option to make a larger, profitable investment at a later time. Growth has become the principal preoccupation of many IT companies today. Indeed, the high stock prices of many Internet companies such as Google have been linked to investor expectations of nonlinear growth opportunities (translating into greatly increased future revenues).

Yet many of these same companies are subject to the danger of value-destroying growth. How can a firm pursue aggressive growth strategies while retaining the financial discipline to be sure that its strategy is *increasing* value rather than destroying it?

A typical scenario in the provision of web-based personalized services helps illustrate the point. A major retail investment advisor believes that there may be an enormous future market for customized web-based investment services, including a variety of personalized functionalities that can be configured for each individual client. To prepare for entry into this new market, the company will have to create the infrastructure that permits such rapid configuration. The infrastructure consists of comprehensive object-oriented frameworks, components, and trained personnel, and will be created by an internal project under the code name of StockFrame.

We assume it will take two years and an investment of 80 million dollars to create the infrastructure. At the end of two years, the decision will be made whether to enter the market with a new venture called myStocks, depending on current market conditions. Market entry would involve an investment of 800 million dollars, with a total expected present value of revenues of 600 million dollars. However, a high level of uncertainty is associated with this market assessment: the revenue estimates have historically been subject to an annual percentage fluctuation with a standard deviation of 40%.

This scenario is similar to the one in the decision tree example. Suppose that the StockFrame investment is a pure loss leader, that is, with no cash inflows. Then the NPV of that investment is –80 million dollars. To calculate the NPV of the myStocks venture, we discount the 800 million investment in two years back to the present using the risk-free interest rate (let us assume 4% for this example) to obtain about 740 million dollars. Thus the NPV of myStocks is about 600 – 740 = –140 million dollars.

No value-conscious manager would even begin the StockFrame project based upon these figures. However, a standard deviation of 40% in its possible revenues means that the payoffs to myStock *might* be *much higher* than the expected worth predicted by the plain NPV. The StockFrame investment, even with its negative NPV, provides the opportunity to capture those nonlinear payoffs, and that opportunity has value that is not reflected in the NPV figure. Furthermore, the ability to block all further investment if the outlook dims for myStock is not reflected in the NPV calculation. These ideas are familiar from the decision tree example, but real options provides the opportunity for a compact representation of the scenario and calculation of the value of the option created by StockFrame.

We can make the following correspondence between the key parameters of the scenario and the parameters of the Black-Scholes formula for evaluating a call option:

- The \$600M present value of expected cash flows from the myStock venture corresponds to the current price of the underlying asset in the call option calculation (S). This represents the payoff from the venture.
- The \$800M investment required to undertake the myStock venture corresponds to the exercise price (X).
- The decision point at 2 years corresponds to the expiration date of the call option (t) .
- The estimated 40% standard deviation of the payoff's annual percentage fluctuations has a direct correspondence in the standard deviation of the underlying stock's returns (σ) .
- The risk-free rate of 4% at which all future costs are discounted also finds a direct correspondence in the Black-Scholes formula (r_f).

Assume for this discussion that we have a calculator available for the Black-Scholes formula for a call option that must be exercised on or before the expiration date of the option. Then:

$$BS\_CALL(S = 600, X = 800, t = 2, \sigma = 40\%, r_f = 4\%) = 89\text{M}$$

The call option formula is given by:

$$BS\_CALL(S, X, t, \sigma, r_f) = S \times N(d_1(\frac{S}{PV(X, r_f)}, t, \sigma))$$
$$- PV(X, r_f) \times N(d_2(\frac{S}{PV(X, r_f)}, t, \sigma)),$$

where:

- $d_1(x, t, \sigma) = \dfrac{\ln x + \frac{1}{2}\sigma^2 t}{\sigma\sqrt{t}}$,
- $d_2(x, t, \sigma) = d_1(x, t, \sigma) - \sigma\sqrt{t}$,
- $PV(X, r_f)$ denotes the present value of X discounted using r_f, and
- N denotes the cumulative standardized normal distribution function.

Thus, the execution of the StockFrame project provides the option to decide whether to invest in the myFrame venture after 2 years. Since the option corresponds to an opportunity to delay a decision for two years in the hopes of exploiting the upside scenario of myFrame's future cash flows (this situation is analogous to the Best-case scenario in the decision tree example), it has value – and the Black-Scholes calculation puts a number on that value, at 89 million dollars.

Adding that value to the present value of its own cash flows, we arrive at an augmented NPV of (−80) + 89 = 9 million dollars. This figure only refers to the value of the StockFrame investment, and is linked to the fact that it is part of an overall contingent investment strategy. Nevertheless it provides the necessary justification to undertake the StockFrame investment in order to have the strategic option to contemplate the myStock venture two years later. Based upon this analysis, a value-conscious manager can proceed with the initial, strategic investment with the confidence that financial discipline has been respected.

The call option value is most sensitive to the present value of the payoff S, the future investment cost X, and the uncertainty measure σ. For example, increasing the present value of the payoff by 25% from 600M to 750M increases the option value by over 90%, from 89M to 172M; decreasing the future investment cost by 25% from 800M to 600M increases the option value by over 70% to 153M; and increasing the uncertainty measure by 25% from 40% to 50% increases the option value by close to 40% to 123M. The least sensitive parameters are time to investment decision t and the risk-free interest rate r_f. For example, extending the time to investment decision 25% from 2 years to 2.5 years increases the option value by about 22% to 109M, and increasing the risk-free interest rate by 25% from 4% to 5% increases the option value by only about 5% to 93M.

Abandonment Options

The growth option represents an important class of real option involving the *expansion* of an investment. Another important class of real option involves the *abandonment* of investment. We saw one case in the decision tree example, involving staged projects. In another important case, strategic investment is oriented toward the conservation of business value if the current course must be abandoned.

One such case is COTS-based development, embodied in the notorious “build or buy” decision. The use of COTS in a project is often costlier in the initial outlay than custom development, including cost of purchase or licensing and the associated learning curve and customization issues. But these outlays also bring flexibility: the COTS-based technology can be put to other uses if the venture doesn’t turn out to be as valuable as originally estimated. The extra investment buys a kind of insurance, an opportunity to bail out of a project if its fortunes begin to dim, without losing all of the investment.

As an example, suppose a venture is being contemplated that involves the construction of a specialized database. The present value of all future payoffs from this venture is originally estimated at 40M dollars, but with high uncertainty, represented by a standard deviation of 50%. Management plans to revise the venture’s outlook in 18 months of operation, and decide what to do based upon the revised outlook. A current dilemma concerns whether to develop the database from scratch, specifically for the venture, or whether to purchase a license for a COTS database, and train the personnel to customize it to specifications.

If all goes well with the venture, the cheaper, custom-built solution will provide the maximum economic value; but if the market sours, management will have no choice with a custom solution but to stay the course or lose the entire investment. The cost outlays for the COTS-based solution would be higher by \$3M, a considerable amount; but management believes that the COTS technology and personnel could be redeployed to other uses worth \$30M if the decision to cancel the venture were taken. Although that is still much less than the estimated \$40M payoff of the contemplated venture, it does provide an escape route. The management dilemma essentially boils down to a tradeoff of the extra expense of the COTS-based solution against the value of the option to change course that the COTS solution makes available.

Whereas the growth option could be modeled as a *call* option, this type of scenario corresponds to a *put* option – an option that provides insurance. Assuming the availability of a calculator for the Black-Scholes formula for a put option, we have:

$$BS\_PUT(S = 40, X = 30, t = 1.5, \sigma = 50\%, r_f = 4\%) = 3.5\text{M}\ ,$$

where

$$BS\_PUT\,(S\,, X, t, \sigma, r_f) = BS\_CALL(S\,, X, t, \sigma, r_f) + PV(X, r_f) - S.$$

Thus, the value of the option to decide after 18 months to abandon the project and put the COTS-based technology to another use rather than stay the course is \$3.5M. In this case, the value of that option just exceeds the extra investment necessary to provide it. In another, less uncertain scenario, we might have found that it was better to simply build the system from scratch in the most cost-effective way possible.

Further Reading

The reader can refer to Chapter 4 (Harrison) for more comprehensive discussions of the basic financial concepts that underlie valuation, such as Discounted Cash Flow, Net Present Value, the relationship between risk and return . These concepts are also discussed under the general topics of capital budgeting and risk in Brealey and Myers (2000). Steve Tockey's text on *Return on Software* (Tockey, 2004) is also a good resource that is accessible to software professionals. For a specific focus on cost-benefit analysis, see Layard and Glaister (1994).

The discussion of real options in this chapter has only skimmed the surface of the vast literature on both theory and practice. The seminal paper on option pricing is by Black and Scholes (1973), providing the original rationale for and derivation of the option pricing model. A few years later, an important alternative approach to option pricing, known as the binomial model, was developed by Cox, Ross, and Rubenstein (Cox et al., 1979). The binomial model, together with its risk-neutral approach to option pricing, is not only simpler than the Black-Scholes derivation, but also more flexible with wider application. Both the Black-Scholes and binomial models are expounded with software process examples in a chapter of *Extreme Programming Perspectives* (Erdogmus and Favaro, 2002).

Options can be modeled and valued using classical decision tree techniques, as we have illustrated in this chapter. While this approach allows for richness in terms of handling multiple interdependent options and arbitrary, discrete models of uncertainty, the size of the underlying decision trees increase exponentially with the model complexity. Steve Tockey's text (Tockey, 2004) includes a chapter that provides an overview of decision tree analysis in the context of software engineering.

Going beyond the simplified exposition of decision trees and options, Smith and Nau (1995) explain the precise relationship between option pricing and decision trees, and demonstrate how the two models together can account for both market and private risk. This hybrid technique is exploited in an article by Erdogmus (2002) to value software projects with multiple sources of uncertainty.

On the one hand, in spite of its analytic power, real options has proven challenging to use in the context of software engineering projects. The original derivation of the Black-Scholes formula was based upon the assumption of being able to trade assets continuously – an assumption already considered by some to be questionable for financial assets, and considered by many to be untenable for real assets (such as software projects). The ensuing controversy has prompted the development of option pricing techniques, such as by Dixit and Pindyck (1995), which do not appeal to market-related arguments in their derivation. Techniques based on Monte Carlo simulation (Mun, 2002) later gained popularity for the same reason and for their practicality in valuing options on real assets.

On the other hand, there is a significant community that accepts the essential validity of the Black-Scholes and binomial approaches as a way to determine *idealized value* and points out the considerable advantages of these approaches, such as the avoidance of the need to specify subjective probabilities and enumerate different outcomes. The Black-Scholes model may be used in a compact fashion, with few key parameters that can often be estimated using market or historical data. The reader can consult the *Extreme Programming Perspectives* chapter by Erdogmus & Favaro (2002) for a comparison of real and financial options and a discussion of the portability of the financial option pricing assumptions.

For a high-level treatment of real options outside the software engineering context, we recommend the books by Amram and Kulatalika (1999) and Copeland and Antikarov (2001). The text by Mun (2002) is an excellent technical resource for real options analysis that exploits numeric techniques, such as Monte Carlo simulation and optimization, that do not appeal to market-related arguments. Additional references can be found in the "Further Reading" sidebar of the IEEE Software magazine's May/June 2004 focus issue on *Return on Investment* (Erdogmus et al., 2004).

3.5 Summary and Discussion

A structured valuation process that accounts for costs, benefits, and uncertainty is required to support software professionals and project managers in making value-oriented decisions. Software projects are subject to multiple sources of uncertainty and incorporate additional complexities, such as intangible benefits, flexibility, interactions among projects, and conflicting stakeholder interests that may impact value to various extents. Different techniques including game theory, real options analysis, utility functions, and portfolio-based approaches, exist for dealing with these factors in valuation. These techniques, when appropriately used, can augment traditional methods to help assess the effects when their consequences are deemed significant.

This chapter focused on the natural tension in software projects between the cost of investment in flexibility and the value of the opportunities such flexibility provides. Much of software development is colored by this tension. Multi-tiered system architectures, application frameworks, modular development, and components are examples of providing insurance, of protecting that which does not change from that which does change. The value of that protection is proportional to the probability that change will occur. The real options approach to valuation reveals the underlying drivers – the costs, the benefits, the timeframe of the investment, and above all, the uncertainty surrounding the investment. In doing so, it brings a rational analysis regime to a difficult problem in software engineering: gauging the benefits of flexibility and dynamic decisions in process, product, and project decisions.

This chapter tried to bridge the gap between theory and application by providing both a survey on theory related to valuation and discussing examples using selected valuation techniques beyond the traditional approaches. The chapter illustrates that value-based software engineering faces interesting challenges. Expertise already exists in selected areas, but various promising concepts from finance and economics are waiting to be tailored, integrated, and applied to the area of software development.

The challenges regarding the use of financial and economic methods, such as option pricing theory and portfolio theory, in the VBSE context are their reliance on objective historical data on observed prices of assets and the ability to buy or sell assets in arbitrary quantities. Such objective data is unfortunately often unavailable for software projects. Neither are software projects and software-based assets liquid or tradable in arbitrary proportions. Strategies to cope with these difficulties include using proxies (data on related activities or assets, thought to be correlated with the actual activity or asset of interest) where possible, using simulation-based and other numeric techniques that don't assume tradability (Mun, 2002), relying on subjective estimates where necessary, tailoring the methods to have less demanding data requirements, focusing on sensitivity analysis where reliable data is unavailable, and most importantly, understanding the implications of violating assumptions. The latter point means treating the valuations obtained as reflecting *idealized* rather than *fair* values and focusing on the insights gained rather than the numbers churned.

Data availability and reliability problems however are not unique to software projects and should not be viewed as an obstacle. Table 3 summarizes the difficulties involved with different techniques and the common strategies used to address these difficulties. Examples of the use of available market or project data as proxies in software project valuation can be found in work by Erdogmus (2000, 2001, 2002).

Table 3. Applying financial and economic techniques in VBSE.

Theory or technique	**When to use?** **Main challenges with application in VBSE**	**How challenges alleviated?**
DCF and traditional NPV	Static decisions; no flexibility; no embedded options. 1. Estimation of cash flows. 2. Determination of proper discount rate.	1. Consider multiple scenarios and aggregate. Use subjective estimates. Use sensitivity analysis for unknown cash flows. 2. See Chapter 5.
Decision trees	Dynamic decisions; flexibility; multiple- embedded options; complex structuring of decisions; able to of identify discrete outcomes and associated probabilities; focus on understanding dynamics of multiple nested decisions; multiple interdependent projects with transparent interactions. 1. Same as NPV/DCF. 2. Modeling uncertainty.	1. Same as NPV/DCF. 2. Simplify by considering only most relevant scenarios. Use sensitivity analysis.

Real options and option pricing theory	Dynamic decisions; flexibility; single or few embedded options; simple decision structure conforming to known templates; probability distribution of outcomes unidentifiable; able to represent uncertainty as percentage variation; quick results; focus on understanding impact of valuation parameters. 1. Estimation of uncertainty due to lack of objective data. 2. Non-tradability of software assets & projects when using models with analytic, closed-form solutions such as the Black-Scholes model. 3. Mapping projects to option pricing problems.	1. Use market proxies and private data from past projects when available. Use industry benchmarks. Use sensitivity analysis. 2. Interpret results as "idealized values". Model options using simple decision trees if necessary. Use simulation- based or other numeric techniques that don't assume tradability (Mun, 2002). 3. Simplify scenarios by considering only the most significant options (earliest, with largest and most uncertain payoffs). Consider most important milestones only and fit into existing templates when possible.
Utility theory	Need to factor in decision-maker preferences and attitudes for risk. 1. Identification of utility functions.	1. Use known techniques for eliciting utility of stakeholders when practical . Use standardized functions when necessary. See Chapter 4.

Portfolio theory	Multiple interdependent projects whose interactions are generally identifiable as positive or negative correlations among project returns; focus on optimal allocation of resources among alternative activities. 1. Determination correlations among projects due to lack of objective data. 2. Projects resources cannot be allocated in arbitrary quantities.	1. Use proxies when possible. 2. Tailor to handle “all or none” type resource allocation; use optimization techniques (Mun, 2002).

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