Using Real Options to Quantify Portfolio Value in Business Cases

George O. Bayer, Jr.

March 27, 2017

Contents

Abstract

With the challenges in quantifying program risks, interdependencies, and the business case impact on portfolios, cost estimators can use real options to estimate probabilistic value in business cases and assess portfolio value. Many business cases not only add value as stand-alone investments, but they provide the opportunity for subsequent investments. Cost estimators can measure this incremental program value and the impact of a specific investment on a larger portfolio by using real options.

1 Introduction

Over the last several years, the Federal Aviation Administration (FAA) has invested billions of dollars into the National Airspace (NAS) in order to (1) replace the aging infrastructure of communication, navigation, automation, and surveillance systems using old or outdated technology and (2) modernize the airspace with next generation (NextGen) of air traffic control systems to more accurately and efficiently navigate aircraft with less dependency on ground-based radar systems and pre-determined way points. During that period of time, the agency implemented a cost-benefit analysis system and investment valuation threshold and set guidance for all new capital investments to demonstrate value in order to receive funding. These valuation requirements help the agency differentiate between investments and acquisitions with positive incremental value to the NAS and those which do not provide sufficient value for funding with limited capital resources.

The FAA's capital budgeting process is stringent and adopts the best finance valuation practices of the private sector while accounting for safety considerations and benefits to all stakeholders, including the flying public.

In order to ensure value thresholds are met, costs do not exceed baselines, and benefits can be realized, the FAA adjusts all estimates conservatively for risk. In addition, the agency groups acquisitions currently in investment analysis or in development within functional portfolios, usually where program interdependencies have been identified and where common problems or shortfalls are being addressed.

With all the attention devoted to identifying and mitigating program and portfolio risk, after deployment some investments still do not meet planned targets, while other investments perform better than anticipated. Adding to program complexity, capital investment program portfolios not only have multiple program interdependencies, but timeline and agency funding fluctuations require scheduling flexibility, requiring individual programs to adjust when scheduling targets cannot be achieved. Given the required long-lead times for the acquisition process, program flexibility and especially portfolio flexibility is difficult to implement.

While government agencies like the FAA are skilled at identifying and applying downside risk, they are challenged to identify opportunities for program upsides. The application of Real Options allows for agencies and decision-makers to better understand and realize opportunities within uncertainty, to make better informed decisions with the flexibility to make program changes as more information is revealed, and to better sequence capital investments to maximize potential value (maximize benefits

and minimize costs). Where large capital investment portfolios in government agencies have multiple interdependencies, limited capital allocations, and uncertainty for success, real options provide a tangible process for quantifying upside risk and maximizing portfolio value.

2   Government Business Cases

2.1   Government Capital Investments & Value Quantification

In many government agencies, large capital investments in information technology, infrastructure, new technologies, or new capabilities are valued mostly with attention to cost estimating and cost savings. In many cases, less time is devoted to the quantification and monetization of capital investment or program benefits. However, some civilian agencies require a combined cost-benefit analysis using associated Finance metrics, like Net Present Value (NPV), payback, Internal Rate of Return (IRR), and Benefit/Cost (B/C) ratio, in order to justify the investment. In these circumstances, special attention is devoted to the monetization of benefits, much like capital investments at private sector companies.

In the private sector, companies conduct discounted cash flow (DCF) valuations of capital investments, where investment outlays are offset by revenue in out years. Capital investment rates of return must exceed company-determined hurdle rates and have positive NPVs in order to be valuable investments. Furthermore, these company capital investments are assessed across a portfolio of investments, and managers must decide which investments to fund that fit within limited annual capital budgets.

What is often missed within these investments in both the government and private sector is the uncertain upside potential of each investment opportunity. Many capital investments are not stand-alone. Instead, they contain a network of interdependencies with other investments. Certain investments provide more upside potential and portfolio value than others, and if this value is not considered, the best investment opportunity may not be chosen.

For civilian government agencies which consider both cost and benefits for capital investments or acquisitions, analysts quantify and monetize benefits to the agency, to stakeholders, and to the public. First, the analysts determine and quantify the problem or program shortfall, the reason why the investment is required in the first place. Then, the analyst will narrow down the shortfall to the portion that the capital investment will resolve, the benefits to the program. These quantified benefits are used to offset program costs.

2.2   Finance Value in Business Cases

2.2.1   Discounted Cash Flow (DCF) Analysis and Net Present Value (NPV)

In agencies conducting cost-benefit analyses, how is value quantified? Just like the build-up of an independent government cost estimate (IGCE), the agency calculates benefits value to the agency and stakeholders – (1) cost avoidance by implementing an infrastructure program that is more efficient than the legacy system it is replacing, (2) time savings provided by a new technology that enables users to do their jobs quicker, or (3) a new technology which provides quicker transportation and saves time for the general public and direct operating costs for service providers. All of these examples can be quantified and provide program value from which the analyst can offset investment costs.

Just like companies in the private sector, value incorporating both cost and benefits are measured according to popular Finance metrics, including NPV and IRR. A positive NPV or an IRR greater than the cost of capital means that, assuming unrestrained capital funding, the project provides value, and the agency should invest in that project.

When calculating value, both benefits and costs are discounted in order to represent present value (PV) of the investment. PV uses a specific discount rate, the long-term government bond rate in government agencies or the company or project cost of capital in the private sector to discount nominal or real dollar benefits and costs. PV discounts for inflation, incorporates the time value of money, and accounts for the opportunity cost of capital.

In total, value for many civil agency capital investments accounts for both program benefits and costs. Both benefits and costs are discounted and risk-adjusted to calculate a project NPV to inform the agency whether or not the investment has economic value. While project value calculated via discounted cost and benefits accounts for investment risks, the program upside opportunities, integration with other capital investments, and portfolio impact are not captured.

2.2.2   Drawbacks of Using NPV and other Finance Metrics for Government Acquisitions/Projects

When evaluating major capital investments or acquisitions, agencies pay special attention to risk. Not only are agencies concerned about the risks associated with implementation, but when conducting investment analysis, risks of cost overruns and unrealized benefits take precedence. Management champion any valuation method that allows them to mitigate these risks, and government agencies continue to developed processes to ensure accuracy and to minimize surprises.

Both cost estimates and quantified benefits are risk-adjusted and discounted to account for downside program risk. Analysts risk-adjust cost estimates to account for uncertainty factors which might drive project costs up. While risk ranges for cost WBS elements represent the uncertainty of both cost increases and decreases, the risk-adjusted cost almost always exceeds that of a point estimate. Similarly, analysts risk-adjust benefits to account for factors that may prohibit all potential benefits from being realized. As a result, mostly downside risk is captured for both benefits and costs.

To apply risk in business cases, the government agencies apply risk range conditions when calculating valuation metrics. To better inform decision-makers about the financial impact of project risk, instead of just calculating a point estimate, analysts risk-adjust benefits and costs using Monte Carlo Simulations. After running risk, the government applies the most conservative Monte Carlo risk ranges, the 80th percentile of costs and the 20th percentile of benefits. By applying these conservative values, assuming that the business case has a sound basis of estimate, the government assures a high probability of not exceeding the 80th percentile cost estimate and a low probability of achieving fewer benefits than what was quantified at the 20th percentile.

Since it is difficult to measure uncertainty when quantifying costs and benefits, government civilian agencies endorse this conservative risk-adjustment approach to reassure government decision-makers that the business case will deliver the value that it proposes. It essentially takes a pessimistic view versus the base case valuation of the capital investment and lowers the bar of performance in the rare event where a business case will realize a higher cost as well as lower benefits. Despite this approach,

public sector business cases sometimes still breach baselines and have cost overruns, but this is partly attributable to the complexity and scope of major federal government acquisitions and the proprietary nature of the business cases.

Often lost in risk-adjusted value is a way to quantify potential upside risk, risk where under certain conditions, benefits might exceed the initial point estimate. Other examples of upside risk not captured by the NPV investment analysis approach include (1) risk where one investment might inform another allowing managers to adjust requirements and cost allocations and realize additional value and (2) risk where not all capital has to be obligated and future phases of poorly performing investments can be cancelled or delayed. Although these risks are not captured in traditional government cost-benefit analyses, the application of real options allows managers to explore these upside opportunities.

2.2.3   Why Do We Need a New Way to Measure Value in Government Acquisitions?

For both public and private sector capital investments, finance professionals measure value by estimating project cost and revenue (or cash flow), applying risk, and discounting the investments by the cost of capital. This is the best capital budgeting methodology for stand-alone projects. However, most government capital investments and acquisitions are not stand-alone investments. For each investment decision, there are subsequent investments that contain interdependencies with the initial investment or which impact the same strategic portfolio. As a result, there is a cascading effect to existing operations. Investment success is not restricted to the development and deployment success of an individual investment. Instead, the impact that investment has on future investments and operations has a more lasting effect.

2.2.3.1   Undervaluing Investments

When government agencies estimate the value of an investment, they assume that programs will realize the benefits that were estimated during investment analysis. The degree to which these benefits are realized is tempered by risk factors and measured by running Monte Carlo simulations on the costs and benefits. Assuming all project benefits are realized, and the program is a success, did the agency account for all of the program benefits and impacts?

Are there additional benefits that the program might enable if successful? Is this specific acquisition a "platform investment" for subsequent acquisitions and capital investments? Would these follow-on investments be achievable without the first investment's deployment success? If incremental future value is dependent upon a specific government capital investment or acquisition to enable value from follow-on investments or a series of investments, discounted cash flow (DCF) analysis and project NPV alone do not capture that value. Essentially, the agency would be leaving value on the table by not accounting for the incremental value of enabling follow-on investments.

In addition, when considering between mutually exclusive investments, where with limited capital resources, the agency must decide between two investments because it cannot afford both, not accounting for this incremental enabling value might artificially discount or impair the total value of an acquisition. Without accounting for this additional subsequent value, agencies might mistakenly fund a less valuable investment.

2.2.3.2   Value to the Portfolio

While some government acquisitions might enable value for subsequent investments, almost all acquisitions have a portfolio impact. By simply calculating present value benefits and costs, agencies do not account for the portfolio impact of a single investment or a series of investments. Using DCF analysis and NPV to measure investment value will accurately measure value of a stand-alone investment. However, this approach does not accurately account for upside opportunity or the aggregate impact on portfolio value.

Related programs within a portfolio often have interdependencies. Software interfaces between programs must be developed within a specific timeframe, or deployment could be delayed and benefits unrealized. If one program is dependent upon the success of another prior to deployment, a reduction in scope of the initial investment could result in additional costs for subsequent investments. Even investment sequence can determine portfolio value and upside. Investments out of sequence can impair the upside value of a portfolio and delay an agency's strategic objectives.

3   Real Options in Business Cases

3.1   What are Real Options?

3.1.1   Definition

A "real option is a choice made available with business investment opportunities" (Investopedia, 2017). Like financial options, real options provide "the right but not the obligation to invest in a project" (van Putten & MacMillan, 2004). Unlike financial options, real options are tangible assets, real decisions, i.e., obligating the development of a software development program or building a radar system. For capital investments, real options are the opportunity to make further or follow-on investments. The initial investment opens the door to that opportunity or option.

3.1.2   Project Valuation

Traditional DCF and NPV valuation techniques are used in government acquisitions to measure the value of business cases. In large companies, when valuing capital investments, NPV is measured as discounted net cash flow (DCF). In government, civilian agencies, value is measured as the net of discounted and risk-adjusted lifecycle costs and program benefits. If discounted benefits exceed costs, the project has value (B/C ratio is greater than one), and assuming no capital spending constraints, the government agency should invest in the project. By discounting costs and benefits, analysts account for the potential downside value of risk.

For stand-alone projects measured by NPV, uncertainty is exclusively skewed to the downside, measuring for risk. However, just accounting for downside risk might cause decision-makers to miss valuable opportunities before they can be properly assessed.

3.1.3   Real Options in Project Valuation

Real options take valuation a step further and help analysts and decision-makers measure potential upside risks of investments. A real option project provides decision-makers with the option to make a potentially valuable follow-on investment. For example, if the FAA invests in Project Alpha, after two years, they will have the option to invest in Project Beta. The opportunity to invest in potentially valuable Project Beta is only made possible by first investing in Project Alpha. Without investment in the

initial project, the option to invest in subsequent dependent projects would not exist. In summary, real options measure the opportunity to realize value of subsequent investments or program segments and identify probabilistic incremental project value that the initial capital investment would enable. NPV alone does not capture this potential upside risk. Real options provide a means of measuring upside uncertainty without exposing investments to additional downside risk.

3.1.4   Real Options in Portfolios

By using real options to value capital investments and government acquisitions, analysts can draw inferences and correlation between like investments and investment portfolios. Often individual investments are part of a larger strategic portfolio of investments and have interdependencies between them. By segmenting initial investments decision-makers can make better informed decisions about follow-on segments, follow-on investments, and a total portfolio of investments. In Strategic Risk Taking, Damodaran (Chapter 8 Real Options, 2017, p. 2) states, "the value of real options stems from the fact that when investing in risky assets, we can learn from observing what happens in the real world and adapting our behavior to increase our potential upside from the investment and to decrease the possible downside."

The real option approach to capital investments or government acquisition decisions provides better insight into the value of projects and the value of an entire portfolio of projects. Real options permit managerial and portfolio flexibility and provide the context of strategic value for the whole portfolio, rather than an isolated investment or acquisition value (Actuary, 2005).

3.1.5   Used in Finance and Fortune 500 Companies to Estimate Future Additive Value for Follow-On Investments or Portfolios of Investments

In the private sector, Fortune 500 companies devote Finance, business development, engineering, and legal resources to evaluate potential capital investment opportunities to growth their businesses organically. Outside of merger and acquisition activities, capital budgeting (investing in capital projects) is the largest source of new business growth. Some industries, especially energy companies, use real options to consider incremental upside value in capital projects or to measure the complete value of an investment portfolio.

3.1.5.1   Private Sector Real Options Example

When considering an investment in a brown field power generation project, an energy company would project the revenue, expenses, cost of capital, and tax impacts on project cash flow and calculate the project's NPV. The company might take the analysis further and determine whether or not the initial power generation project opens markets for the company and allows the company to potentially expand the power generation once the plant is built to monetize potential natural gas reserves the company has in the area.

The initial project developing a new power plant provides a real option for power plant expansion to monetize natural gas reserves. If the company chooses not to invest in the initial power plant construction, they lose the real option to expand the power plant's production and use its own natural gas to fuel the plant.

Private industry business development departments also correlate like investments or strategic geographic assets and investments into portfolios. Certain strategic capital investments like the building of a gas-fired power plant could enable real option value to complement the company's downstream

refinery portfolio. Refinery companies often invest in their own cogeneration power plants to provide power to their own facilities to hedge power costs and take advantage of plant generated heat, turning it into power.

An individual power plant investment might have many times its value in contributions to a larger portfolio than it does as a stand-alone investment. Without taking into consideration the capital investment's real option value and impact on an entire portfolio, decision-makers may underestimate the project's full potential and risk missing important investment opportunities. Government agencies make equally large investments and can use real options to realize incremental portfolio value.

3.2   How Do Real Options Add Value & Insight for Government Acquisitions?

3.2.1   NPV and Real Options are Complementary

How are valuing government capital investment projects enhanced by using real options rather than simply applying the current practices of estimating risk-adjusted costs and benefits measured with NPV? Real options allow managers and decision-makers to "recapture some of the value lost through the conservative DCF valuation while still protecting against the considerable risks of pursuing highly uncertain projects" (van Putten & MacMillan, 2004, p. 3).

For government acquisitions, this means, by using real options, agencies can better estimate the upside value or enabling value brought about by specific investments. And, they can recognize the potential additional value a project brings to a larger portfolio.

DCF analysis and real options are complementary (van Putten & MacMillan, 2004, p. 4). NPV with DCF analysis measures an estimate of value (benefits and costs). Real options valuation measures the "positive potential of uncertainty" (van Putten & MacMillan, 2004). This new combined value is realized in Formula 1.

Formula 1: Total Project Value Using Real Options

$$Total\ Project\ Value\ (TPV) = NPV + \text{Real Option Value}$$

In the formula, for government acquisitions, the analyst would estimate the project NPV as a sum of risk-adjusted discounted benefits and costs and then add the additional real option value if the investment enables future investments or investment decision-making. This upside value measured by real option value provides strategic context. How does this investment impact the entire acquisition portfolio? How does the sequence of government acquisitions influence portfolio value and how could it be optimized? Is there a potential for additional value that this initial investment provides to the agency?

While there may be initial hesitancy for government agencies to adopt the use of real options in capital investment decisions and in portfolio analysis since real options apply concepts of "financial options to complex business projects," agencies that rely on DCF cost-benefit analyses exclusively "for valuing their projects fall inevitably into the trap of underestimating the value of their projects and consequently don't invest enough in uncertain but highly promising opportunities (van Putten & MacMillan, 2004, p. 1)." The benefits of using real options to value government capital investments far exceed the drawbacks.

3.2.2 Four Investment Options for Realizing Real Option Value

According to "The Real Options Approach to Capital Investment Projects" in The Actuary magazine, real options can realize project value by providing the following (Actuary, 2005):

(1) The option to make follow-on investments,
(2) The option to abandon a project,
(3) The option to wait before investing or delay investment,
(4) And the option to vary output, deployment, or production.

Essentially, real options provide investment decision-makers with the flexibility to expand, abandon, delay, or vary the quantity or magnitude of an investment or portfolio without committing too much up front. Real options can provide government agencies, as they do for oil companies, manufacturing companies, and high tech companies, with better informed decisions and the flexibility to react differently with better information.

3.2.2.1 Option to Make Follow-On Investments (Expand)

For capital investments and acquisitions in government civilian agencies, real options value can be realized primarily by the option the to invest in follow-on acquisitions or program segments. Real options are not always applicable to government investments, but for those capital projects in which investment in the initial project or segment enables the option to have a follow-on segment or investment, real options can provide incremental value.

For example, consider an investment in a FAA IT infrastructure program where new software interfaces provide additional information to air traffic controllers. Controllers could use this information at their positions to inform pilots and reroute planes to take more fuel-efficient paths around approaching weather systems. If the FAA is considering new advancements in weather tracking systems, investing in the IT infrastructure program first would enable the value of new investments in weather tracking systems. If the FAA invests in the IT infrastructure program, it would provide the agency with a real option to invest in new advancements in weather tracking systems that would better inform controllers. If the FAA did not choose to invest in the IT infrastructure program, any further investments in weather tracking would not provide value to air traffic controllers.

This is an example of how an initial investment provides a real option for subsequent potentially valuable follow-on investments.

3.2.2.2 Option to Abandon Project (Abandon)

Real options also provide government agencies with the opportunity to react to changing market conditions, and if the future outlook or value of a project diminishes, real options allow decision-makers to abandon a project and not invest any further capital.

In many agencies, investments obligate full program funds upfront. However, in segmented projects or when considering a number of interrelated investments in a portfolio, the real options approach allows the agency to change course and not continue to invest or obligate capital to programs which no longer provide value to the agency.

3.2.2.3   Option to Wait Before Investing (Delay)

For investments where not enough information is known or the value of deploying an operational system cannot be determined, an agency can develop a prototype and test the prototype before committing to an entire system. Real options provide a method of monetizing the value of potential subsequent investments without obligating the full investment funds.

For investment decisions with dependencies on other programs also in development, sometimes delaying an investment in order to coordinate with other investments with uncertain deployment times will add value. If deploying the system too early and before dependent programs are ready, value may be diminished or unrealized. Real option valuation provides decision-makers with a means of realizing the value of a program delay.

3.2.2.4   Option to Vary a Project's Output, Deployment, or Production (Variable Quantity)

Changing risk profiles of capital investments adds to the uncertainty of program value, and NPV does not capture that future uncertainty. If a program value declines over time and with changing technologies or market conditions, agencies can realize additional value by modifying production to meet the needs of stakeholders.

In programs where project output, production, or deployment can vary, real option valuation monetizes the value of choosing different deployment options and provides agencies with better insight into the full potential value of a capital investment. When considering the impact a program has on an overall strategic investment portfolio, variable output or deployment scenarios can be helpful in estimating the total impact an investment might have on the larger portfolio, providing a weighted average incremental value for the investment that changes over time as uncertainty changes.

Using real option valuation, government agencies can add flexibility to capital investment strategy and find a scalable, optimal mix and sequence of investments that maximizes portfolio value to stakeholders.

3.2.3   Strategic Challenge for Government Acquisitions

As defined earlier, one of the ways companies and government agencies can realize value through the use of real options is by exercising the option of abandoning the project. An initial investment or portion of an investment might reveal better data about a project's viability and return on investment. Decision-makers might not have to obligate funds for an entire project or acquisition, and they could limit risk, by affording themselves with this choice – the real option of abandonment.

Since real options provide decision-makers with the option to realize value by exiting an investment or acquisition without obligating the full cost of the project, this exiting real option value can only be realized if major government acquisitions are segmented or phased. If the acquisitions are designed in segments or phases, the agency has the option to withdraw from a project commitment and not invest in phase 2 before obligating the full cost of the project. In some government agencies, this may require a new strategic approach toward large government acquisitions. There are trade-offs to segmenting a program: (1) potentially slowing down design, development, and implementation by establishing a prototype or by limiting deployment, (2) risking a delay of entry into a market or delaying full functionality of a capability for stakeholders, and (3) adding design expense to total project cost in additional phases. However, by applying segmentation, decision-makers can limit value uncertainty (cost and benefits) before committing to full funding, permitting an exit strategy.

3.3   Why Do We Need to Use Real Options in Business Cases?

While discounted cash flow (DCF) and NPV analysis accurately assess the cost-benefit value of an individual investment and account for the risk of cost growth, these project valuation methodologies do not account for potential upside value associated with uncertainty in business cases. Without a means of capturing that upside value, finance managers and project decision-makers might reject business cases which have incremental value for follow-on investments or project segments and strategic value for a project investment portfolio. Real option valuation bridges the gap between NPV value and project risk and helps managers make better informed investment decisions.

3.3.1   Measure Additional Value Not Captured by Net of Cost and Benefits

Using real options, analysts can use additional use additional knowledge gained during investment analysis to take one of four major actions to increase project value:

(1) **Follow-on Investments**

The agency can choose to make a follow-on investment or a second segment of the capital investment. If by only making the initial capital investment in segment one could the agency invest in a subsequent investment, then investing in the initial investment provides the agency with real option value to invest again. It is up to the agency whether or not it wants to exercise that option to invest again, and by the time the agency wishes to make that decision with the knowledge obtained by the first investment, uncertainty in the follow-on investments would be reduced and value more easily assessed. We will explore how to calculate real option value for follow-on investments extensively in Section 4.

(2) **Option to Abandon**

Assuming an agency segments its high-risk capital investments or business cases to limit risk and not overcommit capital, by investing in the first segment the knowledge of the program's feasibility and benefits value will be clearer before the agency decides to invest further. The option to abandon a project after the initial capital investment limits the downside and obligated risk the agency is willing to take.

(3) **Wait before Investing**

Similar to the abandon real option, the agency can wait and see how the first segment, a program prototype, or even other similar industry or agency investments perform before committing capital to a business case. Sometimes the limited capital required to develop a prototype or software tool in agile development can better inform an agency about the potential value of a program to the agency and users before obligating scarce funds and resources.

(4) **Vary Project Output**

Finally, for some business cases option value is determined by real options through reassessments of production volumes before committing to a fixed scope of work. Agencies can write contracts for services for an initial period and then have follow-on option periods to assess

whether or not the continuation or the specific volume or scope still meets the agency's needs. The agency could exercise an option to expand or contract project output, mitigating the uncertainty at the outset of the investment.

3.3.2   Enabling Value for Other Business Cases

Real options can provide agencies more value than that which is isolated to individual investments. Business cases which have dependencies on other investments or which are dependent on the successful implementation of other investments can realize value by choosing or not choosing different phased implementation strategies to gather more information about these program dependencies before obligation. Agencies might wait for the programs on which they are dependent to enter deployment before investing or choose other mitigating options. To assess project value, analysts can quantify the probabilistic value of each dependency and its impact on the dependent program.

3.3.3   Portfolio Value – Sequence, Probability, Strategy

Just as individual capital investments can use real options to assign value to interdependency risks, a portfolio of programs can be valued together using different investment scenarios. In order to calculate option value for a portfolio, risks and interdependencies between programs should be mapped out, and analysts can use decision trees to estimate the probability and value of each sequential investment decision for all upcoming business cases in that portfolio.

The sequence and implementation timing of different investments in a portfolio and the option to change that sequence can add or subtract value to an agency's investment portfolio by minimizing or maximizing investment risk. By using real options to assess portfolio value under different deployment scenarios, agencies can optimize investment portfolio value.

3.4   Problems with How Real Options Are Applied

Despite the complementary value of real option valuation combined with NPV as defined in Formula 1, there are problems with real option application.

First, analysts calculating real options focus on risks associated with revenues as opposed to risks around costs (van Putten & MacMillan, 2004). However, since NPV in discounted cash flow analysis focuses primarily on cost risk, the combination of NPV and real option value account for cost and benefit uncertainty. While not usually a consideration in government agencies, if a project or investment fails to perform and add value, in the event of abandonment, the remaining asset can be sold or traded.

Another major error in real option valuation is the application of uncertainty in option value. Although increased uncertainty can increase the potential upside value of potential benefits of a business case, that same level of uncertainty applied as cost volatility should equally reduce option value. If a business case has a substantial chance of realizing higher costs, that should reduce or offset the real option value. Also, historically for government business cases, where unexpected benefits are less likely to be realized, cost overruns, schedule delays, and implementation challenges are more frequently realized in large government acquisitions.

3.5   When to Use Real Option Valuation in Government Business Cases

The Harvard Business Review's article, "Making Real Options Really Work" describes and illustrates when to use and not use real option valuation (2004). In Figure 1, where the x-axis is uncertainty and the y-axis total project value, van Putten and MacMillan (2004) define the value of a project over time and

the source of that value – NPV versus Real Option Value. Also in the graph, analysts can determine as outlined in a grid which projects in which business cases real option value should be applied and in which business cases the valuation is unnecessary.

Figure 1: Total Project Value
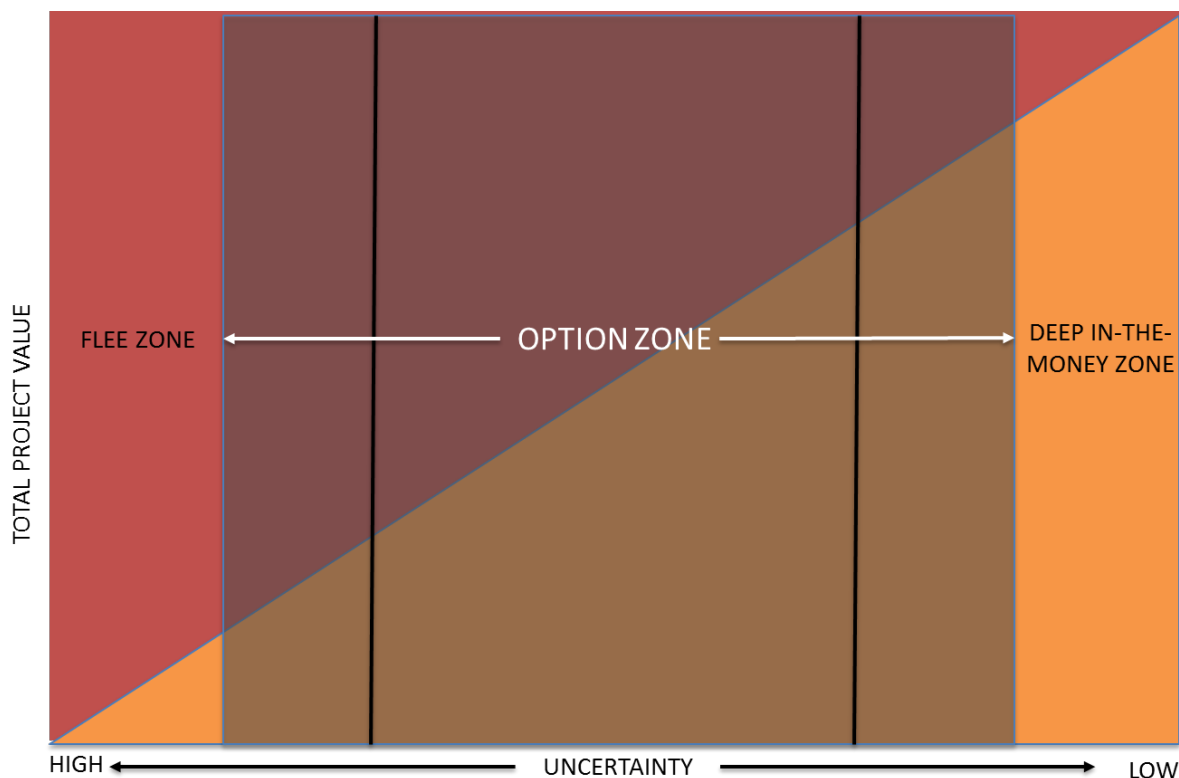
At the beginning of a project, most of total project value is attributed to real option value (as opposed to NPV), which measures the upside uncertainty. Since the risk-adjusted business case is discounted more pronouncedly in the beginning of investment analysis due to high uncertainty, NPV value is lower. At a later time (either late in investment analysis, after prototyping, or in a follow-on segment), risk associated with project uncertainty is lower, so NPV is higher, and real option value is lower. In two cases for capital investments, it is unnecessary to calculate real option value at all:

(1) If the DCF component of valuation is high, and the project has high benefits much in excess of costs (B/C ration greater than 1.5 or NPV significantly greater than zero), the project value is almost assured, and calculating real option value to bolster the value of the business case is unnecessary. In Figure 1, this is represented in the section on the right that van Putten and MacMillan define as the "deep-in-the-money zone" (2004).

(2) Conversely, if a project's NPV is very negative, and risk adjusted discounted costs far outweigh the risk-adjusted discounted benefits, the analyst should not bother calculating option value,

and the agency should reject the project outright. Van Putten and MacMillan define these kinds of investments in the left side of Figure 1 as "the flee zone" (2004).

Projects that fall in between the "flee zone" and the "deep-in-the-money zone," the majority of all business cases, should be evaluated by calculating both project NPV and real option value. HBR refers to investments that fall between flee and in-the-money as "the option zone" (van Putten & MacMillan, 2004).

There are some exceptions to the traditionally defined flee zone for government agencies as certain value factors can outweigh Finance measures of value. In the case of the FAA, safety projects do not require a positive NPV or high option value in order to be considered. They can simply reduce the chance of a safety accident or reduce the likelihood of a high-risk event from occurring, that which exceeds a certain threshold of manageable risk.

Since air traffic accidents are so rare in modern aviation, it is difficult to monetize accident avoidance benefits for FAA business cases. The FAA and other civilian agencies also are more lenient when evaluating infrastructure projects that replace aging IT operations of hardware or software, and even if Finance metrics like NPV and B/C ratio are not positive for the investment, the agency might endorse the investment simply because there is no tolerance for system failure.

4 Calculating Real Options in Business Cases and Program Portfolios

Unlike the traditional discounted cash flow (DCF) or NPV analysis that Fortune 500 companies and some government civilian agencies use to measure value of capital investments, real options provide another layer of value by measuring the upside potential of uncertainty, quantifying risk by calculating the value of a series of probabilistic-weighted investment decisions.

4.1 Influence Diagrams and Value

In order to understand the application of real options in business cases, analysts must first understand the use of diagrams to depict the business case decision process and value drivers. To determine real option value in government business cases, analysts most often apply decision trees, binomial decisions, and probabilistic-weighted investment decisions to business cases.

Diagrams are important visual aids and can be used as strategic methods of documenting the value of decision-making. In 2000, when I started working as an Economist in Investment Appraisal at ConocoPhillips, for each business case and capital investment decision, I began by documenting value through influence diagrams.

In business case economics, influence diagrams are developed to trace back investment value to each value input through a visual flow diagram. To develop an influence diagram, an investment starts with total investment value or project NPV. Then, NPV is broken down into revenue, costs, discount rate, and escalation. For government business cases, business cases substitute benefits for revenue. As each component of the diagram is broken down further, the individual driver of value becomes more detailed or specific. Influence diagrams are best constructed as a brainstorming exercise with all team members contributing in a room so that all stakeholders are heard and to account for all value drivers (See Figure 2 – Influence Diagram).

Figure 2: Influence Diagram – Energy Example
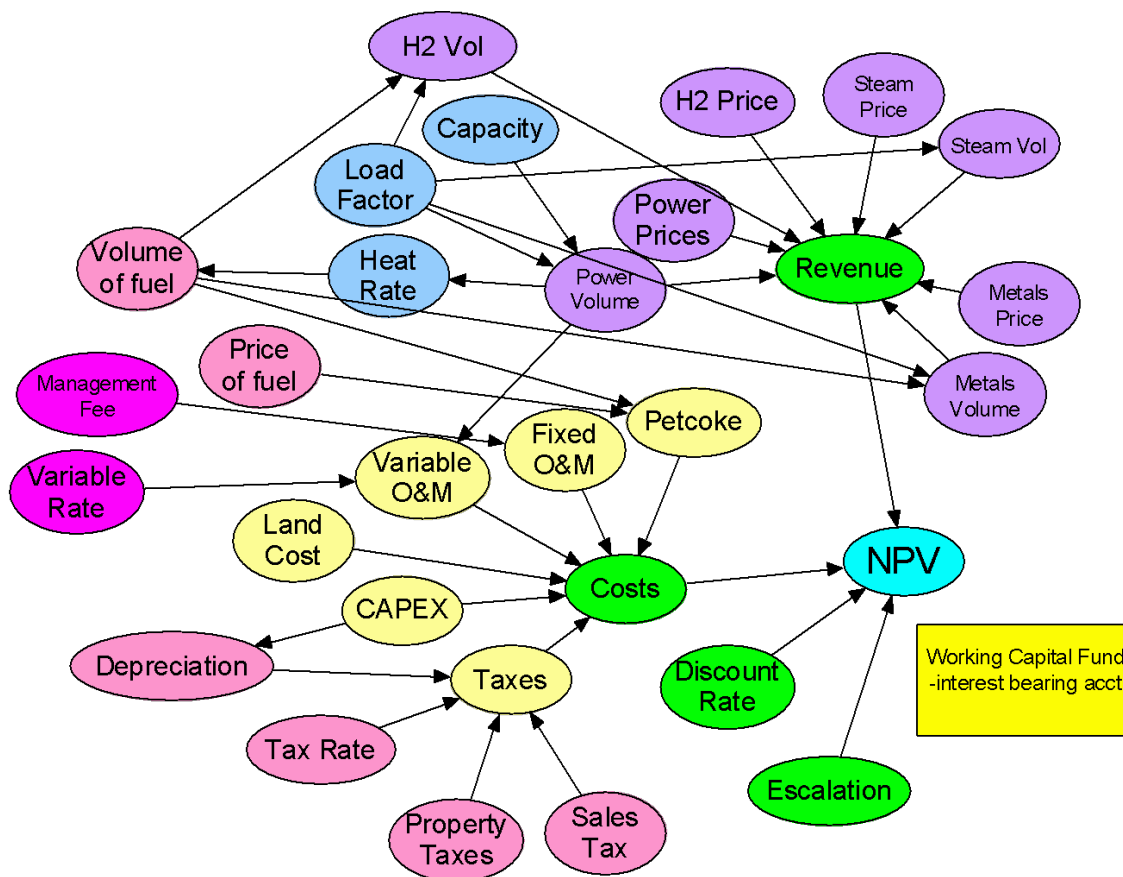
In Figure 2, an investment appraisal team documents the value drivers for an energy investment, starting at project NPV, working backward to revenue, costs, discount rate, and escalation rate, then back to the drivers of revenue and cost through fixed and variable O&M, capital expenditures, power prices, power volume, and multiple prices and asset volumes. Influence diagrams like these not only help investment analysts to capture all critical inputs in an economic model and valuation, but they also identify future potential sources of value, captured as interdependencies and portfolio value, variable production volumes, and abandonment value, all of which can be quantified as real option value.

Other diagrams can also impact current and future investment decisions. After determining the value drivers in an influence diagram and after an initial Monte Carlo simulation run to calculate investment value, the team assesses which variable inputs and drivers of value could be modified for the investment and have the largest impact on total project value. For this exercise, the team runs a tornado diagram in which the NPV range of each major variable would be stacked by largest volatility on the top and lowest volatility on the bottom as measured by changing the value of one variable at a time, holding all other

variables constant (See Figure 3 – Tornado Diagram). In this diagram, each factor is evaluated around its incremental impact on NPV on the x axis.

Figure 3: Tornado Diagram for Energy Project
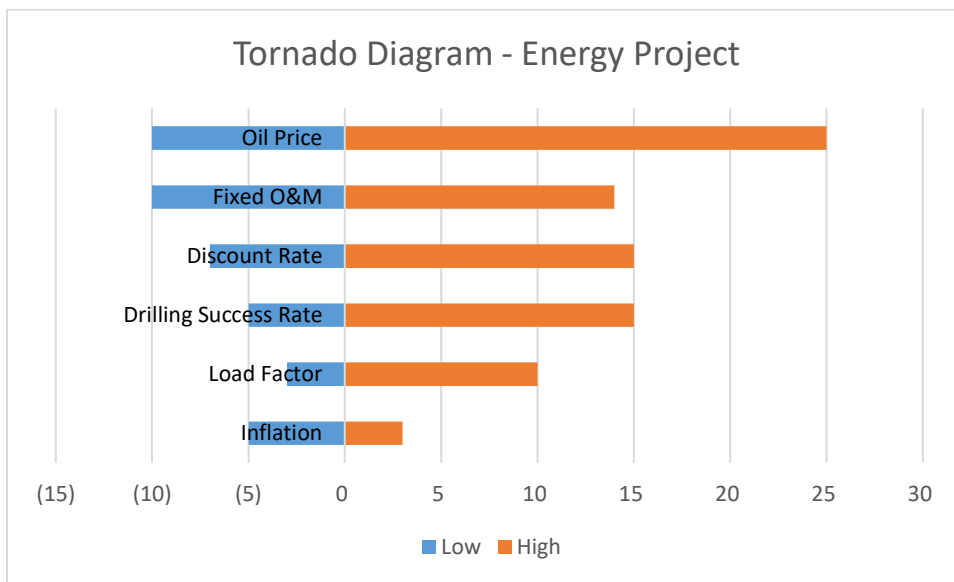
An assessment of value drivers in capital investments helps decision teams identify potential subsequent investment decisions, sources of project uncertainty, and real options decisions managers could consider for the investment.

For instance, if investing in an oil field, after the initial well drilling investment, an oil company would have the real option of (1) varying oil production output between 50% of the production rate to 100% of the production rate depending on the current price of oil. Since the price of oil fluctuates, if the price of oil is lower at full production than the total cost of drilling and producing the well, slowing production rate may allow the company to realize higher oil prices at a later date. The company would also have a real option to (2) drill additional wells within the same oil field if the initial well discovery resulted in much more oil volume than anticipated or (3) abandon the well and sell the operation and mineral rights to a small producer if the oil field size was determined to be too small after drilling the first well.

4.2   How Do We Calculate Real Options in Business Cases?

4.2.1   Multiple Methodologies

When calculating real options for capital investments, there are a few methodologies that financial analysts practice with varying degrees of difficulty. Often the variables, standard deviation of project volatility and discount rates require multiple calculations in themselves, and calculations for standard deviation of project volatility often require many iterations in a Monte Carlo simulation. Of the multiple valuation techniques for calculating real options in capital investment decisions, the primary techniques are the following:

- Black-Scholes Model for Individual Option Decisions
- Binomial Model Using Decision Trees
- Binomial Model Using Decision Trees following Geometric Brownian Motion (GBM)

4.2.2   Preferred Methodologies

From a practical application of real option valuation for government acquisitions and capital investment decisions, the Black-Scholes Model adds complexity to each real option. While the Black-Scholes model is well suited for financial options and can be used effectively for real options without too many decision tree nodes, for investments with multiple decision tree branches, other real option valuation approaches are preferred.

The preferred approach toward real option valuation for large government capital investments is the application of decision trees using the binomial model. Using the GBM approach, the analyst assumes that "the estimate (of a project's value) at any point in time has a lognormal distribution" (Brandao, Dyer, & Hahn, 2005). This means that the probability value for both the "up" and "down" branches of each decision will have the same probability for each up node and the same probability for each down node. In some cases, this will be impractical, especially when evaluating multiple decisions within a portfolio.

Using the binomial model and decision trees is the most effective approach toward estimating real option value for government capital investment decisions as it allows the following flexibility:

- The valuation of multiple decisions within an investment,
- The application of time constraints imbedded in the decision tree,
- And the ability to model volatility for each decision using Monte Carlo simulations of benefits and its potential impact on node value.

In the next few sections, I demonstrate two approaches toward calculating real option value in government acquisitions and capital investments.

First, I provide an example of calculating real option value using binomial decision tree modeling. This approach requires multiple financial calculations for each node.

Then, I provide a project example that my team and I used for a government project to estimate the impact of potential multiple investment decisions, facilitated by one initial platform investment in a supply chain. In this supply chain example, instead of explicitly estimating volatility and different discount rates by node, and instead of applying the GBM probability convention, I assigned subjective probabilities for each decision node and each subsequent investment decision based on subject-matter-expert (SME) estimates and the informed likelihood of agency investment approval. Then, for option value, I estimated the incremental benefits value each subsequent investment would add at each node, partially offset those benefits with project cost, and built out a complex decision tree with multiple nodes and branches.

4.2.3   Real Option Value Calculated Using Binomial Decision Trees

Over the last two decades, decision tree analysis (DTA) has been used to value uncertainty and supplement discounted cash flow (DCF) analysis in the valuation of capital investments. DTA is used to measure the incremental value of manager flexibility, the ability to adjust future decisions or future capital investment segments by information learned by the first investment. Given a favorable first investment and a positive value proposition for a follow-on investment, an investment manager might expand operations in a follow-on investment. If value in the proposed follow-on investment is eroded, the manager might choose to abandon future segments or postpone the investment decision until favorable conditions add value to the investment again. These flexible decisions for capital investments or real options account for value not captured in traditional DCF analysis.

Decision tree analysis depicts investment decisions as nodes with up and down branches as one of two possible decisions, usually a "yes" to investing in the up branch and a "no" to further investment in the down branch. However, other option decisions can use binomial decision trees as well.

A straight-forward approach for valuing real options is the introduction of the binomial model using GBM approach which replicate financial options. In GBM binomial decision trees, investment decisions result in one of two possible choices per decision node, the up and down branches of the tree. Following the GBM convention, the probability attributed to the up and down choices are consistent for each up and down branch in the tree. For example, if at time 1 in the first decision node the up-choice probability is 70% and the down-choice probability is 30%, then, according to this model, these percentages (70/30) for up and down would hold true for the next decision node and the third decision node as well. In Figure 4, an initial capital investment probability-weighted decision results in two additional nodes for follow-on investments or investment decisions. At each node in the GBM binomial decision tree, the probabilities of the up branches are the same, and the probability of the down branches are the same (See Figure 4). In this example, at the end of time 3, the final investment decisions are made.

Figure 4: Binomial Model Decision Tree
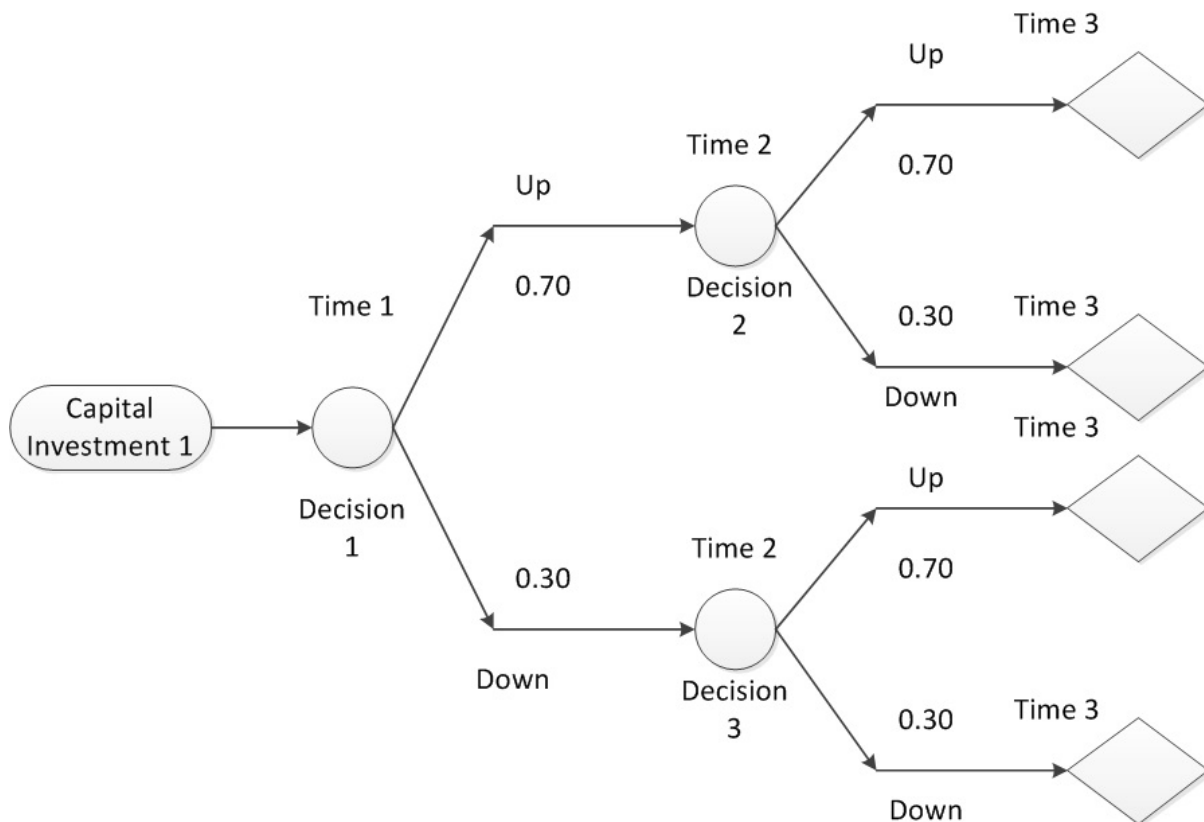
In the next example, a binomial GBM decision tree is used to estimate option value. To estimate the project value and provide the potential values at each node, I will introduce a series of formulas for the binomial tree valuation estimate.

In the Informs article, "Using Binomial Decision Trees to Solve Real-Option Valuation Problems," Brandao, Dyer, and Hahn introduce a series of formulas and variables to use to solve binomial trees, and they are listed below (2005).

For the capital investment, we are provided with the Time 1 DCF value of the project as V(o). The other known variables are discount rate, which for most government investments in civil agencies with benefits to both the agency and non-government stakeholders is 7%. Depending on the riskiness of the project, this value can change, and in the private sector, this discount rate is either a reflection of project risk or the weighted average cost of capital (WACC) of the company. In this example, we assign the value of r as 7.0%. The final known variable is volatility, and volatility is measured based on the volatility of cash flows or in the government the annual project value (cost plus benefits) over the project lifecycle. Volatility can vary greatly depending on the risk and expected returns of the project over time. In this case, I assume a volatility of 25%, so sigma = 25%.

When building the binomial decision tree, we must estimate the probability of each up and down branch. For binomial decision trees, the probability of each up node is the same and the probability of each down node is the same. This may not be practical for many capital investment decisions with multiple decision tree nodes, but it is an efficient decision tree model that is effective for evaluating real options for one or two layers in a decision tree. For each node, there is an up and a down option and the sum of the probabilities for both branches is 100%. For binomial decision trees, we calculate both a probability for the up branch, P(u), and the down branch, P(d). Before calculating the P(u) and P(d), we must estimate the U and D, the proportional increases and decreases in asset value. According to Brandao, Dyer, and Hahn, since binomial decisions are designed to follow GBM, so "the estimate of value at any point in time has a lognormal distribution" (2005). As a result the values for U and D are as follows:

Formula 2: The Value of U – Proportional Increase in Asset Value at Each Node

$$U = e^{(\sigma)\sqrt{\Delta t}}$$

Formula 3: The Value of D – The Value Relationship Between U and D

$$U = \frac{1}{D}$$

The value for each branch of the binomial tree are calculated by the value at time 1 multiplied by U for the up and D for the down, adjusted by the discount rate for present value.

Formula 4: The Value of Each Up Branch in a Binomial Decision Tree following GBM

$$V_U = \frac{(V)(U)}{(1 + r)^t}$$

Formula 5: The Value of Each Down Branch in a Binomial Decision Tree following GBM

$$V_D = \frac{(V)(D)}{(1 + r)^t}$$

For the final binomial decision tree real option formula, probability is calculated by the following formula. If we use this formula for P(u), then P(d) would just be 1-P(u) to get the percentage for the percentage applied to each down branch.

Formula 6: Binomial Model Probability Formula for Up Branch

$$P_U = \frac{(1 + r - d)}{(u - d)}$$

Formula 7: Binomial Model Probability Formula for Down Branch

$$P_d = 1 - P_U$$

In the following example, we consider a government capital investment of $300 M as estimated by discounted cash flow analysis. As a civilian government acquisition with benefits for both the government agency, the public, and other private industry stakeholders, the discount rate by OMB guidance is a 7% real discount rate (BY$), written as r = 0.07. Based on annual cash flows or the net of discounted benefits minus costs, the calculated volatility is provided at 25%. The known variables are captured in Figure 5 below.

Figure 5: Binomial Decision Tree Example Known Variables

Binomial Decision Tree Example

Variables

Project Value	V	300 $M
Discount Rate	r	7.0%
Volatility	sigma = σ	25.00%

The objective of this exercise is to use binomial decision trees to estimate the value of a project at any point in time based on multiple decision nodes, using a lognormal distribution. This is just one of the approaches to estimate project value using decision trees.

For the binomial decision tree, Figure 6 shows the steps in order to calculate the value of each decision tree node.

Figure 6: Binomial Decision Tree Example – Decision Tree Calculation Steps

	Binomial Tree Steps	Unknown Variables & Calculations			
Step 1	Calculate U	U=e^sigma		U	1.28
				D	0.779
Step 2	Choose time at nodes	delta t	choose 1 year		
	Usually 1 year	t	1		
Step 3	Calculate P(u)	P = (1+r-d)/(u-d)		P(u)	0.576
	& P(d)			P(d)	0.424
Step 4	Calculate Time 2 decision values				
	V(u)	V(u) = (v)(u)/(1+r)		V(u)	360
	V(d)	V(d) = (v)(d)/(1+r)		V(d)	218
Step 5	Calculate Time 3 Upper Branches				
	V(uu)	V(u) = (v)(u)/(1+r)		V(u)	432
	V(ud)	V(d) = (v)(d)/(1+r)		V(d)	262
Step 6	Calculate Time 3 Lower Branches				
	V(du)	V(u) = (v)(u)/(1+r)		V(u)	262
	V(dd)	V(d) = (v)(d)/(1+r)		V(d)	159
Step 5	Calculate Time 4 Upper Branches				
	V(uuu)	V(u) = (v)(u)/(1+r)		V(u)	518
	V(uud)	V(d) = (v)(d)/(1+r)		V(d)	314
	V(udu)	V(u) = (v)(u)/(1+r)		V(u)	314
	V(udd)	V(d) = (v)(d)/(1+r)		V(d)	191
Step 6	Calculate Time 4 Lower Branches				
	V(duu)	V(u) = (v)(u)/(1+r)		V(u)	314
	V(dud)	V(d) = (v)(d)/(1+r)		V(d)	191
	V(ddu)	V(u) = (v)(u)/(1+r)		V(u)	191
	V(ddd)	V(d) = (v)(d)/(1+r)		V(d)	116

The binomial value calculations and associated probabilities for each branch in this example are depicted in Figure 7.

Figure 7: Binomial Model Decision Tree Example
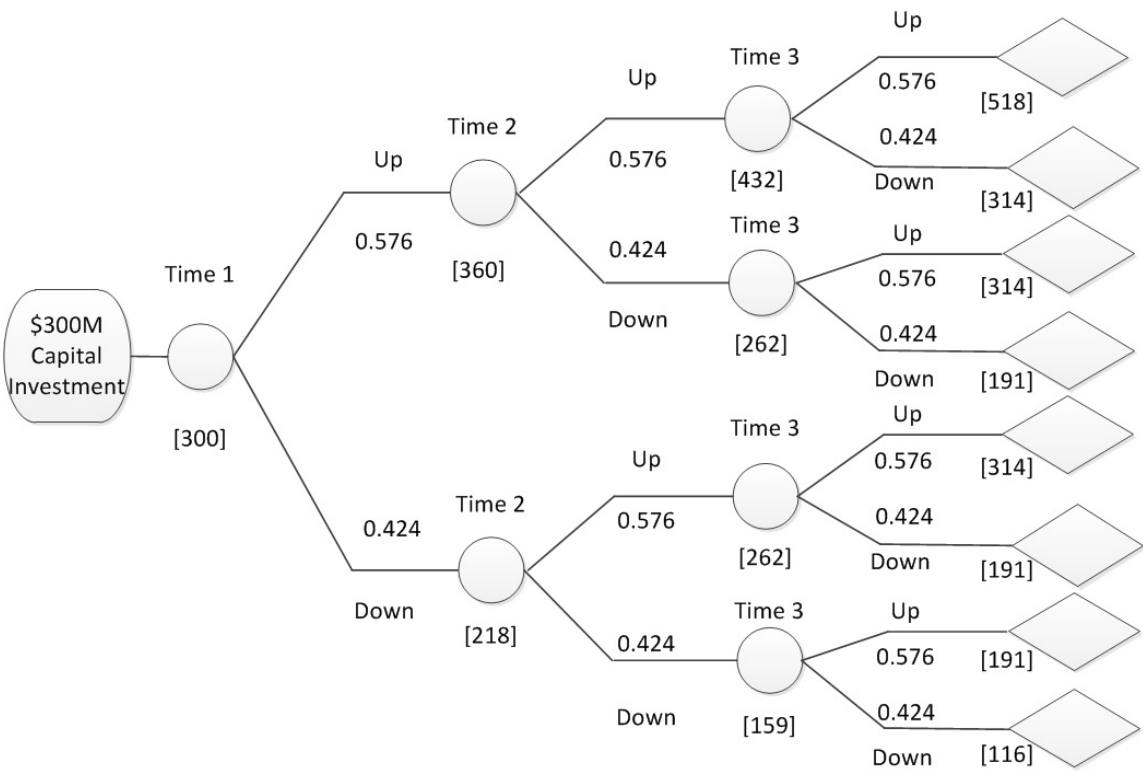
In order to approximate total project value using real options, the analyst would use a decision tree model like this example, multiply the probabilities for each branch to one end point at the triangle value nodes, and multiply this aggregate percentage times the end point value. The sum of those probability weighted values would be project option value. I demonstrate the application of option value calculations in section 4.2.4.

Binomial decision trees with constant up and down probabilities for each node is not always applicable for investment decisions, program portfolios, or real option decisions, but it does demonstrate the techniques of using decision trees to calculate project value.

In the next example in section 4.2.4, I will demonstrate the application of real options of a real business case without the same binomial characteristics as our previous example and, instead, subjective estimates of option probabilities based on investment decision sequence, affordability constraints, and program interdependencies.

4.2.4 Real Option Value and Portfolio Value Using Estimated Probabilities and Decision Trees
Unlike the previous binomial decision tree example, using the techniques defined by Brandao, Dyer, and Hahn, the government capital investment application of real options has more subjective probability estimates, not constant up and down branch probabilities, and applies real options to (1) expand, (2) delay, and (3) abandon capital investments (2005). While real options are rarely applied to civilian

government agency business cases, there are many instances where real option valuation could demonstrate the value of management investment flexibility by changing course in investment decisions and by making strategic decisions in the larger context of an investment portfolio.

In some government agencies, like the FAA, capital budgeting and finance groups segment programs to address affordability constraints with limited annual capital budgets and to address the uncertainty of government funding for new investments. Segmentation allows the agency to redefine subsequent phases, requirements, and functionalities of a business case without obligating all of the funds up front. By the time the second segment proceeds to an investment decision, new information from segment one better informs program managers and decision-makers, dollars-at-risk are minimized, and the distribution of limited capital funds can be better allocated to the most valuable and strategically important investments. This segmentation process, while not explicitly identified, is a form of real option valuation. Wouldn't decision-makers want to quantify the uncertainty and real options within current business cases, new investments, and existing program portfolios using the existing option structure the agency has already designed?

The agency can apply real option valuation using decision tree analysis by quantifying the impact of real options, like expand, delay, and abandon for new programs in investment analysis and for portfolios of programs as they choose which investments to fund.

4.2.4.1   Drawing Decision Trees with Multiple Decisions or Investments

In the next example, real options are applied to a supply chain capital investment, which begins as a platform investment for supply chain modernization in the agency. It is the first in a series of potential investments, all which build upon the initial supply chain investment, which we will refer to as Supply System Modernization (SSM). In this example, and unlike the previous binomial decision tree example, other subsequent investments could be initiated before SSM or in multiple sequences after SSM, but investing in SSM first enables the largest option value, and it's success increases the possibility that the agency will invest in subsequent supply chain investments.

The SSM real option investment not only demonstrates the incremental value that SSM enables through a series of probability-weighted investment decisions in a decision tree, but with the variety of investment decision paths and sequences, the real option decision tree process helps decision-makers optimize supply chain portfolio value as well. To demonstrate the best portfolio value proposition at any given time, the decision tree could be repeated with different scenarios, values, and probabilities to show the best investment options for an investment portfolio even with constrained capital funds.

In Figure 8, a real option decision tree shows each decision node at different points in time. Each decision node is approximately one year, and a timeline is listed at the top of the diagram. Unlike the previous example, probabilities are assigned by the likelihood that the agency would exercise the option to invest in the next investment decision, which complements the previous investment and which adds to the supply chain portfolio. Probabilities are assigned by the program office team of subject matter experts (SMEs), based on recent agency decisions, the incremental value afforded by each option at each node in the decision tree, and the effectiveness of subsequent investments leveraging SSM and each prior investment.

In this example option sequence provides distinct value to the real option valuation, and each path has different probabilities for success.

Value calculated at each decision node is the PV net of incremental benefits and costs enabled by each subsequent investment. Essentially, a successful SSM implementation enables a series of follow-on investments at values and probabilities that would not be enabled without investing in SSM first. Current legacy maintenance software systems cannot realize the supply chain value that SSM does.

Figure 8: Real Options Decision Tree – Impact on Portfolio – Supply Chain Example
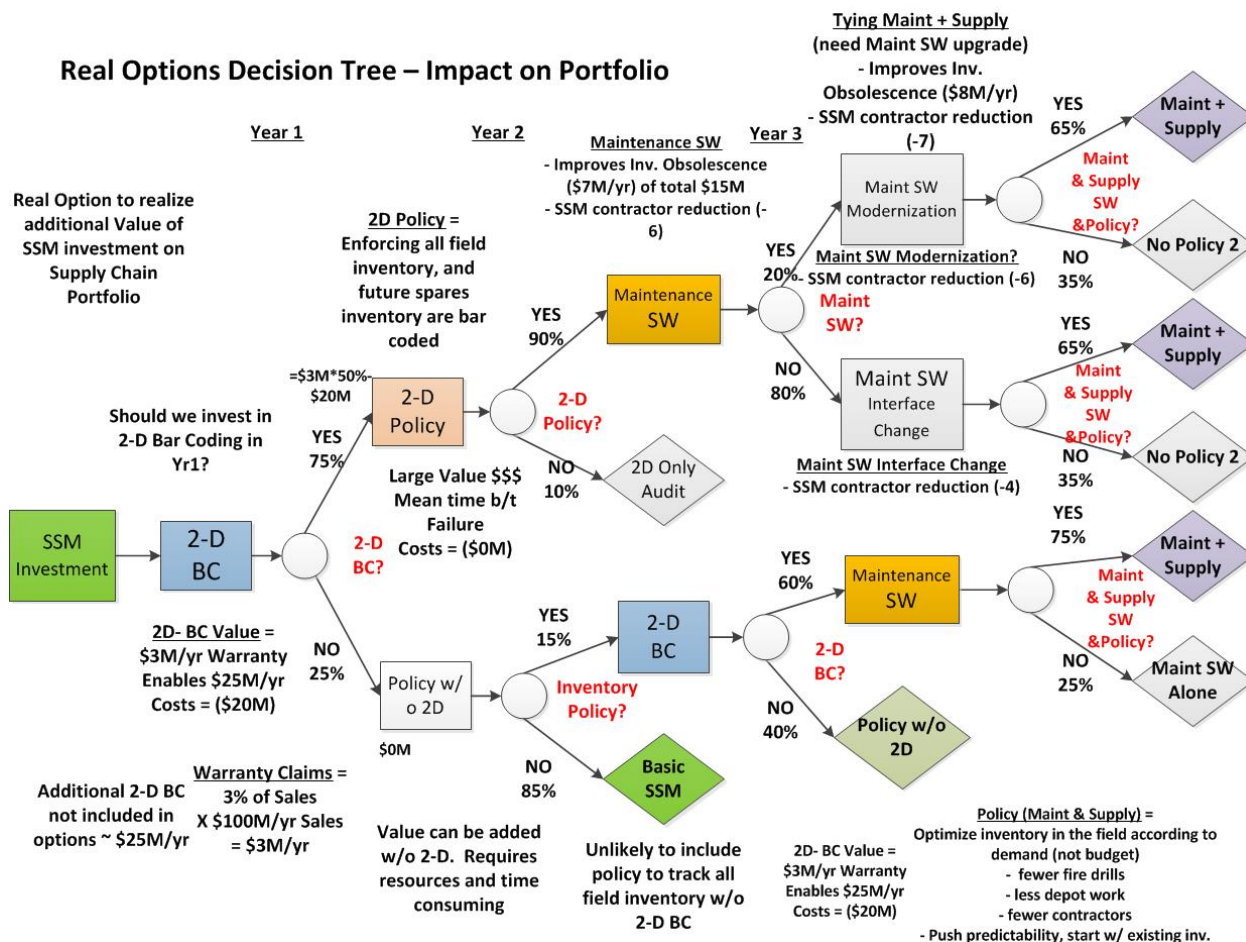
In the Figure 8 decision tree, the first real option is deciding whether or not to invest in 2-D Bar Coding at field locations in the National Airspace (NAS). After investing in SSM, the foundation of a modernized supply chain enterprise resource planning (ERP) system has been established, and the agency's supply system has the capacity to integrate with the maintenance system, something the legacy supply system could not do.

In the first node, the agency considers, now that SSM is being implemented, should the agency invest in 2-D Bar Coding (BC) to record all inventory at field locations in the NAS. The benefit would be a better reconciliation of inventory on the balance sheet and agency and supply chain transparency as to the number and types of spares present at each field facility. This knowledge will improve inventory management at the Logistics Depot, staffing levels at the Depot in order to repair the broken parts in the NAS that are most needed., improve supply chain forecasting to meet sparing needs, and help the

Logistics Center optimize on-site sparing. While 2-D BC would cost more than $20M, over the program lifecycle, it would bring in far more value by allowing the agency to realize warranty claims by tracking field parts ($3M/year) and reduce inventory working capital costs.

Given that the supply chain infrastructure to best utilize 2-D BC capabilities is now in place after a successful SSM investment decision, it is likely the agency will invest in 2-D BC. The team assigns a 75% chance of investing in 2-D BC and a 25% chance of not investing in 2-D BC.

In the second node, on the upper branch, now that the agency has invested in both SSM and 2-D Bar Coding, it must decide whether or not to change the existing field policy of bar coding all inventory in the NAS. This decision has very little cost to the agency but can only be effective if the tools are in place, so if the agency has already invested in 2-D Bar Coding, it would likely change the policy to enable additional value from bar coding. If the bar coding (inventory management) policy is set into place, it will provide transparency into the field and help the Logistics Center track inventory. It will also provide more accurate inventory management and the ability to calculate mean-time-between-failure (MTBF) and estimate which parts and how many should be repaired each month to meet field demand. Currently, the agency has an educated guess at which parts to fix when, but having this policy and 2-D bar coding tool in place will increase the forecasting accuracy by more than 100%.

With such a high benefit and low cost, the team assigned a 90% likelihood that the agency would change the 2-D policy once the 2-D Bar Coding program is approved. If the 2-D policy is unapproved (10% chance), the agency will only conduct periodic field audits for inventory, and no further supply chain modernization will occur. The down node here ends.

Staying on the up node, the next real option decision after a successful (1) SSM investment, (2) 2-D Bar Coding investment, and (3) 2-D Policy decision, the agency decides whether or not to invest in maintenance software (SW) that will support a parts and configuration database and allow field techs to record every part failure in the NAS with a drop-down menu and mandatory fields to record at each maintenance action. For every maintenance action in the NAS, field techs could also use bar coders to record the parts they are replacing, and this would prepopulate the critical maintenance system fields. The Logistics Center would immediately have transparency to failures for each part and better forecast spares needs. And, field techs could use technology to track each maintenance action. This would result in improved inventory management and system obsolescence ($8M/year) and reduce contractor workforce.

Even though there is significant value to the software change in the maintenance system, the team did not feel that the associated change management process would be initiated as there is a fundamental cultural shift in the agency's supply chain. The business case team only assigned a 20% chance of realizing this option.

For the down branch of this decision, since the agency had already invested in (1) SSM, (2) 2-D BC, and (3) 2-D Policy at this node, if the agency did not invest in full maintenance software modernization, it would at least change the interface, so that the maintenance system would communicate with the supply system ERP (SSM). That down node probability was forecast at 80%.

In the up node, the portfolio now has invested in (1) SSM, (2) 2-D BC, (3) 2-D Policy, and (4) Maintenance Software Modernization. In the associated down node, the portfolio has (1) SSM, (2) 2-D BC, (3) 2-D

Policy, and (4) Maintenance Software Interface. The last real option for each of those branches is a real option to invest in tying the maintenance and supply systems together via a 2-way interface and an associated policy to set lean demand-based inventory at each field location, rather than continuing a budget-based inventory system. The demand-based system would result in optimized field inventory levels, significantly reducing inventory carrying costs for the agency and reducing contractor workforce.

Since all of the prior investment decisions were positive (except perhaps the SW modernization), the team assigned a 65% chance of realizing this real option and choosing "yes." In the down branch, the team assumed the two systems would interface and better control inventory, but the agency would not change the policy as retain a budget-based inventory system.

For the down branches, end points would occur sooner since in a portfolio since real option-enabled follow-on investments build on one another. If the agency decides against one of the critical portfolio paths, the full portfolio goals may not be achieved, and further investments are not likely to be successful.

For instance, after an unsuccessful option to invest in 2-D Bar Coding, if the agency invests in (2) a policy change to audit field inventory, the program office would have the real option to invest in 2-D Bar Coding again, but if the agency rejected this decision once before, it is likely to again.

The team assigned only a 15% chance that the agency would approve a 2-D Bar Coding investment within two years of rejecting the investment decision the first time.

4.2.4.2   Calculating Decision Tree Value at Each Node

Calculating real option in a multi-node decision tree like the SSM example is straight forward. In order to demonstrate value, however, it is best to document the decisions leading to each end-node one end-node at a time.

Figure 9 summarizes each of the nine end-nodes, and multiplies all the probabilities to reach that end node times the incremental value (incremental enabled benefits minus costs) of each node in the branch. To check the math, make sure the sum of all the aggregate probabilities of each branch equals 100%.

In Figure 9, the first end-node with all "yes" decisions results in an 8.9% probability of saving $100M. That means that the first end-node contributes $8.9M to the total real option value to the supply chain portfolio. After adding the probability-adjusted savings (or net benefits) of each end node, the total real option value that the SSM investment adds to the supply chain portfolio is $53M.

Figure 9: Real Options Decision Tree SSM Example Calculations

Node	Scenario	Probability	Potential Savings	Probability-Adjusted Savings	Assumptions
1	2DBC, Maint SW Modernization+ Maint/Supply	9%	100.04	8.78	- Includes 2DBC cost ($20M) - 2dbc savings -FY14(3% of $100m inventory) - Maint SW Cost ($3M) - Maint SW (6 FTEs,$7M) - M+S (7 FTEs, $8M)
2	2DBC, Maint SW Modernization+ No Policy	5%	47.08	2.22	- Includes 2DBC cost ($20M) - 2dbc savings (3%) - Maint SW Cost ($3M) - Maint SW (6 FTEs) + $7M - Excludes M&S
3	2DBC, Maint SW Interface Change+ Maint/Supply	35%	92.96	32.63	- Includes 2DBC cost ($20M) - 2dbc savings (3%) - Maint SW Cost ($1M) - Maint SW (4 FTEs) + $4M - M&S (7 FTEs, $8M)
4	2DBC, Maint SW Interface Change+ No Policy	19%	40.00	7.56	- Includes 2DBC cost ($20M) - 2dbc savings (3%) - Maint SW Cost ($3M) - Maint SW (4 FTEs) + $4M - Excludes Policy and M&S
5	2D Audit Only	8%	3.57	0.27	- Includes 2DBC (Year 3) cost ($20M) - 2 dbc savings (3%) - Excludes policy, Maint SW and M&S
6	2D in Yr 3, Maint SW, Maint+Supply	2%	96.95	1.64	- Includes 2DBC cost ($20M) - 2dbc savings (3% of $100M Inventory) - Maint SW Cost ($3M) - Maint SW (6 FTEs) + $7M - M&S (7 FTEs, $8M)
7	2D Yr 3, Maint SW Alone	1%	7.85	0.04	- Includes 2DBC (Year 3) cost ($20M) - 2 dbc savings (3%) - Excludes Maint SW and M&S
8	Policy w/o 2D	2%	0.00	0.00	- 2D policy efficiency - Exludes 2DBC cost and savings, - Excludes Maint SW and M&S
9	Basic Supply Chain SW	21%	0.00	0.00	No Benefit
		100%		53.14	

4.2.4.3   Real Option Value for Capital Investments and Impact on Portfolio

Why does the $53M SSM real option value matter to the agency or the original investment decision? If SSM's discounted cash flow NPV was originally $60M, the real option value would nearly double the investment NPV.

If the NPV of the SSM investment were -$5M, and if the program manager could not demonstrate additional value to the supply chain portfolio which the SSM platform investment would exclusively enable, then the agency might choose not to invest in the SSM project. Even if project NPV is less than zero before option value, program managers can justify the investment of an investment like SSM by quantifying the real option value impact on an investment portfolio. In this case, without option value, SSM would have an NPV of -$5M and a total value after real option value of $48M. From Formula 1 on page 9, we can calculate total project value:

$$Total\ Project\ Value\ (TPV) = NPV + \text{Real Option Value}$$

TPV = ($5M) + $53M = $47M

Real options provide justification for marginal standalone capital investments which have an intrinsic enabling value. They can add value by providing opportunity to invest in more valuable follow-on investments or expand current operations. They can allow managers to postpone project segments until better economic conditions or program dependencies are met, potentially unlocking greater value. They can also hedge acquisition risk by allowing program managers to prototype a new investment solution and validate its effectiveness before committing to a full risky new investment. Real options allow managers flexibility to minimize project risk and realize full program potential.

Similarly, real options can be effective tools to evaluate and optimize portfolio value. Government agency directors and budgeting departments manage large portfolios of investments. In the FAA, acquisition portfolios are divided between specific functional categories – automation, communications, surveillance, terminal, and en route, to name a few. Adding real options to evaluate multiple investments according to risk, interdependencies, and incremental benefits helps managers optimize portfolio mix and even the sequence of investment decisions.

5   Conclusion

For government agencies, where large capital investment portfolios have multiple interdependencies and where government-constrained capital budgets require tough choices between competing capital investments, real options provide a process for quantifying the upside risk and enabling value of program acquisitions and capital investments. Incorporating real options with traditional NPV valuation techniques helps decision-makers make better informed decisions.

To maximize portfolio value, decision-makers must consider the use of real options to calculate the incremental value that one strategic investment or a series of strategic investments can provide to a whole investment portfolio. To effectively understand value of government agency acquisition portfolios, agencies and program managers must spend time assessing program value drivers and the interdependencies between new capital investments. Drawing visual diagrams to illuminate these interrelationships and value drivers through influence diagrams and decision trees will help managers make better informed decisions and consider multiple investment sequences and contingencies to optimize portfolio value.

Using influence diagrams to depict project value will help analysts uncover real option value in projects, especially when considering drivers of project volatility and strategic success. Once the analyst models for management flexibility and project uncertainty, he or she can design decision trees for projects that enable follow-on investments or which have borderline NPV value but large potential portfolio value.

If real option valuation is adopted agency-wide, managers will discover that investment decisions between mutually exclusive investments and affordability-constrained portfolio prioritization will come easier and may already be mapped out by decision trees.

6   References

Actuary, T. (2005, October). The Real Options Approach to Capital Investment Projects. *The Actuary*, p. 1.

Brandao, L. E., Dyer, J. S., & Hahn, W. J. (2005). Using Binomial Decision Trees to Solve Real-Option Valuation Problems. *Decision Analysis 2*, 69-88.

Damodaran, A. (2017). Chapter 8 Real Options. In A. Damodaran, *Strategic Risk Taking* (pp. 1-48). New York: NYU Stern.

Investopedia. (2017). *Real Option*. Retrieved from Investopedia: http://www.investopedia.com/terms/r/realoption.asp

van Putten, A. B., & MacMillan, I. (2004). Making Real Options Really Work. *Harvard Business Review*, 1-17.