A Practical Method for Incorporating Real Options Analysis into US Federal Benefit-Cost Analysis Procedures

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Abstract

This research identifies how Real Options (RO) thinking might acceptably and effectively complement the current mandates for Benefit-Cost Analysis (BCA) defined by the Office of Management and Budget (OMB) in Circular A-94. The research examines opportunities for improving economic analysis using mandated rules for a large complex system, highlights where improvements can be made with RO thinking, and proposes a framework that can be optionally and generically applied to mandated decision-making guidelines. The framework relies on a simple spreadsheet analysis that is augmented with Monte-Carlo simulation. The proposed approach complements existing practices and should be easy to integrate with current tools, procedures, staff, and resources.

This approach builds upon a careful analysis of Federal mandates for benefit-cost analyses, the implementing directions of the OMB, and the way these guidelines are followed by practitioners who have to deal with the particularities that exist in the field. The current practice was determined by examining several case studies of work for the Federal Aviation Administration (FAA) and through discussions with FAA officials knowledgeable about the BCA methods in practice. The proposed approach with FAA Airport Benefit-Cost Analysis Guidelines was applied to a Hypothetical Project for illustrative purposes.

Thesis Advisor: Dr. Richard de Neufville

Title: Professor of Engineering Systems and of Civil and Environmental Engineering

Dedication

In memory of Ann Reinbold

and

In memory of Ronald P. Shipplett

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I would like to express my gratitude to my thesis advisor, Dr. Richard de Neufville, whose expertise and patience added immeasurably to my graduate experience. His extensive knowledge, sound advice and excellent standards were motivational catalysts as I ventured through the many revisions of this thesis.

I have greatly benefited from my collaboration with Michele Steinbach of the MITRE Corp. as a source of feedback and valuable ideas throughout the writing of this thesis. Robert Samis at FAA HQ also provided insightful feedback as well as hard to find public information that was the basis of this thesis. It was a pleasure to work with them and the other employees of MITRE Corp. and the FAA.

Despite having excellent feedback and advice from Richard, Michele and Robert, any inaccuracies of fact, faults in reasoning or other imperfections are my own.

I am very grateful for my wife and son for their love and patience that have made the completion of the thesis possible. Finally, I would be remiss if I were not to acknowledge my mother-in-law and father-in-law who patiently filled in for me while working on this thesis.

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1 Introduction

The US Federal Government is continually involved in the funding of large projects to develop infrastructure where the benefits and costs are distributed amongst many stakeholders. It has a continuing concern for improving methods of project evaluation to ensure funding is utilized in an efficient and cost-effective way. At present, the process of project evaluation employs Benefit-Cost Analysis (BCA), a method that has traditionally compared discrete, fixed project alternatives.

With large-scale projects, a fixed set of alternatives can be limiting, especially as projections for the future typically are of limited accuracy and certainty. Thus there has arisen recognition of the value of flexibility when included in project design through the inclusion of at least one option with real options Analysis. However, methods to include optionality in project design and evaluation have been slowly adopted. In everyday language, an option is synonymous and could be used interchangeably with words like alternative and choice, this thesis defines an option as “a right but not an obligation” that the system managers may exercise in the future. The precise definition of option as “a right but not an obligation” is slowly being adopted as practitioners familiarize themselves with it.

The value of flexibility has been demonstrated, for example, by Post and Bennett (2004), who proposed and applied Real options in their case study of ADS-B. They used the Cox-Ross-Rubenstein binomial option valuation model. Although real options have been introduced and accepted as a possible method of evaluation in government policy mandates such as OMB Circular A-4 (US Office of Management and Budget 2003), these methods are not yet being applied on a regular basis in the BCAs for Federal projects.

> *’Real Options’ methods have also formalized the valuation of the added flexibility inherent in delaying a decision. As long as taking time will lower uncertainty, either passively or actively through an investment in information gathering, and some costs are irreversible, such as the potential costs of a sunk investment, a benefit can be assigned to the option to delay a decision. That benefit should be considered a cost of taking immediate action versus the alternative of delaying that action pending more information (US Office of Management and Budget 2003, p. 39).*

This thesis attempts to show how real options might be applied to situations where long-term forecasts are used as the basis of design decisions for systems and projects that are of sufficient magnitude that, for US Federal spending, would require a formal Benefit Cost Analysis. It first compares prescriptive BCA Guidelines to procedures used by practitioners and then proposes a procedure that complements existing methods as determined by reviewing three Airport Improvement Program (AIP) BCA’s which closely adhere to OMB Circular A-94.

1.A *Thesis Structure*

Chapter 1 – this Chapter summarizes the logical layout of the thesis as shown Figure 1.1.

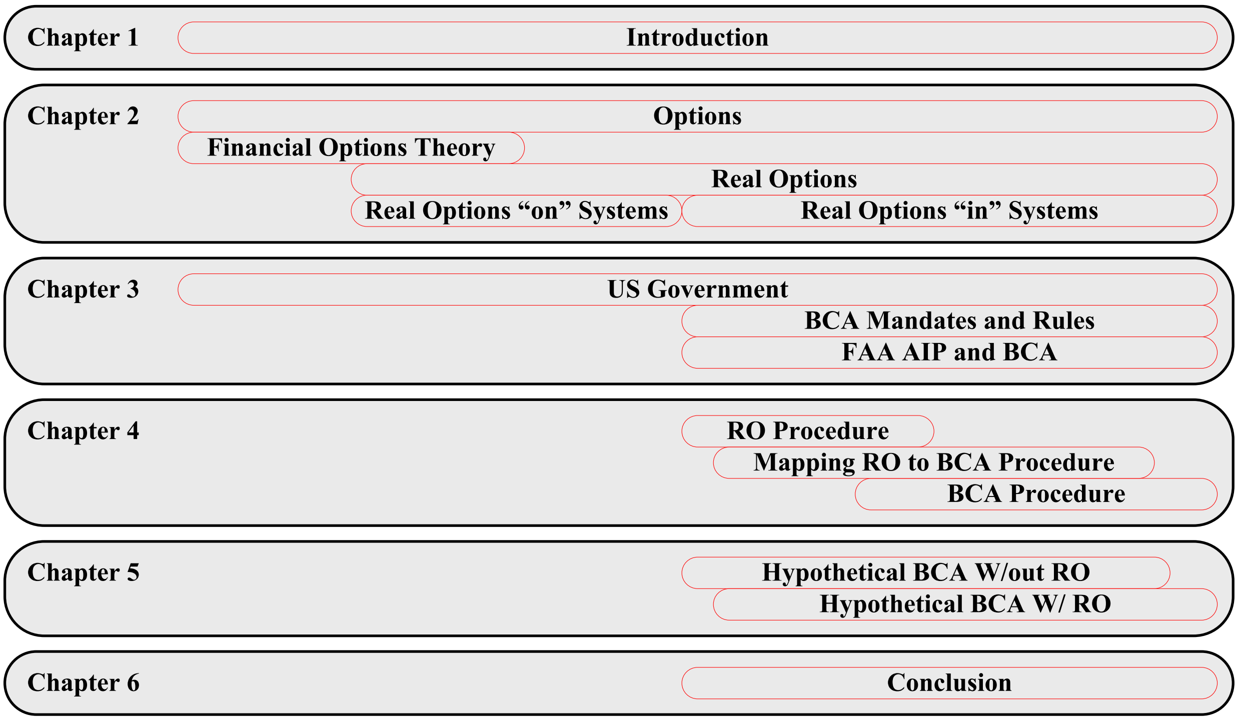

Figure 1.1 - Thesis Road Map

Chapter 2 – provides background information. It presents basic definitions, explains valuation with discounted cash flows and financial derivatives, and introduces real options. It also includes a review of select academic literature.

Chapter 3 – provides background information on US Federal Government mandates, guidelines and the rules that define when a BCA is required. A review of relevant FAA literature is included.

Chapter 4 – introduces and explains the procedure for utilizing real options within the FAA Airport Benefit-Cost Guidelines. Economic factors, forecast assumptions and probability distributions will also be introduced and explained. These procedures, which are known to be used in practice by airport sponsors and reflect the FAA Airport Benefit-Cost Guidelines, are applied in Chapter 5: BCA for a hypothetical project.

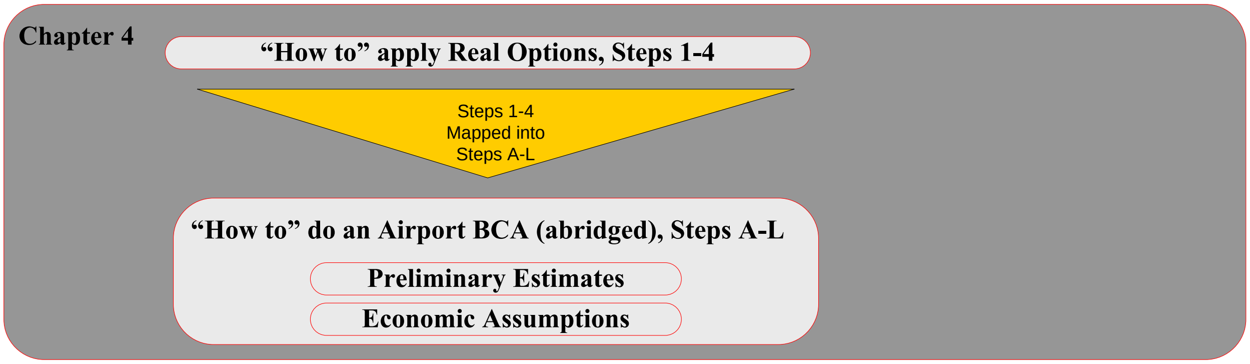

Figure 1.2 - Chapter 4 Road Map

Chapter 5 – Presents a hypothetical project and then compares and contrasts two BCAs for that project: one with and one without real options. Both are based on procedures established by the FAA and on the implementation of those procedures by airport sponsors. The procedure is based on details outlined in Chapter 4. Figure 1.3 shows the Chapter 5 road map and how it relates to the Chapter 4 road map.

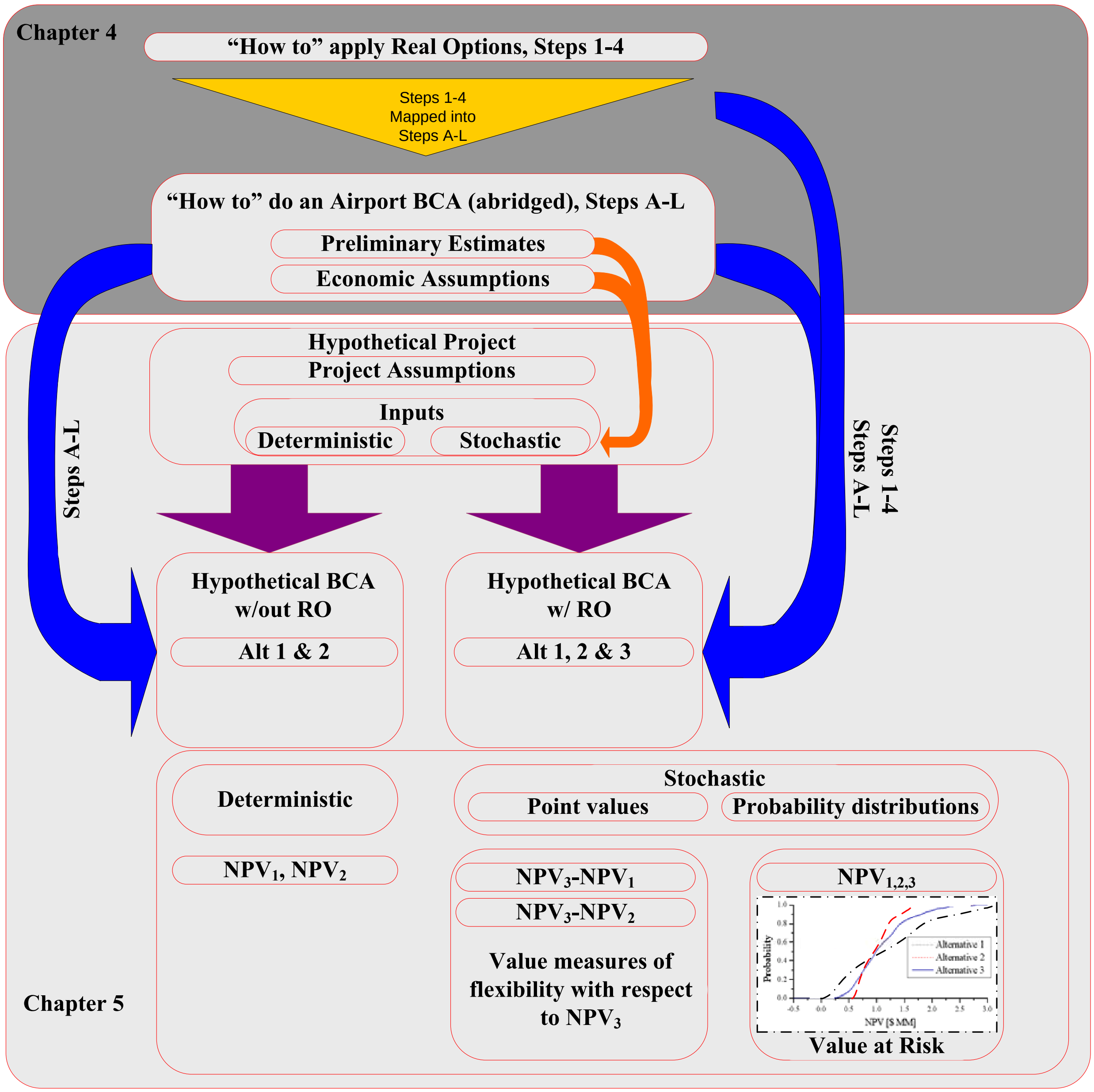

Figure 1.3 - Chapters 4 and 5 Road Map

Chapter 6 – conclusion, opportunities for improvement, and further research.

2 Project and Program Valuation Methods

2.A *Introduction*

This chapter introduces some of the basic concepts used in FAA valuation methods and program evaluations including those where a BCA is required. It also introduces the basic concepts related to real options valuation and BCAs and shows the basic aspects of how real options are complementary to FAA Airport BCAs generally and to the BCA for the hypothetical airport project presented in Chapter 5.

While financial options are typically evaluated by financial markets and derive their value in the difference between the market price of the underlying security or commodity and the option "strike price", no markets exist for options in government infrastructure projects. However, the value inherent in retaining flexibility in decision-making can be seen in any project that is based on uncertain projections of the future. This chapter introduces questions of evaluating flexibility in different contexts: it discusses relationships between financial options and real options and indicates how real options differ from Financial Options.

The Hypothetical Project BCA in this thesis is concerned with showing how to evaluate an option to expand the runway area of an airport where the timing of an anticipated change in the fleet mix is uncertain. Real options evaluation methods reveal the value inherent in being able to expand runway area in response to changes in fleet mix as they emerge, rather than making a fixed, unchanging plan based on projections of the fleet made years before the need to expand the runway is certain.

2.B *Valuation with Discounted Cash Flows*

Benefit Cost Analysis evaluates projects by analyzing their future costs and benefits over their life. In this section, the concept of the time value of money is introduced, which allows comparison of costs and income in the present with those in the future. In addition, other fundamental aspects of BCA related to the time value of money are discussed.

Money has time value that is determined by prevailing interest rates and inflation. When currency fluctuations are excluded, a dollar today is worth more than a dollar tomorrow (or some other time in the future). To adjust the value of a dollar between a present and future period, a discount factor is applied.

It is important to recognize that BCA, which predicts future costs and benefits of a project, depends on uncertain predictions. Stochastic forecasting, quite often implemented with the Monte Carlo method, is the tool used in this case study and in FAA BCA guidelines to attempt to deal with this uncertainty quantitatively. Further, the example in this chapter shows how the use of such methods makes possible the evaluation of real options. Finally, the example in this chapter shows the basic evaluation of real options and the basic principles that are applied in the detailed Hypothetical Project BCA developed in Chapter 5.

2.B.1 Time Value of Money and Discounted Cash Flows

When evaluating a project with cash flows expected over more than one period, it is desirable to recognize that these cannot be summed until adjusted by a discount factor appropriate for the period in which cash flow occurred. The summation of a series of discounted cash flows is called Present

Value (PV). To calculate present value we need to know: 1) cash flow magnitude and direction, 2) timing of cash flows and 3) an appropriate discount factor.

By acknowledging the time value of money, different cash flow scenarios can be evaluated on an equivalent basis. Equations 2.1 and 2.2 show how the present value of a lump sum and a series of payments can be established in period 0. The equations are suitable when the present value is at the beginning of the first period and the cash flows occur or are assumed to occur at the end of each period. The discount factor $1/(1+r)^n$ is equivalent to the value of a zero coupon bond with a face value of $1 in year zero. A zero coupon bond with a 7% interest rate, 20 year maturity and par value of $1 is now worth $0.26 ($1/(1.07)^{20}=0.2584$).

$$PV_0 = FV_n \left(\frac{1}{1+r} \right)^n \qquad \text{Equation 2.1}$$

$$PV_0 = \sum_{t=0}^{n} FV_n \left(\frac{1}{1+r} \right)^n \qquad \text{Equation 2.2}$$

Where
PV_0: Present Value of cash flow(s) in period 0
FV_n: Future Value of the cash flow in period n
r : constant discount rate per period
n: number of periods
t: specific time period instance

2.B.2 Net Present Value

The intention of BCA is to include all the benefits and all the costs for a project. To accomplish this Net Present Value (NPV) is calculated. NPV is the present value of benefits minus the present value of costs; it is based on discounted cash flows with a constant discount rate, equally spaced time periods and cash flow periods. Equation 2.3 shows the standard form of the NPV equation when the discount rate is constant and its period matches the discounting period.

$$\begin{aligned} NPV_0 &= \sum_{0}^{n} FV_{benefits,n} \left(\frac{1}{1+r} \right)^n - \sum_{0}^{n} FV_{costs,n} \left(\frac{1}{1+r} \right)^n \\ &= \sum_{0}^{n} PV_{benefits,n} - \sum_{0}^{n} PV_{costs,n} \end{aligned} \qquad \text{Equation 2.3}$$

Where
NPV_0: Net Present Value in period 0
$FV_{benefits,n}$: Future Value of the cash flow in period n
$FV_{costs,n}$: Future Value of the cash flow in period n
$PV_{benefits,n}$: Present Value of the cash flow in period n
$PV_{costs,n}$: Present Value of the cash flow in period n
r: constant discount rate per period
n: number of periods

The usefulness and simplicity of NPV has made it a very popular and common method of evaluating the desirability of projects. However, it is also known to undervalue investments because one of its key underlying assumptions is that the investment, once made, will remain unchanged. For example, the NPV of a new factory would exclude the value to expand, contract or close the factory operations. Another weakness of NPV is that projects with different life times can not be compared directly but need to have their lifetimes adjusted to an equal and common lifetime. One method of comparing projects with unequal lives is to shorten the longer project life so it matches the shorter project life and include the remaining value of the longer-lived project in the final year cash flow: the opposite is also true and preferred for FAA Airport BCAs (US Federal Aviation Administration 1999a, p. 22) in the absence of equal evaluation periods. Long time periods also distort NPV calculations, so using NPV to evaluate projects longer than 20-30 years may lead to an unreliable NPV because the benefits and costs beyond 20 years are so heavily discounted that they are negligible. With a 7% discount rate project benefits and costs are discounted with a factor of ¼ at 20-years and ⅛ at 30-years (US Office of Management and Budget 1992, p. 3).

In addition to these weaknesses of NPV, it relies on the assumption that the forecasted input parameters are static and precise. Nonetheless, NPV remains a valuable tool and it will be utilized later in this thesis to show the value of a real option when it is assumed that the forecasted input parameters are dynamic and imprecise. Traditional NPV analysis is necessary and useful as a baseline for comparison purposes.

2.B.3 Deterministic and Stochastic Models

Deterministic computational models use static point values for both input and output model parameters. The output of a deterministic model is a single number that summarizes output with the same level of detail that a mean average from a probability distribution does.

Stochastic models have outputs with probability distributions because the inputs are probability distributions. Stochastic models reveal a range of potential outcomes and the probability associated with each. For the purpose of this thesis, the term stochastic is synonymous and interchangeable with Monte Carlo method and Monte Carlo simulation. Credit for coining the term "Monte Carlo method" often goes to Stanislaw Ulam (Metropolis and Ulam 1949) from his demonstration of the procedure with the card game Solitaire.

Monte Carlo simulation is readily available on ordinary desktop computers with commercial off the-shelf software (COTS) like Microsoft® Excel with 1) Microsoft® Excel Analysis ToolPak Add-In, 2) Decisioneering Crystal Ball® or 3) Palisade @Risk®.

Previously-introduced Equations 2.3 and 2.4 now become Equations 2.5 and 2.6. While their form remains the same, the output and at least one input will always be probabilistic. Figure 2.1 shows that the same economic model is used for both deterministic and stochastic calculations and with one of the above-mentioned COTS packages, an existing or newly created deterministic model may also produce stochastic results. The output probability distribution is dependent on the characteristics of the input probability distributions and may take any form as long as the cumulative area is equal to one (1).

$$NPV\left\langle PV_{benefits}, PV_{costs}\right\rangle_0 = \sum_0^n \int_0^i PV_{benefits,n} - \sum_0^n \int_0^i PV_{costs,n} \qquad \text{Equation 2.4}$$

$$\mathrm{BCratio}\left\langle \mathrm{PV_{benefits}}, \mathrm{PV_{costs}}\right\rangle_0 = \frac{\sum_0^n \int_0^i \mathrm{PV_{benefits,n}}}{\sum_0^n \int_0^i \mathrm{PV_{costs,n}}} \qquad \text{Equation 2.5}$$

Where i: the number of random samples (iterations)

$\langle \ \rangle$ angle brackets indicate the arithmetic mean of "i" iterations.

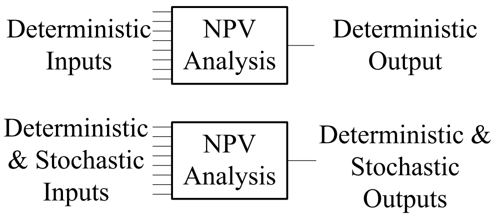

Figure 2.1 - Traditional NPV

2.C Options

The term "option" as mentioned earlier is "a right but not an obligation", certainly a very broad definition that needs to be narrowed for a particular application. The context that the option is used in provides further insight into its classification. When it is accepted that an option is "a right but not an obligation" it should become apparent that it has an asymmetric nature. For decision-makers in search of managing the outcome of their decisions it is natural to look for ways to structure a decision in a way that limits undesirable outcomes while placing no limits on desirable outcomes. Everyday examples of strategies that have asymmetrical characteristics are insurance policies, defined benefit plans, and fixed interest rate loans. In each one of these examples one party pays an upfront fee and the other party bears the risk; this is commonly known as risk transference and occurs often in transactions where both the quantitative and qualitative information can be monetized. In planning large projects, managerial flexibility is desirable because it allows system managers to make adjustments at a future date when details emerge and uncertainty is reduced. Real options analysis, which is the focus of this thesis, allows the incorporation of flexibility into plans and allows evaluation of that flexibility.

2.D Financial Options

Financial options are financial instruments that derive their value from one or more other financial instruments or indices. For example, a stock option derives its value from the stock it is based on. They are one of three classes of financial derivatives, the other two being forwards and futures which are outside the scope of this thesis. More specifically, a financial option is an exchange-traded option. An exchange is a regulated institution that facilitates the exchanging of financial instruments between buyers and sellers. An exchange-traded option has standardized terms set by the exchange(s) that the option is traded on and are available to all market participants. Strike price, expiration date, and initial price are the most important standardized terms. A strike price is the predetermined price on which the option may be executed in the future but prior to the expiration date. Only when an option is initially listed on the exchange does it (the exchange) have control over the price; after that point the activities of market participants will set the bid and ask prices of the option.

There are option-pricing models that have become very successful and are widely used in capital markets (Chriss 1997; Kritzman 2005). For equity-based options the well-known option pricing models are Black-Scholes (1973) and Cox-Ross-Rubenstein (1979). Although these models are successful in pricing options found in capital markets, they are dependent on assumptions that are unlikely to be satisfied for real options. For example, pricing (and valuation) of financial options depends partially on observable market parameters such as interest rates and the financial instruments the options are derived from. Financial options also have relatively short lifetimes when compared to real options. Financial options on equities quite often expire within 12 months and rarely have expiration dates of greater than 3 years whereas options on real assets with long operating life times usually far exceed 3 years. Even when the parameters are satisfied, the option-pricing models are only well understood by a small number of computational finance experts. A very important goal of this thesis is to demonstrate the simple and transparent nature of real options analysis that both decision-makers and analysts can have confidence in.

2.E Real Options

The term "real options" was coined by Stuart Myers (1976, 1984; Mehta 2005). Real options extend financial options theory and are a method of bridging corporate finance (mostly quantitative) and strategic planning (mostly qualitative). Quantitative factors can be represented numerically; where as qualitative factors are either not quantifiable or quantifiable with ambiguity. In either case the factors chosen may not necessarily be the correct ones to choose and may not necessarily be accurate. Decision-makers include both quantitative and qualitative data in their decisions and real options can bring these incompatible data types together to form a complete picture. A real option, when present, permits a decision-maker to make changes to an investment as new information emerges in the future. Real assets are different from financial assets in that they are tangible and are what Dixit and Pindyck (1994) call "irreversible investments". Real assets are unlike financial assets, which can be traded in and out of without experiencing irreversibility. Pouring concrete that shortly thereafter hardens is an example of irreversibility and shows the asymmetric and one-way nature of the process.

Real options analysis is an innovative method acknowledged by the OMB (US Office of Management and Budget 2003, p. 39) and complementary to existing FAA Airport BCA guidelines for "quantifying benefits and costs where these methods can be shown to yield superior measures of project merit" (US Federal Aviation Administration 1999a, p. 1).

Table 2.1 summarizes the differences between real options and Financial Options.

Table 2.1 - Financial Options versus Real Options

Financial Options	Real Options
Short maturity, usually in months	Longer maturity, usually in years and decades
Underlying variable driving its value is equity price or price of a financial asset. Volatility can be calculated from observed historical market prices.	Underlying variables are free cash flows, which in turn are driven by competition, demand, and management. Volatility is an assumption without basis: no historical pricing data exists.
Cannot control option value by manipulating stock prices	Can increase strategic option value by management decisions and flexibility
Competitive or market effects are irrelevant to its value and pricing	Competition, market value and stakeholders drive the value of a strategic option.
Values per option contract are usually small, but when aggregated can be in the millions and billions.	Major million and billion dollar decisions are represented by a single option.
Have been around and traded for more than three decades (financial options initially began trading on the Chicago Board of Options Exchange in 1973)	A recent development within corporate finance since the 1990's
Calculated using closed-form partial differential equations and simulation/variance reduction	Calculated using closed-form equations and binomial lattices with simulation of the underlying variables, not on the option analysis. Or, calculated as the difference between the NPV of a flexible project and the NPV of an inflexible project.
Marketable and traded security with	Not traded and proprietary in nature, with no

comparables and pricing information	marketable comparables
Management assumptions and actions have no bearing on valuation	Real option value is derived from decision-making of Management

Source: (Mun 2002)

Decision-makers have different types of real options to choose from and may arrange them in parallel or in sequence. Expand, contract, terminate, and defer are frequently utilized real options that can be exercised by a decision-maker. They have value that is not captured with conventional NPV, IRR, or BC ratio analysis. When NPV analysis is augmented with the procedure recommended in this thesis it will show the value of flexibility that would otherwise be unrecognized. This thesis can demonstrate the ease with which existing BCA procedures can be complemented with real options analysis while retaining process transparency. The presence of one or more real options gives the decision-maker a collection of "caps" and "floors" that can be utilized when needed. A cap is an upper limit and decision-makers find investments that are capped to be undesirable. A floor is a lower limit that restricts the lower limit of an investment outcome.

Real options can be broadly classified into two categories defined by their perspective application to the investment (the system). A real option that is applied to a system and focuses on external factors is a real option "on" systems. These real options are the most widely researched and most likely to use and benefit from financial options theory tools. Real options "in" systems are almost entirely based on factors that are internal to the system.

Real Options "on" Systems

Real options "on" systems are options that take external factors into consideration and regard the system as a black box.. Some of the external factors, like a commodity price and the current risk-free interest rate, may be observable data that could be used in an option-pricing model borrowed from financial options theory. Case study examples of real options "on" systems exist in the Oil and Gas, Pharmaceutical and Aerospace industries (Copeland and Antikarov 2003).

Example – Aerospace Industry

Post and Bennett (2004) pioneered the application of the Cox-Ross-Rubenstein (1979) binomial lattice to the valuation of the FAA's Controller Pilot Data Link Communications system. In their case study, they point out the shortcomings of conventional discounted cash flow methods where the value of flexibility is ignored. Their valuation of flexibility in a project using the binomial lattice is highly realistic and plausible but it also carries with it the weaknesses of applying financial options theory to real options: 1) volatility must be estimated instead of observed from a financial market, 2) the option being valued is unique and cannot be synthetically created in a replicating portfolio, 3) without a replicating portfolio it is not possible to guarantee that the option is arbitrage[1] free, 4) the selected discount rate is meaningful to the project, and 5) the selected discount rate is appropriate for the very long investment evaluation period. As mentioned earlier the strength of financial options pricing models is their dependency on a market observable interest rate (like the 10-year US Treasury Bill) and a relatively short period until expiration when compared to a real asset. Although there are weaknesses in applying financial option theory models to real options, Post and Bennett are encouraging a paradigm shift in how decision-makers can better manage risk by including flexibility in their projects.

[1] Simultaneous risk-free buying and selling of an asset or financial instrument with a profit. Certain market participants actively seek out arbitrage opportunities in capital markets as part of their strategy, and as such when arbitrage opportunities do emerge, they are rapidly eliminated. One example of arbitrage is the simultaneous buying and selling of a specific currency on two different currency exchanges. Assuming negligible trading fees a 1/10th of a cent difference on $100 M simultaneous buy/sell transaction results in a $100,000 risk-free profit.

Real Options “in” Systems

Real options “in” systems are structured to take advantage of flexibility that may be designed into the system. Engineering design is based on technical specifications that become static around the time that the most of the design work commences. The design specifications become decoupled from external changes, like social, economic and political changes. Decoupling has advantages and disadvantages. In the short-term it has the advantage of treating the design as a project with a distinct beginning and distinct end that limits the total design cost. But the total design cost is only a fraction of the total system lifecycle cost and designing a technically optimal system does not necessarily mean that it will be optimal for the non-technical (social, economic, political, etc…) systems with which it will interact. The disadvantage of decoupling design from non-technical specifications is that the system design is also decoupled from forecast uncertainties and is inflexible. By coupling design with non-technical factors that are highly uncertain, the system can be designed to be a flexible system that is positioned to respond effectively to unpredictable futures. A paradigm shift is required to accommodate this change since current engineering design practices are focused on the optimization of design to (for) static specifications that exclude non-technical factors.

One example of an embedded system option is landbanking - the purchase of more land than is immediately needed for a project - so that a manager can expand an airport runway or other infrastructure that is dependent on land for expansion. Another example is a case study of a Parking Garage (de Neufville et al. 2006) where an up-front premium is paid to reinforce the footings of a parking garage so that it may be expanded by adding additional levels, if deemed necessary in the future.

It may seem reasonable to expect that systems should be designed for flexibility and as transparent methods become the norm, the paradigm will shift. A potential catalyst for shifting the paradigm lies in establishing the credibility of valuing real options in systems in a transparent manner. In this thesis it is proposed that real option valuation can be accomplished with ordinary desktop computer software, is compatible with US Federal Guidelines for BCA, and is consistent with FAA ‘best practices’.

Some examples of case studies on real options “in” systems are presented below.

Example #1 – Commercial Real Estate

de Neufville and colleagues (2006) proposed that flexibility be included in a parking garage design by reinforcing the footings at additional initial expense. The authors show that by matching the capacity of the parking garage to the initial demand along with the embedded option to expand that the mean project NPV, NPV(mean), increases. The reasoning behind these improvements is that the flexible project has capacity that is closely matched with the demand in each of the time periods or at least is better matched when compared to the inflexible projects. The flexible project also has a substantially lower initial cost than the larger inflexible project but is capable of being expanded to the larger size when needed in the future. Should it turn out that the project never needs to be expanded then the additional costs to reinforce the footings yield no benefits, but those costs are a fraction of the costs of building a larger garage for demand that may never materialize.

Example #2 – Aviation Industry

An airport sponsor would like to build a new airport that would initially be a towerless General aviation airport and could potentially be expanded to accommodate substantial new services in the future. But there is uncertainty in the long-term Terminal Area Forecast (TAF) and the airport sponsor knows that forecasting the arrival of specific future event would be imprecise. A future event would be the need to expand the airport runway to accommodate substantial services that are commensurate with commercial carrier operations. The airport sponsor proposes three alternatives for consideration:

1) long runway
2) short runway
3) short runway with landbanking and the option to expand the runway

In this example, the airport sponsor proposes landbanking as a way to a) provide the airport flexibility for expansion, b) limit the initial capital outlay for a runway that meets current needs and c) hedge against land value appreciation by buying rural land now instead of sub-urbanized land by eminent domain if needed in the future. This example is reintroduced in Chapter 5 again as the hypothetical project that will be the basis of the Hypothetical Project BCA for this thesis.

Example #3 – Telecommunications Industry

During the 1990's there were significant advances in fiber optic technology that significantly improved the capacity of telecommunication networks. Due to the rapidly changing technology, however, it was not unusual for fiber optic network elements and in particular fiber optic cable to become obsolete prior to the completion of construction. Many telecommunication carriers built highly interconnected global, national, and metropolitan fiber optic networks to support growing demand for voice and data networks. Almost all the carriers had the same options to expand their networks as technology and business conditions changed. One carrier in particular, a new market entrant, Level 3 Communications, added an additional dimension of flexibility when building out their global fiber optic network. Level 3 Communications included empty conduits in 23,000 intercity route miles of their network during the build out. When fiber optic technology changed or there was additional demand between points on the network they could expand by pulling in newer-generation fiber optic cable in existing empty conduits instead of unearthing previously buried trenches[2]. With modest upfront costs (approximately $100 M on a $3,000 M project) Level 3 positioned itself to expand when needed with negligible lead-time (Kiewit Corporation 2006; Level 3 Communications 2006).

Summary

The common theme in the above examples and in real options "in" systems is that the option is based on a technical characteristic of the system that is not obvious if it is treated like a black box. To embed a Real Option "in" a System, the technical characteristics must be known and well understood. In large infrastructure systems the available option(s) may be obvious because they are visible, as in, for example, landbanking so expansion can occur in the future. For a system with additional layers of abstraction the option may not be as easily discernable. In the telecommunications industry example, the incumbent system planners planned on expanding their network by selecting fiber optic cable that would accommodate multiple wavelengths simultaneously. Table 2.2 summarizes uncertainty and the flexibility for the above examples.

Table 2.2 – Summary of Real Option(s) "in" Systems Examples

Industry	Uncertainty	Flexibility	Option Type
Commercial Real Estate	Uncertain demand for parking garage spaces	Reinforce parking garage footings so that additional levels can be added in the future	Expansion
Aviation Industry	Uncertain runway requirements	Landbank so runway can be expanded when necessary	Expansion
Telecommunications	Fiber optic	Include empty conduits	Expansion

[2] Cable installation in a conduit is a one-way process. When a cable is obsolete or completely fails it is common practice to abandon both the conduit and the cable. A fiber optic cable with hundreds of fiber optic pairs rarely fails entirely, unless accidentally severed, but they can become technologically obsolete.

Industry	technology and future demand	for future fiber optic technology and expansion	

2.F Forecast Accuracy

Forecasts are a key part of planning what and when organizational resources will be needed. Although forecasts are thoughtfully prepared with the best intentions they are known to be imprecise. The degree of precision is approximately correlated with the forecast period where short-term forecasts have more precision than long-term forecasts. In retrospect, forecast errors in long-term forecasts are a result of the unknown unknowns – events that are entirely unpredictable and excluded from the forecast. When planning is based on a forecast it would be logical to include flexibility that would enable the then-current system manager to adjust the system when new information emerges in the future. The utility of real options in systems is not the flexibility they offer but their ability to gracefully accommodate a wide range of future scenarios without depending on a precise forecast.

In recent years the Annual FAA Aerospace Forecasts (2003, 2004, 2005 and 2006) have each included a retrospective summary of their respective forecast accuracies. For these forecasts, short-term is the period from 1-5 years in the future and long-term is 10 years out (US Federal Aviation Administration 2006b). Short-term forecasts have a high degree of accuracy and they are frequently relied upon for planning variable operating costs (staffing plans), whereas long-term forecasts have a noticeably reduced level of accuracy and they are typically used for capital expenses (infrastructure investments).

Table 2.3 summarizes aggregated accuracy data found in the FAA Aerospace Forecast (2003, 2004, 2005, and 2006). The 1-year absolute average error of Route Passenger Miles (RPM) for each of the 1-year forecasts between 1996 – 2002 was 2.6%. The same retrospective 7-year period was used for the periods ending in 2002, 2003, and 2004. For the period ending in 2005 the FAA Aerospace Forecast expanded to a 10-year retrospective period and also introduced an additional category for en-route operations (not shown in the table). The period ending in 2005 split the 10-year period to show that prior to 2002 the long-term forecasts were more precise. The table provides quantitative proof that forecasts are imprecise and that long-term ones are less reliable than their short-term equivalents.

Table 2.3 - FAA Aerospace Forecast Accuracy (Retrospective)

FAA Aerospace Forecast FY	Retrospective Forecast Period	Route Passenger Miles (RPM)		Commercial carrier domestic enplanements	
		1 year	10 year	1 year	10 year
		[Absolute Average Error in %]			
2003-2014	1996-2002	2.6	9.6	(0.7)	5.5
2004-2015	1997-2003	2.2	9.2	(0.4)	4.6
2005-2016	1998-2004	2.5	8.7	(2.3)	3.3
2006-2017	1995-2005	2.4	N/A	2.1	N/A
	1995-2001	N/A	1.9	N/A	2.0
	2002-2005	N/A	3.3	N/A	2.2

Source: FAA Aerospace Forecast (US Federal Aviation Administration 2003b, 2004d, 2005e, and 2006b)

The summarized data in the above table doesn't convey information about the year-to-year variances since it aggregates 7-years of information into a representative average. Year-to-year data are available in the FAA Aerospace Forecast and additional in-depth accuracy analysis could be performed. But, instead of showing variability of the year to year forecast accuracy, it would be more important to point out that the relative numbers in the above table translate into very large absolute numbers. Annual RPMs are in the order of 500 B (miles) and Commercial carrier domestic enplanements are in the order of 750 M (enplanements). In 2005 they grew by 8.0% and 7.1% respectively. When using the order of magnitude estimates a forecast accuracy error of ±1% would result in an RPM error of ±5 B (miles) and a Commercial carrier domestic enplanements error of ±7.5 M (enplanements). Small accuracy differences in the FAA Aerospace Forecast have a significant impact when measured in absolute terms.

As the accuracy of forecasts decreases, the need to integrate flexibility that can help manage uncertainty increases. As commented on in the Federal Register: "The FAA agrees that there are more unknowns associated with long term projects just because of the longer time horizon" (US Federal Aviation Administration 1999c, p. 70110). Because long-term forecasts are imprecise, flexibility embedded into projects allows a greater range of responses to the unpredictable future. Infrastructure projects that are planned without any flexibility in the design cannot be conveniently or easily adjusted to accommodate any long-term forecast errors.

Perhaps the motivating factor for reduced reliance on long-term forecasts is not that they are wrong but that they are increasingly wrong. Correlation between aviation activity and leading economic indicators was known to be much stronger in the past than it is today (US Federal Aviation Administration 2006b). In the past an economic model could remain unchanged for long periods of time and have a high degree of forecasting reliability (US Federal Aviation Administration 2006b). Unanticipated events are occurring with higher frequency and more volatility (measured as an increase in standard deviation) than they have in the past. Their impact on a forecast cannot be evaluated because they are not known in advance. Examples and anecdotal evidence of recent unanticipated events are: Gulf War II, Hurricane Katrina, and rising Crude Oil prices.

Forecast Accuracy Example

Iridium and Globalstar both separately forecasted, designed, built, and operated celestial wireless voice and data networks that were technical successes and economic failures. Their independent demand forecasts for voice and data services were used as the basis for the system design. Both carriers made the same fatal mistakes: 1) they designed and optimized their systems to specifications that were inflexible by assuming that external factors could be neglected and 2) they assumed forecast would remain unchanged over a seven-year design and build period. The technically optimal design was unforgiving because it was designed to meet specifications that were based on a long-term forecast (de Weck, de Neufville, and Chaize 2004). The result was a system that functioned technically correctly but was unable to support itself economically because consumers in need of a wireless service could choose from a terrestrial wireless service provider with a significantly smaller handset and recurring fees. Both Iridium and Globalstar are partial economic successes because the original assets continue to operate today as a result of successful bankruptcy filings that permitted the assets to be sold off for a very small fraction (approximately 0.5%) of the original investments. A complete economic failure would have been to decommission the celestial networks by adjusting satellite trajectories to burn up in the earth's atmosphere. Iridium and Globalstar services are in demand in geographical locations where there is no local terrestrial carrier service either because of sparse population or natural disaster. The original demand forecast, which the system design was closely optimized for, relied heavily on subscribers from densely populated areas.

The issue of forecast accuracy is central to understanding the need for real options. If forecasts are known to be frequently wrong and long-term forecasts are especially wrong, then why design a system with specifications derived from a long-term forecast? Why not design a system with flexibility that will offset the uncertainty in the long-term forecast, assuming that flexibility and uncertainty can be matched? Real options are intended to produce results that can successfully and profitably accommodate a wider range of outcomes, and thus designs with real options are less sensitive to failures in long-term forecasts.

Nullifying Uncertainty with Flexibility

The experience of the system planners and designers suggests that there should be design flexibility that can accommodate the forecast uncertainties. The cost of the proposed flexibility is acceptable when all benefits exceed all costs. The result should be a nullification of uncertainty with flexibility.

The premise of real options is that system uncertainty should be offset with flexibility. At least two organizational changes need to happen for this to occur:

1) the paradigm to design and optimize to specifications without regard to economic considerations must be abandoned, and
2) planning needs to be a collaborative and iterative process that involves the system planners and the system designers. The system planners communicate the uncertainty in the plans to the system designers and the system designers communicate the flexibility choices available to the system planners. Eventually, the two groups select the flexibility that will be included to offset the planning uncertainties.

Value At Risk

For the purposes of real options analysis, Value at Risk (VAR) is the Cumulative Probability Distribution (CDF) of the Net Present Value. The upper and lower boundaries of the CDF are explicitly defined as the floor when the CDF=0 and the cap when the CDF=1. Alternative notation for the floor, mean, and cap would be NPV(0), NPV(mean=0.5), and NPV(1) respectively[3]. A Flexible system is expected to have NPV boundaries that are the same as or better than those of an inflexible system, specifically $NPV_{flexible}(0) \geq NPV_{inflexible}(0)$ and $NPV_{flexible}(1) \geq NPV_{inflexible}(1)$.

Consider the example VAR diagram in Figure 2.2 and the accompanying data in Table 2.4 where the three alternatives are equivalent in all respects except NPV. Data in the table summarizes the floor, mean, and cap in the figure for each alternative. The best project is alternative 1 which has the highest NPV, more specifically the highest NPV(mean). However, NPV(mean) alone does not adequately describe the range of potential outcomes of an alternative. To get an improved understanding of the range of potential outcomes the VAR diagram can be examined where it can observed that:

- $NPV_2(0) \geq NPV_3(0) \geq NPV_1(0)$ and
- $NPV_1(1) \geq NPV_3(1) \geq NPV_2(1)$

Table 2.4 - Example VAR Data

Alternative	NPV(mean)	NPV(0%)	NPV(100%)
1	~1.2	>(0.25)	<3.3
2	~0.9	>0.60	<1.5
3	~1.1	>0.24	<3.0

3 NPV(x) is read as the NPV with probability x.

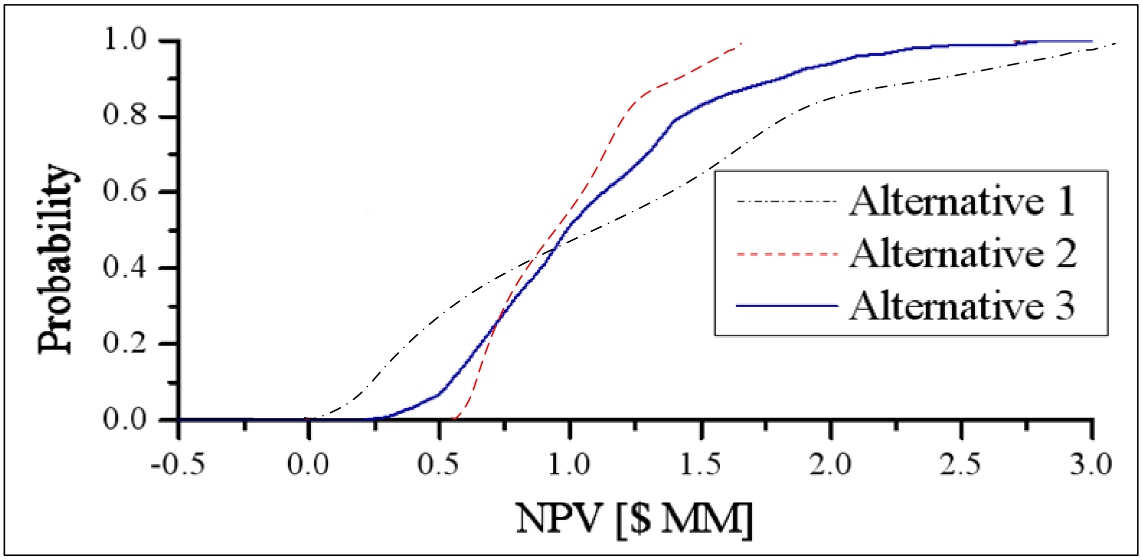

Figure 2.2 - Example VAR Diagram

Value at Risk is highly useful in circumstances where the option value is either difficult to determine or is superseded by other factors relevant to the decision-maker and the specific system being evaluated. In the absence of a real option value, the strategy still has value and it is conveyed through a Value at Risk diagram. The asymmetric nature of an option is usually apparent in a Value at Risk diagram by shifting the boundaries in a favorable way. From a positive perspective a Real Option should: 1) improve upside potential and 2) limit downside exposure by introducing a floor and/or removing a cap.

Project Risk Management

There is another paradigm shift that can also be facilitated when real options in systems are adopted. Risk Management for projects is heavily skewed towards protecting from downside risk exposure by including floors. But little attention is given to taking advantage of upside opportunities by exploiting opportunities by removing caps. Projects infrequently have the benefit and convenience of transferring risk, the dominant method used in capital markets, but do manage risk through a combination of 1) acceptance, 2) avoidance or 3) mitigation techniques. An opportunity exists to find methods of exploiting upside risk (removing caps) instead of only managing the downside risks (inserting floors).

Caps are any upper limit barrier that precludes a system manager from increasing performance, capacity or other desirable characteristic when necessary in the future. The Parking Garage (de Neufville et al. 2006) presented at least two caps that limited the number of total levels that could be built. One cap was at capacity and would permit no additional expansion – the footers supported n levels and n levels were constructed. Another cap was under capacity and would permit a future expansion – the footers supported m levels and n levels were built initially and m-n levels could be built in the future where n>0, m>0 and m>n.

2.F.1 Valuation of Real Options

Real options, like financial options, can be valued with financial options theory equations or with the difference between the flexible and inflexible NPV, $NPV_{flexible} - NPV_{inflexible}$. Financial options equations commonly applied to equity options and used to value real options require assumptions that are readily available from a financial market but difficult to apply port to the real option. For example, the volatility of a stock is calculated with observed historical stock price information. For a real option there is no historical pricing information. In the absence of historical pricing information a proxy could be used, however, a real asset, unlike a capital market financial instrument, is unique and although a suitable proxy may be found it may not be credible. But if there is it is from unique assets that are assumed to be the same. Figure 2.3 shows three different levels of details that summarize $NPV_{flexible} - NPV_{inflexible}$. The top two levels show that the value is calculated with either a deterministic or a stochastic model, both of which may be in a spreadsheet model.

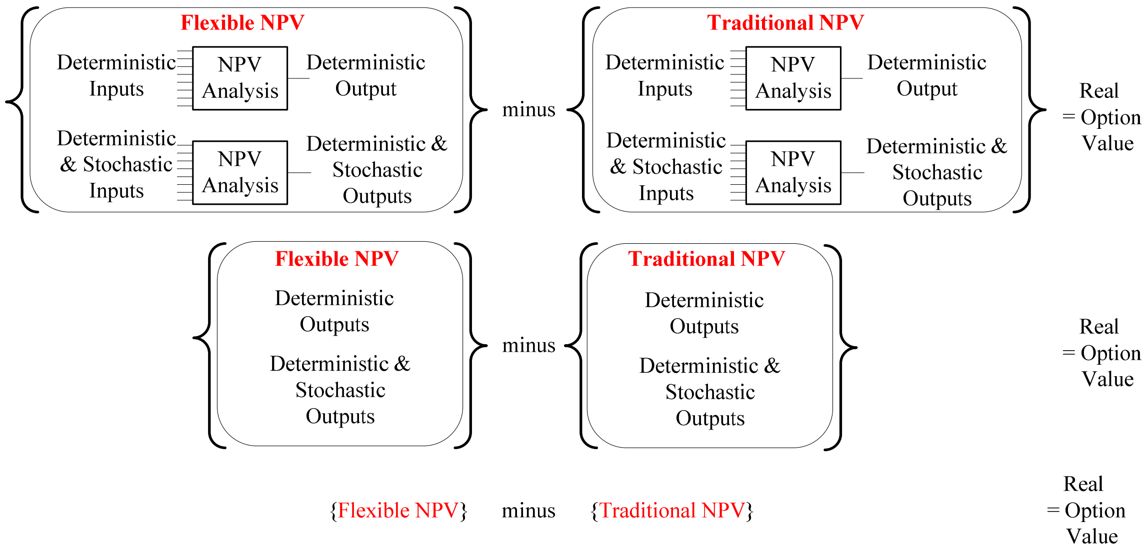

Figure 2.3 – Calculate Real Option Value

B-S and Binomial Lattice

The two common methods of option valuation are Black-Scholes (1973) and Cox-Ross-Rubenstein (1979). The Black-Scholes Pricing Model is a partial differential model with many different solutions. When boundaries are applied, a specific solution can be identified. When initially proposed, this model was limited to pricing a call that can be exercised only on the same day it expires. Cox, Ross and Rubenstein (Cox, Ross, and Rubenstein 1979) introduced a simplified approach to valuing options that relied on a binominal lattice with discrete time periods instead of a continuous time partial differential equation.

The common option valuation models described above are thought to be suitable for real options “on” systems where the system itself is a black box that is subject to external factors which form the basis of input for Real Option valuation.

There are several weaknesses with these models in the financial domain and even more in the non-financial domain:

- How is arbitrage enforced pricing maintained outside of an exchange-traded option market?
- How is volatility calculated when the investment is a one-time opportunity?
- How can a replicating portfolio be created when the underlying asset is unique?
- Does the concept of risk-free interest rate have meaning outside the context of capital markets?

Practitioner Method

de Neufville et al (2006) demonstrates a practitioner method of evaluating system flexibility intuitively. The authors propose in one of their examples that a system be built with flexibility that will exploit the uncertainty in the forecast by matching the initial system capacity with the initial forecasted demand and, for a small additional cost, embedding a feature to permit the system capacity to be expanded to match future demand, if it does in fact emerge. This practical method is logically repeatable for practitioners and transparent for decision-makers; however, it goes against the current paradigm, which is to build a technically optimal system that matches current specifications.

2.G Adoption Rate of Real Options

Real options analysis, which utilizes NPV analysis, has displaced traditional NPV analysis at a rate of adoption that is industry dependent. Figure 2.4 shows the attributes that impact the rate of absorption (Rogers 1995). It is debatable, but some industries have adopted real options (Petrochemical, technology, pharmaceuticals, etc…) and some have not (Pulp and Paper, Government, etc…). The proposed real options valuation method, and soon to be introduced in Chapter 4, meets all of the Rogers' attributes for unimpeded adoption.

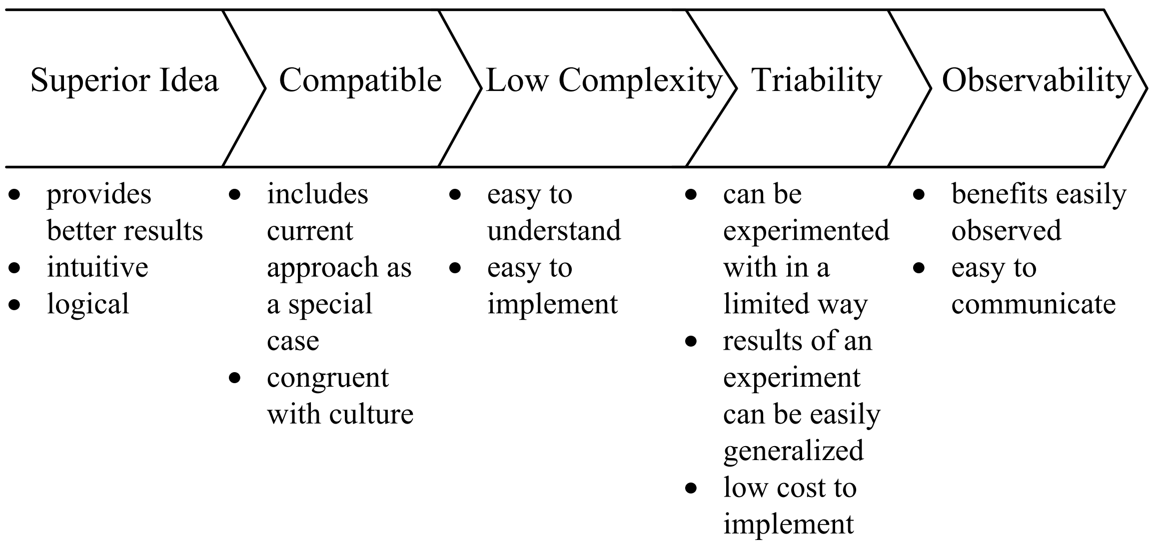

Figure 2.4 - Attributes of innovation that affect the rate of adoption
Source: Diffusion of Innovation (Rogers 1995)

2.H Summary and Basic Definitions

Real options analysis is a technique that allows one to incorporate the value of flexibility into Benefit Cost Analysis. The proposed method complements existing BCA procedures and is both transparent and understandable to a very broad audience. This Chapter has introduced the basic concepts that lie behind the real options evaluation that will be used in the case study in Chapter 5. Motivation for the consideration and use of real options is that forecasts are known to be inaccurate and are becoming increasingly imprecise with unanticipated exogenous events.

2.H.1 Comparison of Real Options and Financial Options

A Real Option is "a right but not an obligation" on an investment in a real asset that is irreversible. A position in a liquid and actively traded financial instrument can be opened and closed with convenience and little transaction overhead. The same cannot be said about taking a position in a real asset, where the investment is often one-way due to the absence of liquidity and presence of irreversibility. Although a real option is irreversible and illiquid, it can be structured in a way that is flexible to offset the uncertainty in a forecast when it includes a real option. The presence of one or more real option(s) changes a fixed real asset into a flexible real asset.

2.H.2 Selected Definitions

- Alternative/Choice – A selection from a group of two or more possibilities – for example a group of different plans for a specific project.

- BCA – An analysis of all benefits and all costs associated with each alternative in a proposed investment or project. Quantifiable benefits and costs that can be monetized are discounted and summarized as a Benefit Cost ratio.

- BC ratio – Dividing quantified benefits by costs will create a BC ratio. There are three significant outcomes for the BC ratio. A desirable BC ratio is greater than 1. Projects must have a BC ratio > 1 to be funded.

    - BC ratio > 1 means the Benefits exceed the Costs
    - 0 < BC ratio < 1 means the Costs exceed the Benefits
    - BC ratio = 0 means the project has no benefits
    - BC ratio = 1 means the project benefits and costs are equal and corresponds the NPV=0

- Deterministic Model – a model that assumes that for each input there is one value known to occur. A deterministic model is a special case of a stochastic model where each input is discrete and has probability = 1.0

- Flexibility – a characteristic of a system that can accommodate change to meet a new requirement

- NPV – Net Present Value is the difference between a positive and a negative series of discounted cash flows. A desirable project will have benefits exceed the costs: when ranking NPVs, the largest NPV is ranked highest with each lower NPV being ranked lower than the preceding one.

    - NPV > 0 means Benefits > Costs
    - NPV = 0 means Benefits = Costs
    - NPV < 0 means Benefits < Costs

- Option – a right but not an obligation to buy or sell an asset at a pre-determined price.

- Option, Financial - a right but not an obligation to buy or sell an exchange traded asset at a pre-determined price.

- Option, Real – an option on a real asset

- Option "in" a System, Real – real options thinking that requires some technical knowledge of the system; relies on ordinary quantitative tools that are easily understood by decision-makers.

- Option "on" a System, Real – real options thinking applied to a black box system quite often with option valuation models intended for capital markets. In general, no technical knowledge or details of the system are necessary.

- Stochastic Model - a model that assumes that for each input there is a probability distribution that represents the range and probability of potential values. Monte Carlo simulation is a common, open-form stochastic model method.

- Uncertainty – Elements and facets of a forecast that are not known with certainty.

- Volatility – In statistics, this is the dispersion from the mean. A variable with a high (low) volatility has a wide (narrow) dispersion.

3 US Federal Rules and Practices for Project/Program Evaluation

The purpose of this thesis is to show a method of real options analysis that is compatible with federal guidelines for BCAs and compatible with FAA practices. The proposed real options method focuses on FAA practices as an example of a larger set of federal practices the aim is not to demonstrate perfect legislative compatibility, but rather to show the main principles and their compatibility with federal BCAs. Although the Airport BCAs are not perfectly compatible in all respects with the federal BCA mandates, they are largely based on them and do not differ in ways relevant to real options analysis.

When the FAA spends its annually-appropriated budget on infrastructure projects it does so in two categories with different statutory requirements for BCAs. When spending on itself or other federal government entities it is statutorily obligated to follow legislated BCA mandates (US Office of Management and Budget 1992, p. 3). However, when spending on non-federal government entities there is no statutory requirement for BCA. The Airport Improvement Program (AIP), which provides grants to non-federal entities, is an example of where "the decisions to award AIP discretionary grants or LOIs are matters for FAA discretion, the FAA may establish criteria for their award as policies, and need not follow the procedures for rulemaking in the Administration Procedures Act" (US Federal Aviation Administration 1999c, p. 70107). Although spending on nonfederal government entities is at the sole discretion of the FAA, acting on behalf of the Secretary of Transportation, their current best practices mirror existing BCA statutory requirements (US Federal Aviation Administration 1999a; US Federal Aviation Administration 1999c, p. 70107).

Since 1997 the FAA has delegated responsibility for Airport BCAs to airport sponsors while retaining oversight and funding decision responsibilities (US Federal Aviation Administration 1997c, p. 34108). A common misconception is that the FAA owns and runs airports. With the exception of Reagan National and Washington-Dulles International airports the FAA has no airport ownership[4] (Metropolitan Washington Airports Authority 2006, 49 U.S.C. § 49101). Airport sponsors are responsible for operating and maintaining their facilities and, in larger airports, may have FAA Air Traffic Control employees. Airport sponsors are encouraged to conduct a BCA with their initial airport master plan. Upon receipt of an Airport BCA the FAA will independently and rigorously analyze the data, assumptions, and recommendations. The FAA has encouraged airport sponsors "to make use of innovative methods for quantifying benefits and costs where these methods can be shown to yield superior measures of project merit" (US Federal Aviation Administration 1999a, p. 1). The "FAA is considering developing standard guidance for the application of BCA requirements to General Aviation (GA) airports. In order to do this, we need to be able to quantify the benefits of GA activity. Accordingly, the FAA is willing to receive input on developing methodology to identify and measure these benefits" (US Federal Aviation Administration 1999c, p. 70107). This Chapter discusses FAA practices to show the foundation on which the real options analysis is built and its compatibility with existing procedures.

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[4] Reagan National Airport and Washington Dulles International Airport property is almost entirely owned by the US government and currently operated and maintained by the Metropolitan Washington Airports Authority with a lease that expires in 2067. The Metropolitan Washington Airports Authority is an independent entity that is neither a federal or state level agency.

3.A.1 The Federal Aviation Administration

The FAA is responsible for the safe use and management of civilian airspace, referred to as the National Airspace System (NAS) (US Federal Aviation Administration 2005f). The FAA manages 41,000 pieces of equipment[5] and is actively engaged in irreversible investments to maintain and/or expand existing infrastructure (US Federal Aviation Administration 2006a, p. 11). Adding complexity to the decision-making process is uncertainty about the best geographic location for investments and what investments will have the largest overall positive impact on the stakeholders.

The FAA is one of many sub-entities of the United States Department of Transportation (DOT), which falls under the Executive Branch of the United States Government. The FAA was created with the passing of the Federal Aviation Act of 1958. Subsequently it became part of the Department of Transportation in 1967 after the Department of Transportation Act of 1966. Since its inception, the FAA has retained the same three-letter acronym, but changed its name from Federal Aviation Agency to Federal Aviation Administration when absorbed by the Department of Transportation in 1967. Figure 3.1 shows the 2006 organization of US Government entities, including the top levels of the FAA and the Office of Airport Planning and Programming and Office of Aviation Policy and Plans which play a key role in managing the Airport BCA Guidelines.

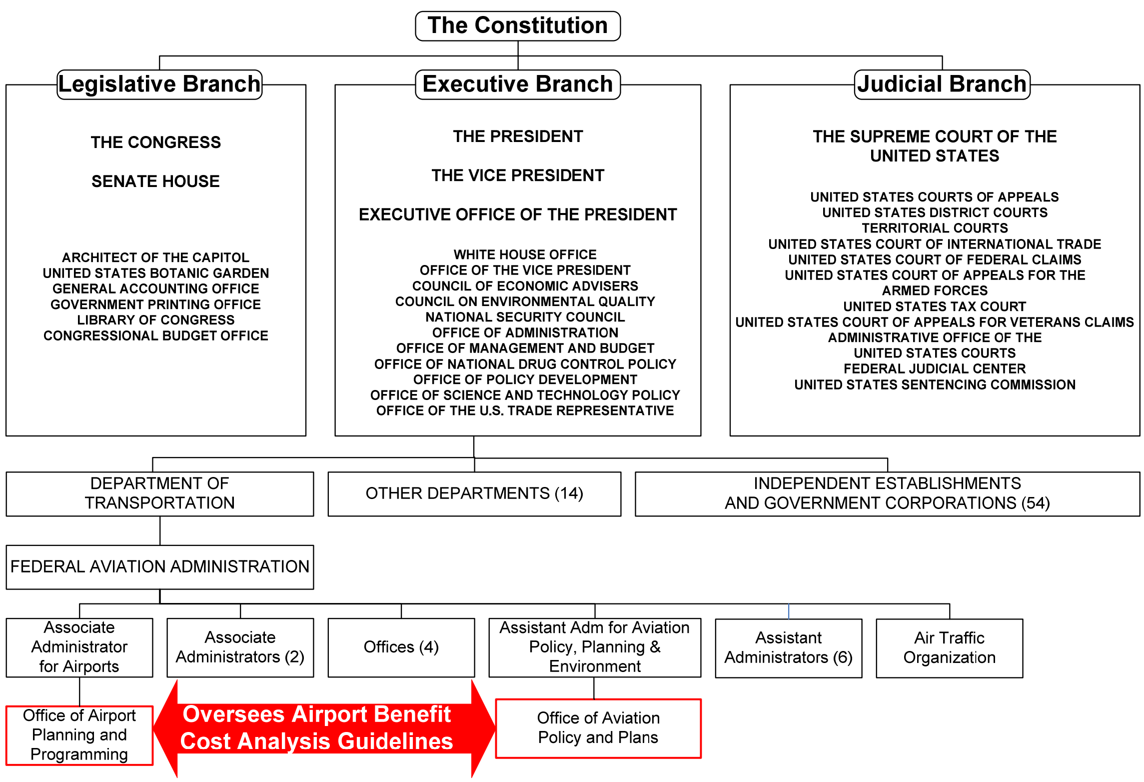

Figure 3.1 - Selected US Government Organizations Related to the FAA (2006)
Sources: www.faa.gov and www.gpo.gov

[5] On December 31, 1998 and 2005 there were 38,209 and 41,099 pieces of equipment in service, respectively (US Federal Aviation Administration 2006a, p. 11) an annual increase of 1% per year.

3.B Mandates, Guidelines, and Rules

Many of the mandates, guidelines, and rules for Federal BCAs are listed in Appendix I. Like all federal agencies, the FAA is statutorily obligated to comply with the mandates, guidelines, and rules when spending federal funds on itself or another federal entity. For Airport BCAs the FAA manages the guidelines and sets the policies that closely resemble OMB Circular A-94 and Executive Order 12893, both of which are substantial components of ordinary federal BCAs. The largest difference between a federal BCA and an FAA airport BCA is that the FAA, acting on behalf of the Secretary of Transportation, is the sole decision-maker. A federal BCA has a common format so that the OMB, acting on behalf of the Office of the President, can review substantial proposed spending of any federal entity statutorily obligated to conduct a federal BCA.

3.B.1 Legislation and Mandates That Define FAA Airport BCAs

Decision-making by the FAA is guided by mandates from the Executive Branch of the US government, specifically Executive Orders 12291, 12866, and 12348, Office of Management and Budget Circulars A-4, A-94, and A-94, Appendix C. Executive Order 12866, issued during the Clinton administration in 1993, provides policy level guidance to keep federal agencies within their legislated jurisdictions, to ensure that their spending is not wasteful, and to provide improved decision-making transparency to the public. Executive Order 12866 further clarified Executive Order 12291, issued in 1981 during the Reagan administration. Executive Orders 12291 and 12866 are relevant when the proposed impact on the economy will exceed $100 million.

The Office of Management and Budget Circular A-4, A-94, and A-94, Appendix C advocate and mandate the use of BCA with discounted cash flows, while at the same time acknowledging the weaknesses of these methods (US Office of Management and Budget 1992; 2003; 2006). Office of Management and Budget Circular A-4 mentions real options but does not go into details or provide a reference to real options as a method for the treatment of uncertainty (US Office of Management and Budget 2003, p. 39). Guidelines provided by the FAA for airport sponsors conducting BCA indicate that “airport sponsors are encouraged to make use of innovative methods for quantifying benefits and costs where these methods can be shown to yield superior measures of project merit” (US Federal Aviation Administration 1999a, p. 1).

Economic Analysis at the FAA conforms very closely to OMB Circulars A-4 and A-94 which are based on BCA that relies on discounted cash flow techniques. Office of Management and Budget Circular A-11, titled “Preparing and Submitting Budget Estimates”, clearly states that “OMB Circular No. A-94, Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs… …This guidance must be followed in all analyses you submit to OMB in support of legislative and budget programs” (US Office of Management and Budget 1999, p. 559). Compliance with OMB Circular A-94 is a mandatory requirement and a positive NPV is preferred but not necessarily required “Programs with positive net present value increase social resources and are generally preferred. Programs with negative net present value should generally be avoided” (US Office of Management and Budget 1992, p. 3).

For the purposes of this thesis the focus will be on the application of real options in a case study that is constrained by FAA Airport Benefit-Cost Analysis Guidelines and influenced by OMB Circular A-94.

3.B.2 FAA Airport BCAs

Airport infrastructure projects are financed with funds from a variety of sources which may include the Airport Improvement Program (AIP), which is funded entirely by the Airport and Airway

Trust Fund through 12 excise taxes and fees on aviation system participants. Additional funding sources are local taxes, specifically, the Passenger Facility Charge (PFC) and other non-federal resources. Many of the grants from the AIP are disbursed without a BCA because compliance with safety standards supersedes the need for an explicit BCA review or because they are legislative entitlements. In the 2004 fiscal year (FY) the FAA reviewed 14 Airport BCAs requesting $380 M in future years from the AIP fund and during the same time period the FAA awarded 2,150 AIP grants totaling $3.3 B (US Federal Aviation Administration 2006h, p. iv). Funds from the AIP are either formulary or discretionary. Formulary funds are determined by legislation and a prioritization process that is consistent with the needs of the NAS as defined in the National Plan of Integrated Airport Systems (NPIAS).

When an Airport BCA is required, it is for a substantial funding request for a capacity project that the FAA will review independently but in close consultation with the airport sponsors. An Airport BCA is required when a discretionary funding request for a capacity project exceeds $5 M (US Federal Aviation Administration 1999c, p. 70107). A capacity project is one that adds new infrastructure to accommodate more passengers, aircraft, and/or cargo. AIP eligible projects over $5 M that do not require a BCA are "Safety, security, conformance with FAA standards, or environmental mitigation" (US Federal Aviation Administration 1999c, p. 70107). AIP eligible projects over $5 M that may require a BCA are capacity expansion projects at non-hub small, medium and large airports. Medium and large (small) airports are defined as having greater (less) than 0.25% of national enplanements. At the discretion of the FAA a BCA may be requested if the requested funds are thought to be in excess of what would be necessary or to establish that the project will be beneficial.

Airport sponsors rely on funding from different sources. GA airports typically are highly dependent on the AIP for funding and by legislation may have up to 95% of their eligible AIP projects funded with AIP grants. Small, medium, and large airports may have up to 75% of their eligible AIP projects funded with AIP grants. However, small, medium, and large airports are capable of self-financing their projects through local taxes (PFC, local aviation fuel taxes and landing fees), current income (rental income), or long-term debt. For example the $1.1 B expansion at Lambert-St. Louis International Airport, which was completed in 2006, received 22% of its funding from the FAA AIP (US Federal Aviation Administration 2006f). The remainder was paid for with long-term debt backed by income from rates and charges to concessionaires, airlines, and airport passengers or meters and greeters.

3.C BCA Case Studies

Three FAA Airport BCAs, each prepared by or on behalf of an airport sponsor, were used as examples of current practices outlined in the "FAA Airport Benefit-Cost Analysis Guidance" (US Federal Aviation Administration 1999a). When preparing an airport BCA for the FAA the airport sponsor is seeking funding of an AIP eligible project. If the FAA concurs with the airport sponsor's BCA, then funds from the AIP and/or the airport sponsor's PFC would be approved. Successful funding requests will result in a Letter of Intent (LOI) (US Federal Aviation Administration 1994a, p. 54482) which is a formal announcement that the project will be funded. A brief description of each is listed below with interesting observations and a summary of the findings.

3.C.1 BCA #1 – Proposed Western West Virginia Regional Airport

Benefit-Cost Analysis #1 (Earth Tech, Inc. et al. 2003) proposes the consolidation of commercial air traffic at a new regional airport. BCA data are summarized in Table 3.1, and were calculated with a 7% discount rate over a 20-year term.

- Base Case - the base case assumes that the Regional Airport will not be built and that no major capacity-enhancing capital improvements will be made to Yeager (Charleston, WV) and Tri-State (Huntington, WV) airports during the study period.
- Alternative 1 - Completion of safety and capacity-enhancing improvements at Yeager Airport by increasing Yeager 5-23 runway length from its current 6,302' to 7,870'. Enhance and expand taxiway at Yeager and expand runway at Tri-State.
- Alternative 2 – Acquire land and construct a new regional airport with an 8,000' runway. Yeager and Tri-State would remain open as General Aviation airports.

Table 3.1 - Benefit/Cost Summary Data for Western West Virginia Regional Airport

		Base Case	Alternative 1	Alternative 2
PV of Benefits	[$ M]	None	51.2	541.5
PV of Costs			107.0	348.5
NPV			-55.8	193
BC ratio	[no units]		0.48	1.55

Source: (Earth Tech, Inc. et al. 2003)

In a deterministic model, sensitivity of the output variable is measured with respect to changes of one or more of the input variables. These changes are known as One Variable Tests. Sensitivity testing is useful for determining the impact of a change in input variable on the output. One Variable Tests are determined by the model analyst and will have a magnitude that represents the anticipated changes in each input being shocked. A weakness of these tests is that the impact of only one variable can be measured at a time in models that has have input variables which may be correlated with each other (US Federal Aviation Administration 1999a, p. 86).

Alternative 1 was removed from further consideration in the BCA since it had a negative NPV and no sensitivity analysis was performed. Alternative 2 had four sensitivity tests and they are shown in Table 3.2. Variations in future aviation activity were based on anticipated increases in benefits due to the recapture of passengers that would use the proposed airport instead of traveling to larger airports with similar commercial services. Increase in construction costs were estimated to be 15% and were based on an average 15% cost overrun of similar projects. The decreased discount rate of 2.85% was based on OMB Circular A-94 Appendix C (2003). Increased airport operating costs of 20% were based on the range of increased airport operating costs after 9/11 which were between 10% and 30% (Earth Tech, Inc. et al. 2003).

Table 3.2 – One Variable Test Data for Western West Virginia Regional Airport (Alternative 2)

Sensitivity Description	NPV Change	Net Effect on NPV	BC ratio
	[$ M] base → new	[$ M] NPV_{new}-NPV_{base}	[no units] base → new
Variations in future aviation activity	115.8 → 200.2	84.4	1.55 → 1.80
Increase in construction costs	235.4 → 270.8	-35.4	1.55 → 1.41
Decreased discount rate (7% → 2.85%)			
All costs	348.5 → 473.0		
All benefits	541.5 → 931.4		
All benefits and all costs		222.3	1.55 → 1.97
Increased airport operating costs	29.0 → 34.8	-5.8	1.55 → 1.53

Source: (Earth Tech, Inc. et al. 2003)

Note: 2.85% was the 20-year bond yield in 2003 (US Office of Management and Budget 2003a). Net Effect on NPV is measured relative to the base of Alternative 2 NPV, which is $193 M.

The BCA submitted by the airport sponsor was deemed ineligible for AIP funding. After a rigorous and thorough analysis the FAA assigned a substantially lower and more realistic value to the proposed benefits, which resulted in an NPV of less than zero for Alternative 2 (Flannagan 2004). As mentioned earlier the FAA AIP BCAs resemble the OMB A-94 BCAs but are not statutorily obligated to do so. This BCA proposed two (2) alternatives while the minimum required for OMB A-94 BCA is three (3) (US Office of Management and Budget 1992, p. 1).

3.C.2 BCA #2 – Cincinnati/Northern Kentucky International Airport (CVG) Proposed New Runway 17-35 Construction

Benefit-Cost Analysis #2 (Cincinnati/Northern Kentucky International Airport Authority 2000) proposes the construction of a new runway. BCA data are summarized in Tables 3.3 and 3.4 and were calculated with a 7% discount rate over a 20-year term that excluded the initial 5-year construction period.

- The Base Case is to operate the existing runway without modification.
- Alternative 1: the proposed runway will be 8,000' long by 150' wide and is to be connected to the remainder of the airfield by existing and new taxiways. The new runway will be constructed over a 5-year period and operated for a twenty-year period.
- Alternative 2: many Alternatives were investigated but only one was proposed in the BCA.

Table 3.3 - Benefit/Cost Summary Data for Cincinnati/Northern Kentucky International Airport (CVG) New Runway 17-35 Construction

		Base Case	**Alternative 1**	**Alternative 2**
PV of Benefits	[$ M]	None	2,895	None
PV of Costs			203	
NPV			2,691	
BC ratio	[no units]		14.2	

Source: (Cincinnati/Northern Kentucky International Airport Authority 2000)

To test sensitivity the airport sponsor suggested a systematic range from 90% to 50% and 10% intervals (Cincinnati/Northern Kentucky International Airport Authority 2000). Not shown in the sensitivity analysis is the three benefit categories of aircraft delay savings, benefits of induced demand, and passenger delay savings. Although they are not shown in the table below for brevity any one of the three benefits alone would have been sufficient as justification for Alternative 1.

Table 3.4 – One Variable Test Data for Cincinnati/Northern Kentucky International Airport (CVG), Alternative 1

Sensitivity Description		NPV Change	Net Effect on NPV	BC ratio
		[$ M] base → new	[$ M] NPV_{new}-NPV_{base}	[no units] base → new
90%	of Projected Benefits	2,895 → 2,606	-290	14.2 → 12.8
80%		2,895 → 2,316	-579	14.2 → 11.4
70%		2,895 → 2,027	-867	14.2 → 9.9
60%		2,895 → 1,737	-1158	14.2 → 8.5
50%		2,895 → 2,443	-1448	14.2 → 7.1
10%	of Additional Costs	203 → 223	-20	14.2 → 12.9
20%		203 → 244	-41	14.2 → 11.8
30%		203 → 264	-61	14.2 → 10.9
40%		203 → 284	-81	14.2 → 10.2
50%		203 → 305	-102	14.2 → 9.5

Source: (Cincinnati/Northern Kentucky International Airport Authority 2000)

Table 3.5 introduces a Two Variable Test for sensitivity. Two variables are simultaneously changed so that that the output change can be measured. As a generalization, sensitivity tests for multiple variables can be described as N Variable Tests, where N is the number of variables being simultaneously changed. In all of the BCA examples this was the only occurrence of a sensitivity test on more than one variable simultaneously.

Table 3.5 - Two Variable Test Data for Cincinnati/Northern Kentucky International Airport (CVG), Alternative 1

Sensitivity Description	NPV Change	Net Effect on NPV	BC ratio
	[$ M] base → new	[$ M] NPV_{new}-NPV_{base}	[no units] base → new
90% of Benefits 10% of Additional Costs Cumulative effect	2,895 → 2,606 203 → 223	-308	14.2 → 11.6
80% of Benefits 20% of Additional Costs Cumulative effect	2,895 → 2,316 203 → 244	-619	14.2 → 9.5
70% of Benefits 30% of Additional Costs Cumulative effect	2,895 → 2,027 203 → 264	-928	14.2 → 7.7
60% of Benefits 40% of Additional Costs Cumulative effect	2,895 → 1,737 203 → 284	-1,238	14.2 → 6.1
50% of Benefits 50% of Additional Costs Cumulative effect	2,895 → 1,443 203 → 305	-1,553	14.2 → 4.7

Source: (Cincinnati/Northern Kentucky International Airport Authority 2000)

The BCA submitted by the airport sponsor was funded with $34.2 M of entitlement funds and $100.0 M of discretionary funds dispensed between 2002-2006 and 2003-2011 respectively (US Federal Aviation Administration 2006f, p. 10).

3.C.3 BCA #3 – Philadelphia International Airport (PHL) Runway 17-35 Extension

Benefit-Cost Analysis #3 (DMJM Aviation and Leigh Fisher Associates 2005) proposes an extension to the existing Runway 17-35. BCA data are summarized in Tables 3.6 and 3.7 and was calculated with a 7% discount rate over a 12-year term: "the Project is only expected to be in service between 6 and 12 years before being superceded [sic] by proposed Master Plan airfield improvements" (DMJM Aviation and Leigh Fisher Associates 2005, p. 7).

- The Base Case is to operate the existing runway without modification.
- Alternative 1 extends Runway 17-35 by 640' to the north and 400' to the south for a total length of 6,500'.
- Alternative 2 would extend Runway 17-35 by 1,140' to the north and 400' to the south to provide a total length of 7,000'.

Table 3.6 - Benefit/Cost Summary Data for Philadelphia Runway 17-35 Extension

		Base Case	Alternative 1	Alternative 2
PV of Benefits	[$ M]	None	559	304
PV of Costs			31	50
NPV			528	254
BC ratio	[no units]		18.0	6.1

Source: (DMJM Aviation and Leigh Fisher Associates 2005)

Table 3.7 - One Variable Test Data for Philadelphia Runway 17-35 Extension (Alternative 1)

Sensitivity Description	NPV Change	Net Effect on NPV	BC ratio
	[$ M] base → new	[$ M] NPV_{new}-NPV_{base}	[no units] base → new
TAF Forecast Scenario (2003 TAF)	559 → 554	-5	18.0 → 18.0
10% Increase in Project Costs	31 → 35	-4	18.0 → 18.0
20% Increase in Project Costs	31 → 38	-7	18.0 → 18.0
10% Reduction in Project Benefits	559 → 503	-56	18.0 → 16.9
20% Reduction in Project Benefits	559 → 447	-112	18.0 → 15.2
1-year delay in Project start date (B)	559 → 529		
1-year delay in Project start date (C)	31 → 29		
Cumulative effect		-28	18.0 → 17.3
3-year delay in Project start date (B)	559 → 462		
3-year delay in Project start date (C)	31 → 26		
Cumulative effect		-92	18.0 → 15.9
2-year delay in Project completion	559 → 494	-65	18.0 → 16.5
No savings In passenger time value	559 → 234	-325	18.0 → 2.9
12-year Project life (B)	559 → 418		
12-year Project life (C)	31 → 31		
Cumulative effect		-141	18.0 → 13.7
6-year Project life (B)	559 → 248		
6-year Project life (C)	31 → 30		
Cumulative effect		-310	18.0 → 1.53

Source: (DMJM Aviation and Leigh Fisher Associates 2005)

Table 3.8 - One Variable Test Data for Philadelphia Runway 17-35 Extension (Alternative 2)

Sensitivity Description	NPV Change	Net Effect on NPV	BC ratio
	[$ M] base → new	[$ M] NPV_{new}-NPV_{base}	[no units] base → new
TAF Forecast Scenario (2003 TAF)	304 → 303	-1	6.1 → 6.1
10% Increase in Project Costs	50 → 55	-5	6.1 → 6.1
20% Increase in Project Costs	50 → 60	-10	6.1 → 6.1
10% Reduction in Project Benefits	304 → 274	-30	6.1 → 5.9
20% Reduction in Project Benefits	304 → 243	-61	6.1 → 5.6
1-year delay in Project start date (B)	304 → 288		
1-year delay in Project start date (C)	50 → 47		
Cumulative effect		-13	6.1 → 6.1
3-year delay in Project start date (B)	304 → 251		
3-year delay in Project start date (C)	50 → 41		
Cumulative effect		-44	6.1 → 5.7

2-year delay in Project completion	304 → 269	-35	6.1 → 5.8
No savings In passenger time value	304 → 126	-178	6.1 → 3.2
12-year Project life (B) 12-year Project life (C) Cumulative effect	304 → 227 50 → 49	-76	6.1 → 5.2
6-year Project life (B) 6-year Project life (C) Cumulative effect	304 → 135 50 → 48	-167	6.1 → 3.6

Source: (DMJM Aviation and Leigh Fisher Associates 2005)

Alternative 1 was selected by the airport sponsor and the FAA independently concurred (US Federal Aviation Administration 2005k).

3.C.4 Observations

Airport sponsors propose up to two Alternatives in their BCAs but, in the case of Example 2 and 3, explore many feasible alternatives that are briefly mentioned. A discount rate of 7% is consistent with BCA Guidelines and is used in all BCAs. BCAs test for sensitivity in cost and benefit categories mostly with One Variable Tests and, in one instance only, a Two Variable Test. Benefits are tested for downward sensitivity and construction costs are tested for upward sensitivity. In Table 3.9 the only sensitivity test common amongst all BCAs was increased project costs. The only general sensitivity test common amongst two BCAs was decreased project benefits: all others were unique to the BCA. For example, induced demand in BCA #2 and decreased discount rate in BCA #1 are both unique sensitivity test categories.

Table 3.9 - Sensitivities Testing in Example BCAs

Description of Sensitivity Test	BCA Example		
	#1	#2	#3
Increased project costs	Yes	Yes	Yes
increase by 10%	No	Yes	Yes
increase by 15%	Yes	No	No
increase by 20%	No	Yes	Yes
increase by 30%, 40%, 50%	No	Yes	No
Decreased project costs	No	No	No
Increased project benefits	Yes	No	No
aircraft delay savings	No	No	No
benefits of induced demand	No	No	No
passenger delay savings	No	No	No
Decreased project benefits	No	Yes	Yes
aircraft delay savings	No	Yes	Yes
benefits of induced demand	No	Yes	No
passenger delay savings	No	Yes	Yes
Project start date delay	No	No	Yes
Project completion delay	No	No	Yes
Project life	No	No	Yes
Decreased discount rate	Yes	No	No
Increased discount rate	No	No	No
Increased operating costs	Yes	No	No
Induced demand	No	Yes	No
Decreased benefits and increased costs (two variable)	No	Yes	No

The BCA Process Tasks in Table 3.10 were present in the example BCAs and closely reflect FAA Airport BCA guidelines. These tasks are explained in Chapter 4 and applied to a hypothetical project with and without real options in the Hypothetical Project BCA in Chapter 5. In all observations the BCA was deterministic, however, the underlying analysis details were not present in the BCA cases.

Table 3.10 - FAA Airport BCA Guidelines

FAA Process Task
Define project objectives
Specify assumptions about future airport conditions
Identify the base case (no investment scenario)
Identify and screen all reasonable alternatives to meet objectives
Determine appropriate evaluation period
Establish reasonable level of effort for analysis
Identify, quantify, and evaluate benefits and costs of alternatives relative to base case
Measure impact of alternatives on airport usage
Compare benefits and costs of alternatives
Evaluate variability of benefit-cost estimates
Perform distributional assessment when warranted
Make recommendation of best course of action

Adapted from: (US Federal Aviation Administration 1999a, p. 6)

3.C.5 Summary

Funding appropriated may or may not be subject to formal BCA requirements. When the FAA is spending appropriated funds on its infrastructure, it is obligated by statute to follow OMB BCA guidelines. However, when the FAA is disbursing appropriated funds through the AIP to airport sponsors, which are not federal government entities, there is no statute that indicates a BCA is necessary. Based on current statutes, the FAA has sole jurisdiction over what, if any, BCA guidelines an airport sponsor would be obligated to comply with when seeking AIP funds. FAA negotiated with OMB to establish the minimum threshold limit, $5 M, that must be exceeded for a BCA analysis to be required. As indicated earlier the statutory obligation of for the FAA to strictly follow OMB BCA guidelines is when the funds are spent on federal projects. Since AIP fund recipients (airport sponsors) are non-federal organizations and the AIP derives its funding from non-General Fund monies, there is no statutory requirement to adhere to OMB mandates (for AIP funded projects).

The FAA is responsible for reviewing Airport BCAs, which are customarily prepared by independent airport sponsors seeking substantial funding from the AIP discretionary fund. In certain circumstances, the FAA may prepare an independent BCA. The FAA also encourages airport sponsors "to make use of innovative methods for quantifying benefits and costs where these methods can be shown to yield superior measures of project merit" (US Federal Aviation Administration 1999a, p. 1).

4 Proposed Enhanced BCA Procedure with Real Options

This Chapter explains the "how to" procedures for real options and FAA Airport BCAs (US Federal Aviation Administration 1999a, p. 6). To show how real options can be integrated into existing BCA guidelines, the primary steps of the process are summarized and presented in a mapping table (maps Steps 1-4 to Steps A-L) and then discussed in the description of the FAA Airport BCA Guidelines. For consistency, each set of sequential steps has either a numerical (real options) or alphabetical (FAA BCA guideline steps) label. Steps A-L are labels that represent the Airport BCA steps (US Federal Aviation Administration 1999a, p. 7). The main point of this Chapter is to show that the proposed real options steps are compatible, complementary, and repeatable with the existing BCA guidelines. It also introduces preliminary estimates and economic assumptions that are necessary for the Hypothetical Project BCA in the following Chapter. Figure 4.1 summarizes the intentions of this Chapter.

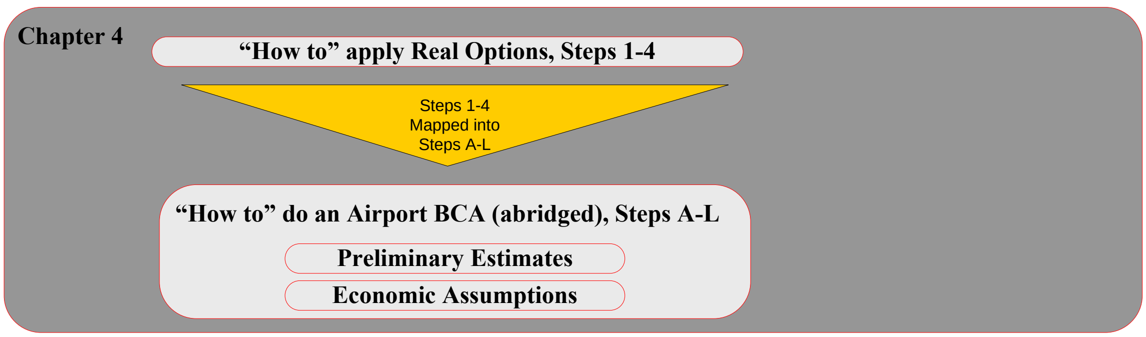

Figure 4.1 - Chapter 4 Road Map

4.A Real Options Procedure

This section presents and describes the four basic steps needed to carry out real options analysis. The following section shows how these steps can be incorporated into existing Airport BCA guidelines.

Step 1 - Identify sources of uncertainty and flexibility

The basic principle of real options posits that embedded flexibility can offset forecast uncertainty. To measure the value of flexibility, one first needs to identify forecast uncertainties. Uncertainty drives the value of the real option, and when flexibility is used to offset uncertainty, the system is adapted as needed in the future.

Uncertainty will be found in specifications that are derived from long-term forecasts where it is readily known that there is a high degree of uncertainty. The flexibility will be a technical aspect of the system that, with an embedded option, can be acted upon in the future.

There are three key assumptions here: 1) the source of uncertainty is the long-term and 2) flexibility is a technical attribute that offsets the long-term forecast uncertainty, and 3) both 1) and 2) are quantifiable and monetizable.

In the Parking Garage Case Study example (de Neufville et al. 2006), long-term demand uncertainty was paired with reinforced columns which reduces volatility when compared to constructing the larger and smaller design choices. This case mapped one source of uncertainty into one source of flexibility.

In the Level 3 Communications example, the uncertainty of long-term demand and evolution of opto-electronics and fiber optics was paired with empty conduits. These empty conduits would accommodate future changes in demand and technology. This case mapped two sources of uncertainty into one source of flexibility.

Step 2 - Select an option strategy for each uncertainty and flexibility pair

After identifying an uncertainty and flexibility pair, the next step is to select one or more options that would be appropriate. The option strategy has been implicitly created in the previous step when the source of flexibility was identified, and now is the point where it will be explicitly identified. By identifying the installation of new cable as a source of flexibility, Level 3 chose an (expansion) option strategy to fulfill future demand. The strategy they chose was to lay empty conduits that would allow easy deployment of additional cables and newer cable technologies in the future. Although the option is implicitly defined by pairing uncertainty and flexibility, it would only be acknowledged as a valid option if it were in alignment with the goals of the decision-makers and compatible with the technical aspects of the system.

Common option strategies are expansion, contraction, and abandonment. For example, landbanking is an expansion strategy and closing down a factory is an abandonment strategy. When two or more options occur sequentially, they are referred to as a compound option. Compound options are well suited for situations where decision-makers can exploit the embedded flexibility to adjust the system as new information arrives and operating conditions change when there are multiple decision paths and each path may introduce additional uncertainty.

Parking Garage Case Study – The reinforced columns provided for the expansion option. The parking garage could be expanded in the future when expansion is necessary. The parking garage can also be abandoned in the future if demand is far lower than anticipated. Contraction is also possible by sub-dividing the parking garage into individual parking spaces and then selling some, but not all of them.

Level 3 Communications – Empty conduits are an expansion option when used to increase capacity and/or introduce newer technology – pulling in a newer generation fiber optic cable does both. Demand uncertainty was paired with the flexibility to expand by installing new (or newer) cable in the available spare conduits.

Empty conduits being filled as needed are an example of a compound expansion option. Demand uncertainty was paired with the flexibility to contract services partially or completely by selling off the assets. Filled conduits with outdated technology are an example of an ongoing abandonment option. Demand uncertainty was paired with the flexibility contract services partially or completely by selling off the assets.

Step 3 - Find the option value in each Alternative with embedded option(s)

The option value is calculated as the difference between an Alternative with flexibility ($NPV_{flexible}$) and the traditional NPV base case ($NPV_{basecase}$). Figure 4.2 summarizes how the traditional NPV ($NPV_{basecase}$) is subtracted from the flexible NPV ($NPV_{flexible}$) to calculate the real option value. The calculation of real option value may be done with either a deterministic model or a stochastic model. The stochastic model has the additional advantage of conveying VAR information, which will be discussed in the next Step. When the economic model is deterministic the deterministic, NPVs are compared and when the model is stochastic the NPV means are compared.

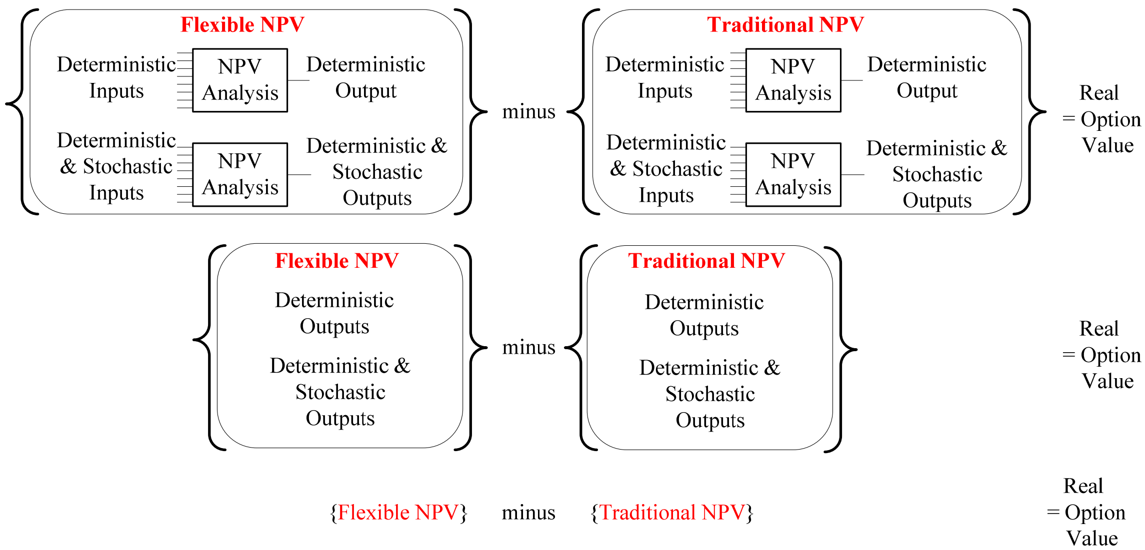

Figure 4.2 - Calculate Real Option Value (same as Figure 2.3)

To show the practical application of real options valuation the NPV is calculated for the three alternatives that will be further explained in Chapter 5. Both alternative 1 and 2 are NPV calculations for inflexible systems. Alternative 3 is a calculation for a flexible system, specifically a new airport that landbanks and expands in the future. The calculation of real option value is the difference between NPVs and is shown in Table 4.1. It should be noted that the real option value is calculated with spreadsheet software using calculations with the same level of complexity as what is used in current practice. Also note that calculating the real option value is done without regard to the option valuation models mentioned earlier in this paper that are commonly used in calculating the value of financial options. Alternative 3 shows costs and benefits associated with an expansion to accommodate significant services arbitrarily occurring when t=11. Later, when Monte Carlo simulation is introduced, the year that the significant services arrive in will be randomly selected in the simulation.

Table 4.1 - Calculate Real Option Value

	Flexible NPV	Inflexible (Traditional) NPV $ M	Real Option Value
$NPV_{3,flexible}-NPV_{1,inflexible}$	$423 Table 4.4	-$34 Table 4.2	$457
$NPV_{3,flexible}-NPV_{2,inflexible}$	$423 Table 4.4	$80 Table 4.3	$344
$NPV_{3,flexible}-NPV_{3,traditional}$	$423 Table 4.4	$73 Table 4.4	$351
	{Flexible NPV} minus {Traditional NPV} = Real Option Value		

It is important to see the value from correctly timing the expansion around the time of the initiation of significant services. It is significantly less important and trivial to specify a specific expansion year when there is no information to support that assumption credibly. The value of the real option is highly dependent on properly timing the expansion.

Table 4.2 - Example inflexible NPV, Alternative 1

		Benefits for Alternative 1				Costs for Alternative 1					
		Reduced Delay, Initial Fleet Mix				Land Acquisition		Construction		Maintenance and Operations	
		Aircraft		Passenger							
year	discount factor 7%	Benefit	PV	Benefit	PV	Cost	PV	Cost	PV	Cost	PV
0	1.000					$24.5	$24.5				
1	0.935							$32.4	$30.3		
2	0.873							$81.0	$70.7		
3	0.816							$48.6	$39.7		
4	0.763	$8.3	$6.3	$5.4	$4.1					$1.8	$1.4
5	0.713	$8.5	$6.1	$5.5	$4.0					$1.8	$1.3
…	…	…	…	…	…	…	…	…	…	…	…
22	0.226	$13.6	$3.1	$8.9	$2.0					$1.8	$0.4
23	0.211	$14.0	$3.0	$9.1	$1.9					$1.8	$0.4
			$88.8		**$57.8**		**$24.5**		**$140.7**		**$15.6**

PV Benefit SUM	**$147**
BC ratio	**0.81**
NPV	**-$34**

PV Cost Sum	**$181**

Table 4.3 - Example inflexible NPV, Alternative 2

		Benefits for Alternative 2				Costs for Alternative 2					
		Reduced Delay, Initial Fleet Mix				Land Acquisition		Construction		Maintenance and Operations	
		Aircraft		Passenger							
year	discount factor 7%	Benefit	PV	Benefit	PV	Cost	PV	Cost	PV	Cost	PV
0	1.000					$6.1	$6.1				
1	0.935							$12.6	$11.8		
2	0.873							$31.5	$27.5		
3	0.816							$18.9	$15.4		
4	0.763	$8.3	$6.3	$5.4	$4.1					$0.7	$0.5
5	0.713	$8.5	$6.1	$5.5	$4.0					$0.7	$0.5
…	…	…	…	…	…	…	…	…	…	…	…
22	0.226	$13.6	$3.1	$8.9	$2.0					$0.7	$0.2
23	0.211	$14.0	$3.0	$9.1	$1.9					$0.7	$0.1
			$88.8		**$57.8**		**$6.1**		**$54.7**		**$6.1**

PV Benefit SUM	**$147**
BC ratio	**2.19**
NPV	**$80**

PV Cost Sum	**$67**

Table 4.4 - Example flexible NPV calculation, Alternative 3 (Benefits)

		Benefits for Alternative 3									
		Reduced Delay, Initial Fleet Mix				Rent back on excess land		Reduced Delay, Fleet Mix 2 (probabilistic start date)			
		Aircraft		Passenger				Aircraft		Passenger	
year	discount factor 7%	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV
0	1.000										
1	0.935					$1.0	$0.9				
2	0.873					$1.0	$0.9				
3	0.816					$1.0	$0.8				
4	0.763	$8.3	$6.3	$5.4	$4.1	$1.0	$0.8				
5	0.713	$8.5	$6.1	$5.5	$4.0	$1.0	$0.7				
6	0.666	$8.8	$5.8	$5.7	$3.8	$1.0	$0.7				
7	0.623	$9.0	$5.6	$5.9	$3.7	$1.0	$0.6				
8	0.582	$9.3	$5.4	$6.0	$3.5	$1.0	$0.6				
9	0.544	$9.5	$5.2	$6.2	$3.4	$1.0	$0.5				
10	0.508	$9.8	$5.0	$6.4	$3.2	$1.0	$0.5				
11	0.475	$10.1	$4.8	$6.5	$3.1	$1.0	$0.5	$74.0	$35.2	$48.0	$22.8
12	0.444	$10.3	$4.6	$6.7	$3.0	$1.0	$0.4	$74.0	$32.9	$48.0	$21.3
...	...	...	...	...	...	...	...	...	...	...	...
22	0.226	$13.6	$3.1	$8.9	$2.0	$1.0	$0.2	$74.0	$16.7	$48.0	$10.8
23	0.211	$14.0	$3.0	$9.1	$1.9	$1.0	$0.2	$74.0	$15.6	$48.0	$10.1
			$88.8		**$57.8**		**$11.3**		**$314.4**		**$203.9**

	no exp.	exp.
PV Benefit SUM	**$158**	**$676**
BC ratio	**1.85**	**2.67**
NPV	**$73**	**$423**

Note: all dollar values in millions of dollars
exp. is short for expansion

Table 4.5 - Example flexible NPV calculation, Alternative 3 (Costs)

		Costs for Alternative 3									
		Land Acquisition		Construction		Maintenance and Operations		Maintenance (probabilistic start date)		Construction (probabilistic start date)	
year	discount factor 7%	Cost	PV	Cost	PV	Cost	PV	Cost	PV	Cost	PV
0	1.000	$24.5	$24.5								
1	0.935			$12.6	$11.8						
2	0.873			$31.5	$27.5						
3	0.816			$18.9	$15.4						
4	0.763					$0.7	$0.5				
5	0.713					$0.7	$0.5				
6	0.666					$0.7	$0.5				
7	0.623					$0.7	$0.4				
8	0.582					$0.7	$0.4			$100.0	$58.2
9	0.544					$0.7	$0.4			$100.0	$54.4
10	0.508					$0.7	$0.4			$100.0	$50.8
11	0.475					$0.7	$0.3	$1.0	$0.5		
12	0.444					$0.7	$0.3	$1.0	$0.4		
...	...	...	...	...	...	...	...	...	...	...	...
22	0.226					$0.7	$0.2	$1.0	$0.2		
23	0.211					$0.7	$0.1	$1.0	$0.2		
			$24.5		**$54.7**		**$6.1**		**$4.2**		**$163.4**

	no exp.	exp.
PV Cost Sum	**$85**	**$253**

Note: all dollar values in millions of dollars
exp. is short for expansion

Step 4 - Rank and compare the NPV and VAR of all Alternatives

The comparison of the real options process with NPV demonstrates its complementary nature. The introduction of VAR offers a practical extension to the existing BCA guidelines.

Assuming all other factors are equal, the NPVs of the different alternatives are ranked highest to lowest, where the alternatives with the highest NPVs are the recommended course(s) of action.

To make use of the stochastic information, the cumulative probability of each NPV distribution can be overlaid onto the same graph. When NPVs are displayed as cumulative probability distributions they display VAR information. A VAR graph is used to compare the probabilistic NPVs with each other. With a VAR the cap (100%), floor (0%) and intermediary outcomes can be compared. A correctly embedded option should show NPV floors and caps that are better than those of the alternative without flexibility. In general, these boundary conditions should be present for all flexible alternatives when compared to an inflexible base case: $NPV_{flexible}(0\%) > NPV_{basecase}(0\%)$ and $NPV_{flexible}(100\%) > NPV_{basecase}(100\%)$. Stated in words: flexibility limits downside losses and improves upside potential.

For example, in Figure 4.3 and Table 4.6 the benefits of Alternative 3 are better than the other alternatives and can be summarized with these inequalities below.

- $NPV(100\%)_{Alt3} > NPV(100\%)_{Alt2} > NPV(100\%)_{Alt3}$
- $NPV(0\%)_{Alt3} < NPV(0\%)_{Alt2} < NPV(0\%)_{Alt3}$

- NPV(mean)$_{Alt3}$ > NPV(mean)$_{Alt2}$ > NPV(mean)$_{Alt3}$

Figure 4.3 and Table 4.6 were derived from a Monte Carlo simulation and will be elaborated upon further in Chapter 5.

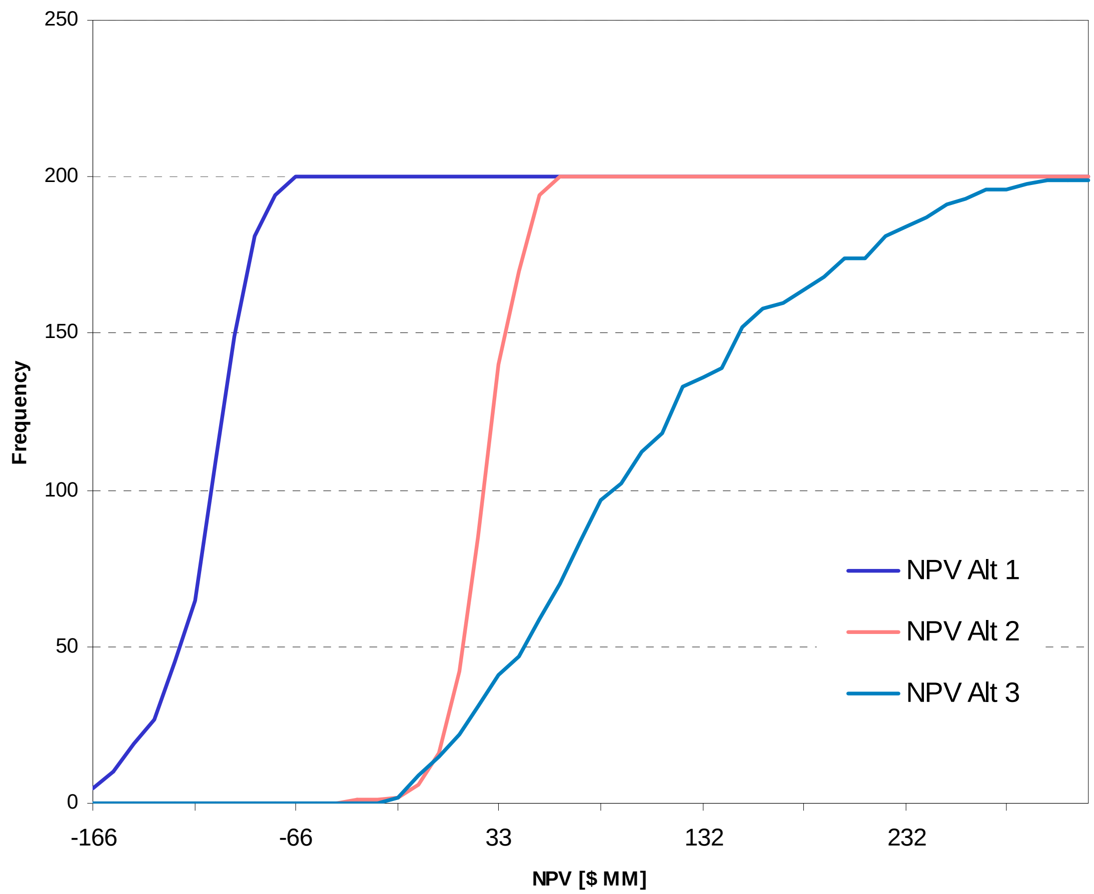

Figure 4.3 - Example VAR Graph of Alternatives 1, 2 and 3 NPV's

Table 4.6 - Example VAR Summary Data of Alternatives 1, 2 and 3 NPV's

		Alternative 1	Alternative 2	Alternative 3
NPV$_{base}$	Deterministic	-75	-39	383
NPV(mean)	Stochastic	-106	30	108
NPV(0%)		-189	-32	-15
NPV(100%)		-64	65	326

4.A.1 Summary

The basic process of applying real options requires four steps:

1) identifying and pairing sources of uncertainty and flexibility,
2) developing options strategies that exploit the potential of the uncertainty-flexibility pairs,
3) evaluation of the options strategies, and
4) ranking the alternatives.

Chapter 5 shows that the practical application of these steps is straightforward where BCA guidelines are applied to a Hypothetical Project with and with out real options.

Table 4.7 shows how the complementary real options procedural steps 1-4 map into the FAA Airport BCA procedural steps A-L (introduced in the following sub-Chapter).

Table 4.7 - Mapping of RO steps into BCA steps

		Complementary Real Options Procedural Steps 1-4			
		1	**2**	**3**	**4**
FAA BCA Procedural Steps A-L	A				
	B	✓			
	C	✓			
	D	✓	✓		
	E				
	F				
	G			✓	
	H				
	I			✓	✓
	J				✓
	K				
	L				✓
Thesis page #		45	46	46	52

4.B FAA Airport BCA Guidelines: "How to" apply them with Real Options

This section shows the basic principles involved in applying real options to Airport BCAs in accordance with FAA guidelines and best practices. It introduces Steps A-L and presents this information:

1) A brief and generalized summary of the FAA Airport BCA steps
2) Parameters and probability distributions that will be used in the BCA on the hypothetical project in the next chapter
3) The complementary nature of real options analysis by showing where Steps 1-4 are applied and how they are integrated into the existing Airport BCA guidelines

The guidelines are presented sequentially as they would be in complete or nearly complete BCAs. However, in practice they are not necessarily done sequentially. There are frequent iterations as assumptions are refined and feedback is received from the BCA participants (FAA, airport sponsor, consultants, local government, and, other relevant State and Federal Agencies).

Step A Define project objectives

A concise project objective succinctly addresses the problem or need without preemptively concluding that a particular solution is appropriate. When multiple projects with multiple objectives exist it is best to do a separate BCA for each project. Aggregating objectives by project provides a meaningful way to evaluate those projects independently. When a project has only one objective, that objective is the Principal Objective. Every AIP funded project must declare one Principle Objective (US Federal Aviation Administration 1999a, p. 10).

Step A is identical whether or not real options are being used. All subsequent BCA steps are guided by the project objective(s).

Step B Specify assumptions about future airport conditions

Step B specifies the assumptions about future airport conditions to establish the boundaries and patterns that will be used throughout the BCA process. Since assumptions have uncertainty, this is an appropriate point in the procedure to identify flexibilities that will be used to identify one or more real options (Step 1). Assumptions with the greatest uncertainty are the best candidates that would benefit from flexibility and lead to the highest real option value for the airport sponsor.

The starting point for assumptions about future airport conditions would be based on a new or existing airport master plan written by the airport sponsor. For a new airport "[o]ne of the most difficult applications of BCA criteria is to new/replacement airports." (US Federal Aviation Administration 1999a, p. 61). Important assumptions are 1) Future airport environment, 2) Projected growth in activity, and 3) Economic Values. Assume that the airport will be required to expand in the future.

Economic Values

Many of the economic values important for a BCA are published in "Economic Values for FAA Investments and Regulatory Decisions, A Guideline" (GRA Inc. 2004). Adjustments to the values can be made with appropriate economic indexes. The Hypothetical Project BCA will have a base year of 2006 (t=0) and all economic values will be adjusted to or around 2006. In situations where an economic value needs to be adjusted for a future time period it will be done by assuming an aggregate inflation rate of 3% per year. So, if construction costs were $90/sqft at t=1 and a similar construction project were to commence in t=11 then the inflation adjusted value would be 90*(1.03)^(11-1)=$121/sqft. Once the inflation adjusted value is initialized in a particular time period all subsequent inflation related calculations are based on a real discount rate which is composite representation of the inflation rate and the nominal interest rate. Further examples are shown in Table 4.8.

Table 4.8 - Economic Values, Index Adjusted to 2006

Description		Value Year	Adjustment Factor	Value Year	Index Name
Value of Passenger Time per hour		$28.60 2000	1.22	$34.99 2006	BLS Wage Index
Large	Passenger Carriers – Variable Operating Costs per hour	$2,096 2002	0.9728	$2,039	US Airline Cost Index 187.6 FY2002 182.5 FY2005
Regional		$3,218 2002		$3,130 2005	

Note: The US Airline Cost Index was last updated on 7/14/06, and checked on 1/8/07 (US Air Transport Association 2006). It is based in part on the US Department of Transportation Form 41 (US Department of Transportation 2006).

Schedule of Probability Distributions

Airport BCA guidelines do not explicitly define specific probability distributions for input parameters, but they indicate that they are suitable to evaluate uncertainty when assumptions are justified (US Federal Aviation Administration 1999a, p. 85). The guidelines do differentiate between probability distributions for risk and uncertainty analysis. Known probability distributions are indicative of risk analysis and those that are not are categorized as uncertainty analysis.

> *Of course, there are circumstances when the normal distribution may not be a reasonable representation of the uncertainty associated with a variable; many other probability distributions can be specified, including the Poisson (often appropriate for*

characterizing accident or other events that occur infrequently), uniform (appropriate when a range of values are equally likely) and the exponential (appropriate when there is uncertainty over the length of time between certain events occurring). For practical purposes, the triangular distribution is commonly used; this distribution is characterized by a single most likely value and minimum and maximum values, with the probabilities declining linearly from the most likely to the minimum and maximum values. …there is also commercial software available that helps lead the analyst through the process of
selecting distributions and calculating results (US Federal Aviation Administration 1998, pp. 6-9).

The introduction of input probability distributions in this step (Step B) transforms the entire BCA from deterministic to stochastic and integrates the distributional assessment (Step K) into all subsequent steps. Since the inclusion of Step K is optional and its tasks are accomplished elsewhere in the BCA, with real options it becomes a placeholder step. Use of probability distributions in FAA BCAs has not been observed to be a common practice (DMJM Aviation and Leigh Fisher Associates 2005; Cincinnati/Northern Kentucky International Airport Authority 2000; Earth Tech, Inc. et al. 2003). Nevertheless, their use is consistent with FAA mandates, as stated in the FAA Airport BCA Guidelines: "[t]he U.S. Office of Management and Budget states that risk and uncertainty should be dealt with explicitly in the BCA using sensitivity analysis, probability distributions" (US Federal Aviation Administration 1999a, p. 76).

When a probability distribution is used in the Hypothetical Project BCA it will be one of the following types: 1) Maximum Extreme Value, 2) Minimum Extreme Value, 3) Triangle, and 4) Custom.

Minimum Extreme

The minimum extreme probability distribution is used selectively for benefit-related growth. The distribution has a tail to the left to include extreme events where the forecasted benefits growth is substantially lower and occasionally negative. The absence of a tail on the right side makes the distribution asymmetric and precludes overly optimistic benefit growth. The specific example shown in Figure 4.4 shows the distribution when the likeliest value (m) is 5% and the scale value (s) is 2.5% (or 50% of 5%). The likeliest value is what would ordinarily be expected to occur and coincides with the deterministic value. The scale value changes the dispersion characteristic and is analogous to distribution volatility. The higher the scale value the more dispersed the probability distribution indicating a high value of volatility.

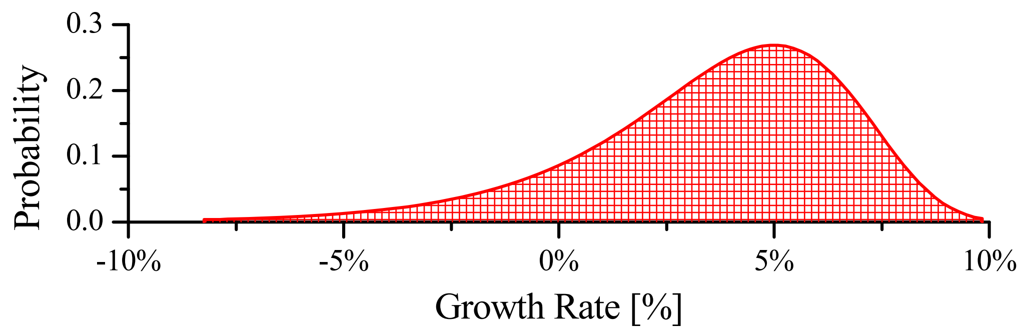

Figure 4.4 - Minimum Extreme Probability Distribution

Equation 4.1 shows how the probability distribution in Figure 4.4 is created.

$$p(x) = \frac{1}{s} z e^{-z} \qquad \text{Equation 4.1}$$

where $z = e^{\left(\frac{x-m}{s}\right)}$ and s is the scale factor for $-\infty < x < \infty$, $-\infty < m < \infty$, and $s > 0$.

Table 4.9 shows parameters for the minimum extreme probability distribution. This is summarized with the notation $p_{min}(x)$=[m, s, lower limit, upper limit]. For example, $p_{min}(x)$=[5.0, 2.5, -∞, +∞]. Since upper and lower limits of infinity are uncommon in practical applications they could be arbitrarily set to some narrower range, like -10% to 10%, $p_{min}(x)$=[5.0, 2.5, -10.0, +10.0]., or 0% to 10%, $p_{min}(x)$=[5.0, 2.5, 0.0, +10.0].

Table 4.9 - Minimum Extreme Probability Distribution Parameters

Mandatory		Default	
Likeliest value m	Scale factor s	Probability p(x)	
5%	2.5%	- infinity	+ infinity

Maximum Extreme

The maximum extreme probability distribution is used selectively for cost-related growth. The distribution has a tail to the right to include extreme events where the forecasted cost growth is substantially higher. The absence of a tail on the left side makes the distribution asymmetric and precludes overly optimistic cost reductions. The specific example shown in Figure 4.5 shows the distribution when the likeliest value (m) is 5% and the scale value (s) is 2.5% (or 50% of 5%). The likeliest value is what would ordinarily be expected to occur and coincides with the deterministic value. The scale value changes the dispersion characteristic and is analogous to distribution volatility. The higher the scale value, the more dispersed the probability distribution indicating a high value of volatility. The difference between the maximum and minimum extreme probability distribution is how they are skewed.

Parameters for the maximum extreme probability distribution are exactly the same as those in Table 4.9. The distribution is summarized with the notation $p_{max}(x)$=[m, s, lower limit, upper limit]. For example, $p_{max}(x)$=[5.0, 2.5, -∞, +∞]. An extreme probability distribution with arbitrary practical limits would be $p_{max}(x)$=[5.0, 2.5, 0.0, 20.0].

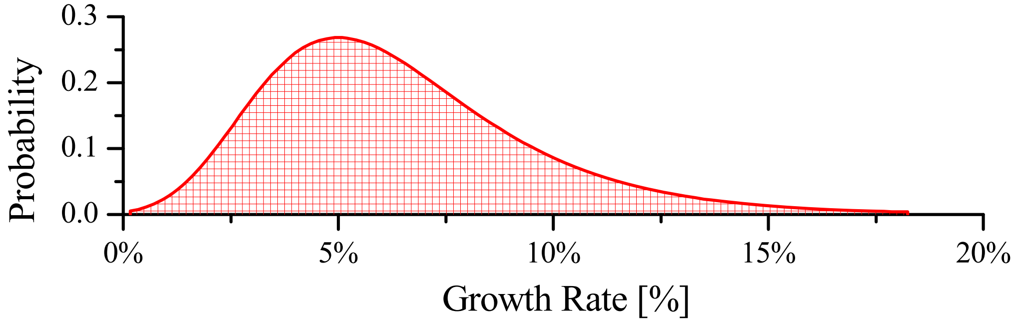

Figure 4.5 - Maximum Extreme Probability Distribution

Equation 4.2 shows how the probability distribution in Figure 4.5 is created.

$$p(x) = \frac{1}{s} z e^{-z} \qquad \text{Equation 4.2}$$

where $z = e^{\left(\frac{-(x-m)}{s}\right)}$ and s is the scale factor for $-\infty < x < \infty$, $-\infty < m < \infty$, and $s > 0$.

<u>Triangle</u>

The triangle distribution represents a peak value with known upper and lower limits. It is suitable when a more elaborate distribution would be unjustified. Unlike other probability distributions where the default boundaries are ±∞, the triangle probability distribution has boundaries set explicitly by the upper and lower limits. A favorable characteristic of this distribution is that its area can be manually calculated with ordinary geometry. An example is a discount rate where the likeliest value is 7% and the lower and upper limits are 4% and 10%. Another example is the inflation rate. The notation $p_{tri}(x)$=[m, lower limit, upper limit]. For example, $p_{tri,r}(x)$=[7, 4, 10] for the real discount rate and $p_{tri,i}(x)$=[3, 2, 4] as an aggregate inflation rate.

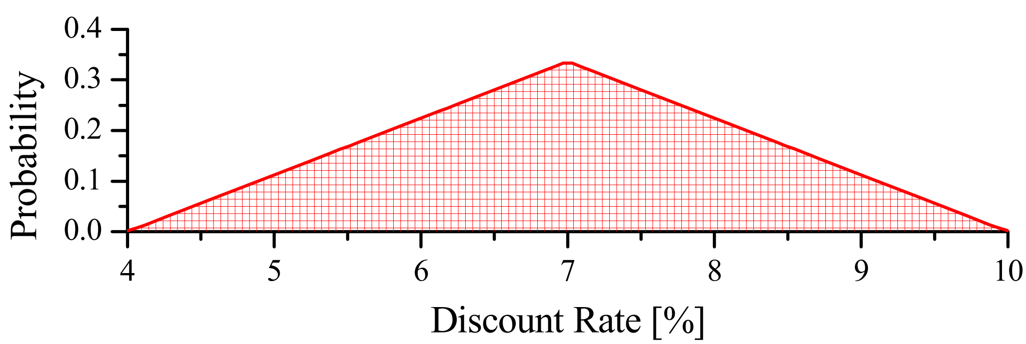

Figure 4.6 - Triangle Probability Distribution

<u>Custom</u>

Circumstances may arise that necessitate a custom probability distribution. An example is where an event occurs during one of many equally-spaced time periods and it is only necessary to know that it arrived in one of many time periods. A discrete probability distribution where the probability of occurrence is divided equally between all time periods would be suitable. In the situation where a non-occurrence also needs to be included, it could be setup in period t=0 when the index generates a value of i=0. More specifically, if there were a need to represent an event occurring with equal probability between time periods 6 and 13, it would be done with the probability distribution shown in Figure 4.7. The probability of the event occurring is 0.10 in any of the 10 periods between 6 and 15. The notation $p_{cust}(x)$ depends on the probability distribution. Since there is only one custom probability distribution in this thesis it will be referred to as $p_{cust}(x)$. Appendix II shows the project evaluation period with respect to the earliest (t=6) and latest (t=13) index arrival time periods.

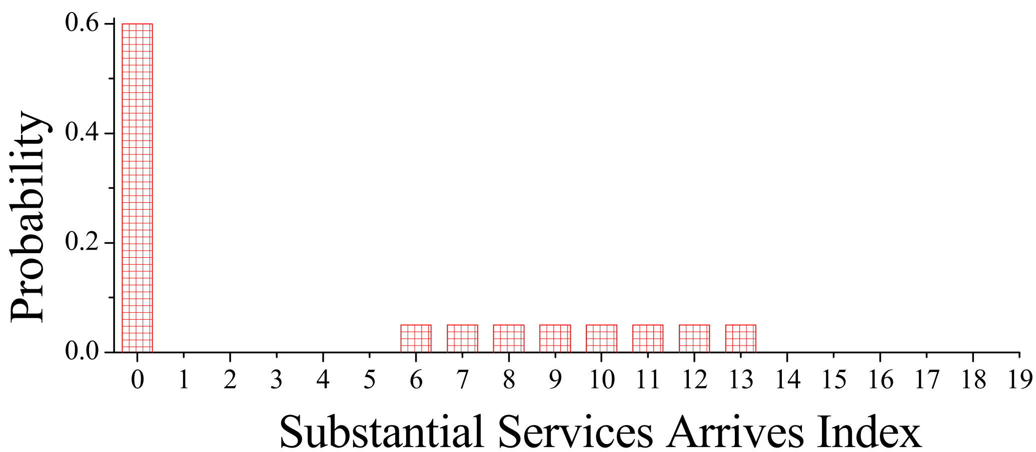

Figure 4.7 - Custom Probability Distribution

Probability Distribution Summary

The probability distributions referenced above will be used throughout the Hypothetical Project BCA with real options. Table 4.10 summarizes the probability distribution notation.

Table 4.10 - Probability Distribution Notation Summary

Distribution Name	Notation	Example(s)
Minimum Extreme	$p_{min}(x)$=[m, s, lower limit, upper limit]	$p_{min}(x)$=[5.0, 2.5, -∞, +∞] $p_{min}(x)$=[5.0, 2.5, -10.0, 10.0]
Maximum Extreme	$p_{max}(x)$=[m, s, lower limit, upper limit]	$p_{max}(x)$=[5.0, 2.5, -∞, +∞] $p_{min}(x)$=[5.0, 2.5, 0.0, 20.0]
Triangle	$p_{tri}(x)$=[m, lower limit, upper limit]	$p_{tri}(x)$=[7, 4, 10]
Custom	$p_{cust}(x)$	None

Step C Identify the base case

Step C now includes Step 1. Uncertainties in the base case can be mapped to proposed flexibilities in the base case, if they are present. An alternative, including the base case, does not necessarily have to include flexibility. For comparison purposes, it is recommended that the base case not include flexibility so that the flexible alternatives, which are introduced in Step D, can be compared to it.

A valid alternative may either partially or fully meet the BCA objective(s) declared in Step A. A base case is the reference point and is itself an alternative that will be compared to alternatives proposed in Step D. As a potential alternative, the base case must propose some action(s) that will meet the proposed BCA objective(s). As such, the base case may not be defined as “do nothing” but it does not necessarily need to meet or be the best choice for the project objective(s). The base case must be presented fairly to include all airport resources which would include funded but not yet operational projects and a knowledgeable and competent operating staff.

Step D Identify and screen all reasonable alternatives to meet objectives

Step D now includes Steps 1 and 2. An alternative may include or exclude flexibility. As indicated earlier the flexibility is chosen so that it offsets the uncertainty in the long-term forecast. Flexibility is highly dependent on the technical characteristics of the system and would be selected to ‘fit’ into the alternative.

For a fair evaluation of alternatives and for the BCA to select the best course of action, it is important that the selection be done impartially even when there are what appears to be an unmanageable number of reasonable alternatives. This is difficult to do in practice since the decision to include or exclude one or more alternatives is a prejudicial action. To keep the number of alternatives reasonable the entire list of alternatives could be reduced to a more manageable sub-set of alternatives that can be closely analyzed in the BCA. For example, a BCA with 200 alternatives would be prohibitively expensive; however, a sub-set of less than 10 alternatives is likely to be within the available budget. To reduce the number of alternatives a select number of mandatory requirements could be applied consistently to the entire pool of alternatives. Alternatives that meet the mandatory requirements become part of the sub-set that will be included in the BCA, all others are excluded from further consideration. To achieve some level of impartiality the same list of mandatory requirements must be applied to each alternative and the list must be openly available for review.

Each alternative must be defined so that its benefits and costs are attributable to itself only.

The suggested minimum range of alternatives that should be evaluated for any airport infrastructure project are:

- Investments in new facilities, both major and minor, on and off the airport
- Refurbishment, replacement, and enhancements of existing facilities
- Demand management strategies, including provision of improved information
- Redistribution of responsibility

> *In some cases, it may be logical to consider the addition of new infrastructure at a site other than the airport itself. If general aviation (GA) traffic is contributing to congestion at a primary airport, construction of a new or longer GA runway at a nearby reliever airport may be a more cost-beneficial means of reducing congestion than would be the construction of a new runway at the congested airport* (US Federal Aviation Administration 1999a, p. 19).

When considering a new airport the minimum range of alternatives is reduced to reflect the narrow range of alternatives that should be evaluated.

Step E Determine appropriate evaluation period

Step E is identical whether or not real options are being used.

“The FAA generally uses an economic lifespan of 20 years beyond the completion of construction for major airport infrastructure projects…” (US Federal Aviation Administration 1999a, p. 21). In Chapter 3, an Example BCA #3 did not use a 20 year evaluation period. It justified the use of a 12-year period which coincided with the useful life of the project.

Step F Establish reasonable level of effort for analysis

Step F is identical whether or not real options are being used.

As BCA and other planning processes can be time and resource consuming, the FAA (as other governmental bodies) attempts to manage those costs proportionally to the complexity of the investment. It is assumed that the level of effort for an analysis with real options would consume no additional man-hours, but would require airport sponsor decision-makers to consciously include Steps 1-4. The airport sponsor decision-makers must actively encourage the system planners to work closely with the system designers so that forecast uncertainties can be paired with flexibility. From a Project Management point of view, Steps 1-4 need to be planned for and included in the BCA Project Plan. The assumption of “no additional man-hours” is bold, but realistic when framed as an improved alignment of tasks with available resources. However, should the inclusion of real options pose any additional burden on the airport sponsor it would be for large and infrequent AIP discretionary funding requests where the incremental cost is a tiny fraction of the BCA budget. Based on data in the FY 2004 AIP Report to Congress it appears that an estimated 0.6% (14 BCA reviewed/2,150 grants) of BCA grants would require a formal BCA conducted by the airport sponsor and reviewed by the FAA (US Federal Aviation Administration 2006h, p. iv). Steps 1-4 are highly repeatable and complementary to the existing BCA procedure.

Step G Identify, quantify, and evaluate benefits and costs of alternatives

Step G now includes Step 3.

Quantifiable Benefits and costs that can be monetized are expressed in constant dollars.

<u>Timing of Benefits and Costs – Knowledge Arrives</u>

To demonstrate the positive impact of the Real Option embedded in Alternative 3 it is necessary to emulate the behavior of a decision-maker in a future period. The decision-maker knows that land is available for expansion and will initiate the expansion when the knowledge arrives to do so. For example, a definitive agreement for substantial services may arise in the near future, but the exact year is uncertain.

<u>Benefits</u>

The monetization of benefits is determined with a three-step process[6]. To accompany the explanation of the process an example of Reduced Aircraft Operating Delay and Reduced Passenger Delay will be included.

Step G1 – Identification of Benefits (US Federal Aviation Administration 1999a, p. 24)
A broad range of benefits can be selected from: airside, air terminal building (ATB), or landside. An abbreviated list of project types:

- Airside Capacity Projects
- Airside Safety, Security, and Design Standards Projects
- Airside Environmental Projects

[6] The FAA Airport BCA Guidelines refer to Steps 1, 2, and 3; this thesis will refer to them as Steps G1, G2 and G3.

- ATB Capacity Projects
- ATB Security Projects
- ATB Inter-Terminal Transportation
- Landside Access Projects

As an example, Reduced Aircraft Operating Delay and Reduced Passenger Delay are both Airside Capacity Projects (US Federal Aviation Administration 1999a, p. 26).

Step G2 – Measurement of Benefits (US Federal Aviation Administration 1999a, p. 34)
After benefits have been identified they can be estimated and mapped to a measurement unit. The benefits measurement would usually be from a simulation model that uses existing data with assumptions to justify the benefit quantity. The appropriate measurement for Airside Capacity Projects of Aircraft Operating Delay and Reduced Passenger Delay are both time in units of hours.

Step G3 – Valuation of Benefits (US Federal Aviation Administration 1999a, p. 49)
Aircraft Operating Delay is valued by multiplying hours by operating cost. More specifically, the value of aircraft delay should consider the aircraft type and operational status. Different aircraft types have different operating costs that depend on the operational status of the aircraft. This can be represented in these states listed in increasing order of operating cost: 1) parked on tarmac 2) parked at gate boarding/unboarding passengers, 3) taxiing, 5) en route and 4) ascending/descending.

Reduced Passenger Delay is valued by multiplying hours by passenger time value. Current practices permit fractional hours (US Federal Aviation Administration 1999a, p. 50).

Costs

Tangible costs are readily quantifiable through vendor quotations, observable market prices or recent historical data. When cost data are not expressed in the desired year they can be adjusted with an appropriately selected factor. Airport projects have a relatively narrow range of potential costs when compared to benefits. Costs are also weighted very heavily at the beginning of a project while the benefits are distributed over the operating period. Land, construction and operations and maintenance are the dominant costs included in practice. The costs listed below are representative and not exhaustive.

Land Acquisition Costs

Land costs can be estimated by observing current market prices, recently closed prices and historical records of similar properties. Land costs would include the price paid for the land, improvements, appraiser fees, broker fees, closing costs, and administration fees expressed in dollars per acre. The airport sponsor may rent back the land to the tenant until the land is needed.

Land acquisition costs occur over a period of less than 5 years and are a one-time cost..

Construction

Construction costs can be estimated through a formal quotation or by analyzing detailed construction cost data from a substantially similar project. When detailed data are available it can be inflation adjusted with the use of appropriate factors. Detailed data would include quantities and pricing of materials, labor and soft costs. Historical costs can be adjusted with a materials index, wage index and Consumer Price Index to estimate the current cost. For example, construction cost data from a recently constructed runway of 9,000’x150’ can be adjusted to a current cost and then converted to a per square foot cost which could then be used to estimate a similar sized runway.

Construction costs occur over less than 5 years and are considered to be non-recurring. Construction for most airport improvements could exceed 3 years, but usually do not.

Operations and Maintenance

"O&M cost data will generally grow at a constant per operation or per passenger unit rate and can safely be pro-rated on this basis. In some cases, the cost of periodic maintenance events may be scheduled for discrete years" (US Federal Aviation Administration 1999a, p. 76).

Staffing costs, materials, utilities, and insurance are examples of recurring operations and maintenance costs. One-time costs are those associated with startup (training, travel and lodging) and large but infrequent repairs.

Operations and maintenance costs occur over the entire evaluation period and are recurring costs. During the operating life there will be small one-time costs in addition to the recurring costs. These costs would be for one-time events that recur infrequently. Startup costs like training and overtime, and capital-intensive repair projects are examples.

Planning and Research and Development Costs

These are the costs that are incurred before construction begins and are requested in the BCA before they are incurred.

- Any necessary research and development expenses associated with the project;
- Project environmental assessment;
- Detailed project design and engineering plans;
- Coordination with regional development and transportation plans;
- Arrangement of project financing; and
- Public outreach.

Step H Measure impact of alternatives on airport usage

Step H is identical whether or not real options are being used for select alternatives. It is an example of where real options could be applied to offset the uncertainty of induced demand.

> *[A] complete BCA should address the dynamic interaction of project benefits and costs and level of airport usage. Specifically, the net benefits generated by an investment for current users of the airport will induce new users to come. These new users will also benefit from the project but, at the same time, they will impose demands on the airport's capacity that may reduce the net benefits of the project to current users. Although it is desirable that induced demand be included in a BCA, because of the uncertainty associated with the data required for this analysis, the FAA leaves it to the option of the airport sponsor whether to include it or not in the BCA submission (US Federal Aviation Administration 1999a, p. C-1).*

Step I Compare benefits and costs of alternatives

This step compares the present value of benefits and costs, and incorporates Steps 3 and 4 from the real options process.

This step is unnecessary because all costs and benefits were explicitly defined for each year instead of using a select number of focus years. The practice of Step I differs from the written procedure in the Airport BCA Guidelines by including all evaluation time periods instead only a handful of time periods called focus years. In practice, the costs and benefits are estimated for each year of the evaluation period: in the written procedure they are estimated for a limited number of focus years. Focus years are described in the Airport BCA guidelines and are selected from the beginning, middle and end of the project evaluation period (US Federal Aviation Administration 1999a, p. 37). The guidelines explain how to interpolate/extrapolate data from focus years (3) to the evaluation period (20).

Step I outlines basic procedures to evaluate costs and benefits with NPV, BC ratio, IRR, and pay back method. In practice NPV and BC ratio are used and the FAA recommends NPV as the measurement that will be given primary consideration:

> *Given equal risk and uncertainty, FAA recommends that the alternative/time scenario with the largest positive NPV be given primary consideration as the preferred course of action (US Federal Aviation Administration 1999a, p. 83).*

As mentioned earlier the FAA BCA guidelines are substantially similar to OMB A-94, but are not statutorily bound because their recipient entities (airport sponsors) are not federal government entities.

Step J Evaluate variability of benefit-cost estimates

This step evaluates the variability of benefit-cost estimates due to uncertainty to see if the NPV rankings of the alternatives change and to see which uncertainties have the greatest impact on NPVs.

Step J includes Step 4.

Computer software stresses the economic model and then ranks the sensitivities with their respective magnitude. The effect of a change in every model input is measured relative to the output parameter(s) being evaluated. Model output is stochastic, a distribution that includes the original deterministic output and the potential range of outcomes along with their respective probabilities. When the outputs, the NPVs for each alternative, are graphed as a cumulative probability distribution, there are conclusions emerge that would not ordinarily be apparent with deterministic data that emerge.

When using real options Step K is now included in many of the other steps in the BCA process. By selectively converting inputs from deterministic to stochastic in Step B, the entire BCA has been conducted in a way that is substantially similar to declaring that a distributional assessment is warranted.

Output data from the economic model includes the original deterministic data (NPV) and its probabilistic distribution (NPV cumulative probability distribution – Value at Risk).

Step K Perform distributional assessment when warranted

This Step is included for sequential completeness with FAA Guidelines but is excluded for brevity.

Step L Make recommendation of best course of action

Step L includes Step 4. The mean of the NPV probability distribution is now used to decide which project is selected. VAR will also influence the selected project by showing how the projects rank with respect to their floors and caps. The flexible alternatives should have improved NPV values, floors, and caps when compared to similar inflexible alternatives.

The best course of action is still based on NPV but is enhanced with the probabilistic NPV outcome. Instead of ranking Alternatives by their deterministic NPV alone it is possible to see the impact of flexibility and make a decision.

4.B.1 Summary

The inclusion of real options in existing FAA Airport BCA procedures is straightforward and highly complementary. Real options build on the best practices of the FAA and provide a way of thinking that offsets forecast uncertainty with flexibility.

Table 4.11 shows the FAA Airport BCA process tasks, indicates if they are changed with the introduction of real options and where stochastic methods would have to be applied to realize the benefits of using real options.

Table 4.11 – Hypothetical FAA BCA Process Tasks W/ and W/Out Real Options

FAA Process Task	With and Without Real Options	With Stochastic Methods	Comments
Step A. Define project objectives	Unchanged	Unchanged	N/A
Step B. Specify assumptions about future airport conditions	Changed	Changed	Inputs become probability distributions
Step C. Identify the base case (no investment scenario)	Unchanged	Unchanged	N/A
Step D. Identify and screen all reasonable alternatives to meet objectives	Changed	Changed	Uncertainty is paired with flexibility
Step E. Determine appropriate evaluation period	Unchanged	Unchanged	The evaluation could change and is dependent on specifics of the systems under consideration.
Step F. Establish reasonable level of effort for analysis	Unchanged	Unchanged	Effort remains unchanged, but is aligned with tasks updated to include real options.
Step G. Identify, quantify, and evaluate benefits and costs of alternatives relative to base case	Unchanged	Changed	Augment selected deterministic data with parameters to convert to stochastic data
Step H. Measure impact of alternatives on airport usage	Unchanged	Unchanged	Opportunity for further research on the optional step.
Step I. Compare benefits and costs of alternatives	Changed	Changed	Augment selected deterministic data with parameters to convert to stochastic data
Step J. Evaluate variability of benefit-cost estimates	Changed	Changed	Stochastic methods needed for meaningful real options Analysis
Step K. Perform distributional assessment when warranted	Unchanged	Unchanged	N/A
Step L. Make recommendation of best course of action	Changed	Changed	Utilize Value-at-Risk information to augment final decision.

Source: (US Federal Aviation Administration 1999a, p. 6)

5 Applying Real Options with a Hypothetical Project BCA

This chapter applies the method proposed in the previous chapter by evaluating a hypothetical project using BCA with and without real options in a manner that is consistent with the FAA Airport Benefit-Cost Guidelines for Airport Improvement Program funding (US Federal Aviation Administration 1999a).

5.A Hypothetical Project

This case study is based on a hypothetical situation where a runway at a new towerless General Aviation airport is being built to meet an aircraft fleet mix that is thought to be stable in the immediate future but is subject to change. The initial fleet mix would start with a base point that would require a runway of not less than 7,000' x 100' and could eventually require a runway of not more than 12,000' x 150'[7]. While forecasts are done with the best intentions they are often inaccurate and, when utilized for long-term decision-making, decisions may lead to decisions that create an unanticipated mismatch of benefits and costs as time passes and new information emerges.

By coordinating the planning and technical needs of the proposed towerless GA airport it is possible to offset uncertainty in the long-term forecast with carefully selected sources of flexibility. The motivation for doing so is the understanding that forecasts are imprecise, based both on the anecdotal consensus and factual details from the FAA Aerospace Forecast (US Federal Aviation Administration 2006b). The Hypothetical Project proposes that uncertainty in aviation forecasts is paired with the flexibility to expand the runway when it is known with a high degree of certainty that activity at the airport will increase substantially. The embedded flexibility is accomplished by landbanking so that the airport sponsor may expand when necessary and may do so without regard to the then-current price of land/or the need to have a priori knowledge of when the expansion will occur.

The Hypothetical Project BCA presents three alternatives to build the runway at the towerless GA airport throughout the project life.

- Alternative 1 (the base case) accommodates near-term and long-term demand by constructing a 12,000' x 150' runway on 2,000 acres;
- Alternative 2 accommodates near-term demand by constructing a 7,000' x 100' runway on 500 acres;
- Alternative 3 accommodates near-term demand and long-term demand with landbanking now and expansion when needed in the future.
    a. Without real options this alternative is <u>excluded</u> from consideration.
    b. With real options this alternative will be evaluated when and if a carrier establishes substantial services at the airport. The year that this occurs in is randomly assigned and triggers construction costs followed shortly thereafter by benefits. Initially a 7,000' x 100' runway on 2,000 acres that may be expanded to 12,000' x 150' (, 9,000' x 200', or some other comparable size).

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[7] For comparison purposes the surface area of a 12,000' x 150' runway is the same as a 9,000' x 200' runway. When altitude adjustments are considered the required length of the airport runway can be adjusted by 7% per 1,000 feet above mean sea level (de Neufville and Odoni, 2003). A 12,000' runway at 5,400' above mean sea level (Denver International) is roughly equivalent to an 8,300' (12,000/(1.07)^1.54) runway at sea level (Boston Logan International). FAA Design Group VI aircraft require a runway width of 200' and the Airbus A380, which was jointly type certified by the FAA and EASA on December 12, 2006, is an FAA Design Group VI aircraft (Airbus, 2006; European Aviation Safety Agency 2006; US Federal Aviation Administration 2006k). A 9,000' x 200' at sea level would be equivalent to a 6,250'x200' runway at an elevation of 5,400'. See Appendix IV for runway area comparisons.

Alternatives 1 and 2 exclude flexibility to accommodate uncertainty in the forecast. Alternative 3 incorporates a real option: the right but not the obligation to expand the runway as new information becomes available to decision-makers in the future.

In the Hypothetical Project BCA with real options, Alternative 3 is exercised in a time period that will accommodate the change in fleet mix by extending the runway. Unlike a staged development project where a subsequent project stage is valued by specifying a date in advance, Alternative 3 has a floating date randomly set by the simulation bounded by an upper and lower limit. For convenience, the Chapters 4 and 5 Road Map diagram is repeated in Figure 5.1

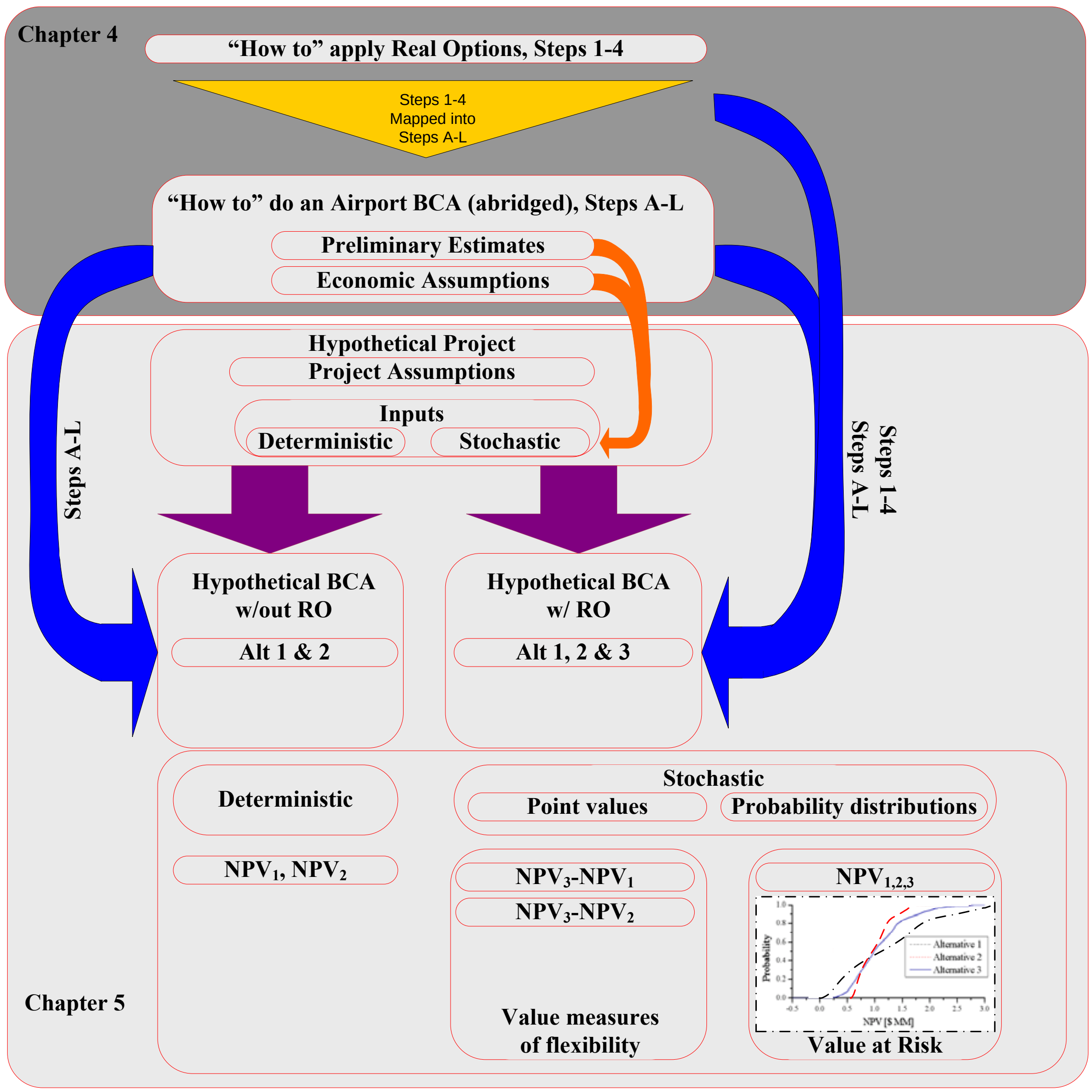


Figure 5.1 - Chapters 4 and 5 Road Map

5.B Hypothetical Project BCA without Real Options

The Hypothetical Project BCA is presented without real options using the FAA Airport Benefit-Cost Analysis Guidelines (US Federal Aviation Administration 1999a) known to be used in practice.

Step A w/out RO Define project objectives

The principal project objective is to accommodate a changing mix of aircraft types that are initially known to be not more demanding than the Embraer ERJ145ER but may eventually progress to accommodate the equivalent of a Boeing 777-300 at some point in the 20-year operating period.

Step B w/out RO Specify assumptions about future airport conditions

The airport sponsor is proposing a new towerless airport to support general and light commercial aviation needs initially, but is also aware that current conditions may change in the future. During the initial operating period it is anticipated that the fleet mix would include aircraft with takeoff and landing requirements that are substantially similar to but not more demanding than the Embraer ERJ145ER which requires an estimated FAA takeoff field length of 7,000' and a width of 100' (de Neufville and Odoni, 2003).

Current forecasts indicate that local businesses will utilize the proposed runway for an Embraer ERJ145ER.

During the 20 year operational lifetime it is forecasted that the fleet mix composition will change to include aircraft substantially similar to but not more demanding than the Boeing 777-300, which requires an estimated FAA takeoff field length of 12,000' (de Neufville and Odoni, 2003). The expanded fleet mix will still include general aviation and will also have a broader range of commercial aviation services and will likely introduce cargo services. It is unknown when the transition will occur, but it is thought to be plausible and flexibility should be included to accommodate this uncertainty with the inclusion of an option to expand in the future. There is significant uncertainty regarding the forecast validity after the first few years and "[u]nfortunately, realistic forecasts are difficult to make" (US Federal Aviation Administration 1999a, p. 11).

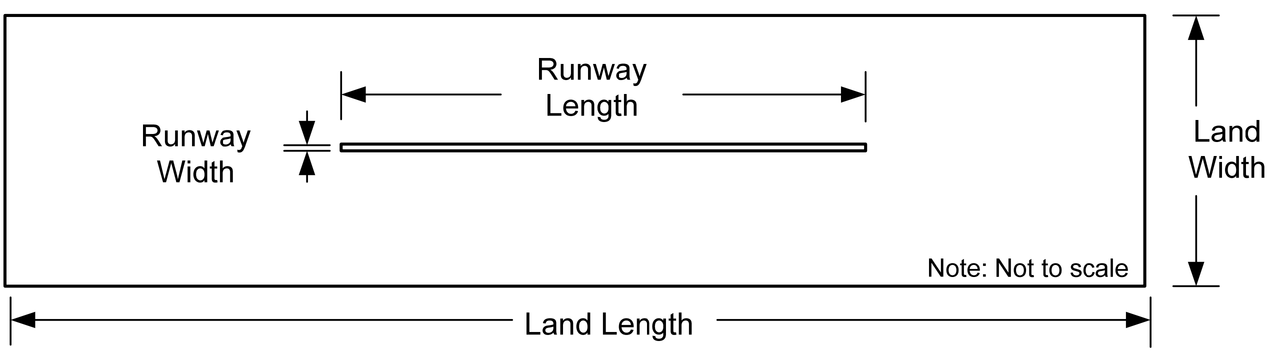
General Assumptions

- It is estimated that a land area between 35 and 138 times the runway area is thought to be suitable for the airport runway and supporting infrastructure in each of the proposed alternatives. The estimate is subjective but thought to be reasonable when compared calculated ratios for other operating and proposed domestic airports that accommodate different mixes of aircraft types. Support for this estimate is based on data in Table 5.1 where the range is between 7 and 121 for current operating airports and 129 for a proposed new airport. As a broad generalization, airports with lower ratios are runway expansion constrained. See Table 5.1 for the summarized data and Figure 5.2 for the method of calculation.
- The runway is level at or around 1,000' above sea level. Most major US airports are located at or below 1,000'.
- FAA takeoff airfield length will accommodate aircraft Maximum Takeoff Weight (MTOW) under a wide range of climate and inclement weather conditions. MTOW is the weight of a fully loaded and fueled aircraft and is summarized in Table 5.2.

Table 5.1 - Airport Comparison Data

		Runway surface area		Land area	Ratio of land to runway area	Elevation above mean sea level
		[sqft x 10^6]	[acres]	[acres]	[no units]	[feet]
Alternative 1		1.80	41	2,000	48	1,000
Alternative 2		0.63	14	500	35	1,000
Alternative 3		0.63	14	2,000	138	1,000
Proposed Western West Virginia Regional Airport		1.31	30	3,400	113	901
Yeager		1.97	45	767	17	981
Tri-State		1.16	27	1,250	47	828
Philadelphia International		5.10	117	2,302	20	36
Covington		6.75	155	7,000	45	896
Proposed Chicago South Suburban Airport	Initial	1.35	31	4,000	129	750
	Ultimate	8.10	186	24,000	129	750
Chicago/O'Hare		7.94	182	6,500	36	668
Chicago/Midway		4.10	94	650	7	620
Denver International		12.20	280	34,000	121	5,341
New York/Kennedy		6.65	153	4,950	32	13
Washington/Dulles		5.03	115	10,000	87	313
Washington/Reagan		2.55	58	733	13	15
Stafford Regional		0.50	11	550	48	211

Sources: airport websites



$$\frac{\text{Land Length x Land Width}}{\text{Runway Length x Runway Width}} = \frac{\text{Land Area}}{\text{Runway Area}} = \text{Ratio of land to runway area}$$

Figure 5.2 - Ratio of Land to Runway Area Calculation

Table 5.2- Aircraft Manufacturer Data

	Aircraft Tare W1	Maximum Payload W2	Maximum Fuel W3	MTOW ΣWn	Takeoff run at MTOW at sea level
	[lb]				[ft]
Embraer ERJ145ER	24,424 (est.)	12,755	11,322	48,501	5,900
Boeing 777-300	353,124	169,600	137,276 (est.)	660,000	9,700

Source: Embraer and Boeing websites (Boeing 2006; Embraer 2006)

- The proposed initial runway lengths exceed the manufacturer's recommended takeoff run at MTOW summarized in Table 5.3. Runway takeoff lengths used in the Hypothetical Project BCA were not precise and this cross check reinforces the assumption that the 7,000' and 12,000' runways are suitable when the manufacturer's specification is adjusted for altitude. A broad generalization is that the takeoff length of a runway needs to increase 7%/1,000' of altitude above mean sea level (de Neufville and Odoni, 2003).

Table 5.3 - Runway Length Verification

	Takeoff run at MTOW at sea level Mfg. Spec. T	Takeoff run at MTOW 1,000' above sea level Altitude Adj. T*1.07	Proposed Runway R	"Excess" runway length R-T*1.07
	[ft]			
Embraer ERJ145ER	5,900	6,300	7,000	700
Boeing 777-300	9,700	10,400	12,000	1,600

Source: Embraer and Boeing websites (Boeing 2006; Embraer 2006)

General Assumptions (continued)

- Runway is aligned to minimize the impact of undesirable surface wind patterns.
- No physical obstacles are located on or around the runway and the approach path of the surrounding area.
- All declared distances are the same as the FAA takeoff field length indicated in earlier in this chapter, specifically 7,000' and 12,000'.
- FAA Airport Reference Code for the initial fleet mix critical aircraft (Embraer ERJ145ER) is CII (approach speed between 121 to 141 knots and a wingspan between 49' to 79') and for the anticipated future fleet mix critical aircraft (Boeing 777-300) is DV[8] (approach speed between 141 to 166 knots and a wingspan between 171' to 214') (US Federal Aviation Administration 1989).
- The proposed assumptions are compatible and in compliance with FAA Regulations, Advisory Circulars and best practices (US Federal Aviation Administration 2004a).

Step C w/out RO Identify the base case (no investment scenario)

This step proceeds with the assumption that the FAA would approve an exception to substitute a no investment scenario with one of the proposed alternatives, specifically alterative 1. This

[8] On June 13th, 2006 in the FAA Aircraft Characteristic Database the Boeing 777-300 Design Group designation changed from IV to V (US Federal Aviation Administration 2006c).

assumption is plausible since the proposed BCA is for a Greenfield runway to be built where no suitable comparison would be appropriate.

The base case is Alternative 1, a full length runway of 12,000' situated on 2,000 acres that will accommodate the anticipated fleet mixes over the entire 20 year operating period. While there is certainty that the runway will be utilized by the smaller sized fleet mix over its entire operational life there is little certainty regarding the timing of the larger fleet mix.

Alternative 1 (Base Case) – Full Sized with no Flexibility

Acquire 2,000 acres to construct a 12,000' runway to accommodate all forecasted demand for the entire operating period.

Step D w/out RO Identify and screen all reasonable alternatives to meet objectives

One additional alternative is proposed to meet the principal project objective.

Alternative 2 – Short Runway with no Flexibility

Acquire 500 acres of land to construct a 7,000' runway to accommodate the initial fleet mix. This runway caps future benefits, excluding benefits that would be available if the runway was able to accommodate a larger fleet mix in the future.

Step E w/out RO Determine appropriate evaluation period

Land acquisition is assumed to occur at t=0 and is immediately followed thereafter by 3 years of construction between t=1 and t=3. When construction is complete at t=3 there will be a 20-year operating period between t=4 and t=23.

Step F w/out RO Establish reasonable level of effort for analysis

As BCA and other planning processes can be time and resource consuming, the FAA (like other governmental bodies) attempts to manage those costs proportionally to the complexity of the investment. However this step is not relevant for this case study as it is highly dependent on the specific BCA being carried out.

Step G w/out RO Identify, quantify, and evaluate benefits and costs of alternatives

Benefit Categories and Details

Proposed benefits for the initial fleet mix are Reduced Aircraft Delay and Reduced Passenger Delay and are the same for Alternatives 1 and 2. A scenario is proposed below to estimate what benefits would accrue from Reduced Aircraft Delay and Reduced Passenger Delay.

It was determined with the FAA General Aviation Airport operations linear regression estimation model that the proposed runway would have initial demand of approximately 40,000 operations per year (GRA, Inc. 2001). It is presumed that well over 40,000 General Aviation operations already exist at the heavily congested commercial airports in the Metropolitan Statistical Area (MSA) and that 40,000 would migrate to the new facility when it becomes available.

A reduction of 40,000 General Aviation operations is assumed to reduce delay by one-sixth of an hour (10 minutes) for 1% of the total commercial operations in an MSA, which in the near future will be in or around 1,500,000 operations/year. For example, the Washington, DC MSA commercial airports are anticipated to have annual aggregated operations growth of 2.8% over the next 20 years and by 2009 the annual operations will be 1,500,000/year (US Federal Aviation Administration, 2006b).

This would be an aggregated annual savings of 2,500 hours for commercial aircraft operators and their passengers and is assumed to grow at 2.8% per year.

Table 5.4- Selected Metro Area Operations of NPIAS Large Hub Primary Airports (2006 est.)

Airport		Operations		
		Daily	Annual	
		Local		MSA
Chicago/O'Hare	ORD	2,627	696,000	981,000
Chicago/Midway	MDW	780	285,000	
Baltimore/Washington International	BWI	995	363,000	1,300,000
Washington/Dulles	IAD	1,819	664,000	
Washington/Reagan	DCA	762	278,000	
New York/Kennedy	JFK	950	347,000	1,188,000
New York/LaGuardia	LGA	1,113	406,000	
Newark/Liberty	EWR	1,193	435,000	

Source: (AirNav 2006)

Note: For airports with greater than 250,000 annual operations.

Reduced Aircraft Delay, Initial Fleet Mix

Annual savings of 2,500 hours will grow at 2.8% per year and can be monetized by assuming that the variable operating costs for all commercial aircraft that will benefit from the delay reduction have a blended cost of $2,937/hr in 2001 dollars (GRA Inc. 2004, p. ES-3). The variable operating expense is adjusted to the base year of the study (2006) with the US Airline Index (GRA Inc. 2004, p. 9-7; US Air Transport Association 2006; US Federal Aviation Administration 1999a and 2005a). The adjusted blended variable operating cost is $2,970/hr in 2005 dollars[9]. All monetary values in this paragraph were introduced in Table 4.8 on page 17.

Annual savings from reduced aircraft operating delay is $7.4 M in 2006 (t=0) dollars.

Changes in variable operating costs have been flat in the recent past and are projected to remain flat in the future. The annual growth rate of the US Airline Composite Index from 2000 to 2005 is 0.22%, almost zero cost growth (US Air Transport Association 2006). Although there have been sharp fuel price increases between 2000 and 2005, they have been offset by other operating costs that make up the index.

Reduced Passenger Delay, Initial Fleet Mix

Annual savings of 2,500 hours can be converted to passenger hours by assuming that there are 55 passengers who each save the same time that the aircraft saves through delay reduction[10]. In other words, an aircraft with 55 passengers that saves one-sixth of an hour will save 9.17 hours for its passengers. Total passenger savings are 2,500*55 = 138,150 hours annually and can be monetized by

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[9] The US Airline Composite Index was 180 in 2000, and, at the end of 2005, was 182: increases in fuel costs have been offset by reductions in other operating expenses. A negligible cost change when all other areas of the US economy inflated by approximately 3% per year over the same period.

[10] Passenger Delay Assumption - "Air carrier-All Purposes" is an aggregate value of passenger time representing all passengers regardless of their specific income, or lack thereof. The value of passenger time will be indexed to the Bureau of Labor Statistics Wage Index. An improvement of the value of passenger time estimate could be made by categorizing passengers by their respective income levels and whether their travel is business or personal related. To apply the categorized valuation of passenger time it would also be necessary to estimate the number of passengers traveling in each category.

assuming that all affected passengers have time that is valued hourly. The value of "Air carrier-All Purposes" passenger time may be taken as $28.60/hr in 2000 dollars (GRA Inc. 2004, p. ES-3). Adjusting passenger time cost to 2006 using would result in a value of $34.99/hr in 2006 dollars. All monetary values in this paragraph were introduced in Table 4.8 on page 17. Annual passenger delay reduction will grow by 2.8%/year.

Annual savings from reduced passenger delay is $4.8 M in 2006 (t=0) dollars.

Hard to quantify benefits

Anticipated benefits that would accrue when a commercial operator establishes significant services in the future are difficult to quantify. Although it is not known when this will occur it is thought to be plausible since the proposed location is within 50 miles of a top 10 Metropolitan Statistical area and within 30 miles of an already expansion-constrained and congested Large Hub airport. When this event does occur the proposed General Aviation airport will be expanded to accommodate the needs of the airline and become a Commercial Services Airport. The present value of benefits that may accrue from new services that may materialize in the future are very uncertain and assumed to be $0.

Cost Categories and Details

Costs are categorized as land acquisition, construction, and operations and maintenance. Land acquisition costs depend on the quantity of land to be acquired and the price to be paid (per unit of quantity). Construction costs are derived from the cost per square foot of similar projects and the proposed runway surface areas. Maintenance costs are based on data from other airports.

Land Acquisition

Land acquisition is assumed to cost $13,250/acre in 2006 dollars. For Alternative 1, 2,000 acres will be acquired and for Alternative 2, 500 acres. The assumed cost/acre is based on the average cost of acquired land for the proposed South Suburban Airport in Peotone, IL of $13,268/acre. (2,045 acres consisting of 93 land parcels for a total cost of $27,134,464) (Illinois Department of Transportation 2006).

Construction

Planned construction will include a runway, taxiways and apron. To estimate the construction costs, an analysis of available airport construction cost data was conducted. For example, costs to reconstruct runway 12-30 at Dulles-International Airport were $33/sqft in 2006 dollars (Metropolitan Washington Airports Authority 2006). While runway 11-29 at Lambert-St. Louis International was $57/sqft in 2006 dollars (Lambert-St. Louis International Airport Expansion Program 2006). With a set of sample data where complete details were available it was determined that a cost of $73/sqft in 2006 dollars, when proportional soft costs were included the cost became $92/sqft in 2006 dollars (Earth Tech, Inc. et al. 2003). If the true costs were $73/sqft in 2006 dollars the FAA BCA guidelines would find it acceptable to adjust the cost with a contingency factor of around 15%, a professional service fee of up to 15% and an administration fee of 2% (US Federal Aviation Administration 1999a, p. 68). A cost range of between $86/sqft and $98/sqft is consistent with the $92/sqft from the sample data set. A weakness of this approach is trying to bundle all costs associated with the infrastructure that would accompany a runway into a single representative number.

For initial construction of the 12,000' and 7,000' runway, a construction cost of $90/sqft was assumed to be sufficient to cover the construction activities for the runway. This is an extreme simplification of runway construction costs that ignores all of the factors that are necessary to calculate a precise and highly refined estimate. However, it is substantially similar to runway construction costs in projects of similar scope and magnitude where sufficient details were available to closely examine the inclusion or exclusion of specific costs.

Construction costs were arbitrarily assumed to be disbursed over the 3-year period as 20% in t=1, 50% in t=2 and 30% in t=3. During this short period there is no adjustment for inflation since it assumed that the majority of the costs were pre-determined in a contractual agreement with a fixed price.

When it becomes certain that the 7,000' runway will be expanded the $90/sqft estimate will be inflation adjusted and disbursed using the same 3-year schedule mentioned above.

Operations and Maintenance

Operations and maintenance are recurring costs necessary to operate and maintain the proposed airport. They ordinarily consist of staff costs, materials, utilities, and insurance.

Yeager Airport (Charleston, WV) reported costs for operations and maintenance of $3.6 M ($2.76/sqft of runway surface area) in 2006 dollars for their 2001 operational year (Earth Tech, Inc. et al. 2003). An FAA recommendation suggests 3% of the initial construction costs which would be approximately $4.5 M ($2.50/sqft) for the 12,000' runway and approximately 2.5 M ($3.57/sqft) for the 7,000' runway. Since this is a single runway at a GA airport, it likely has substantially reduced recurring costs because it will not handle the same number of operations as a commercial facility.

An initial estimate of the runway maintenance costs for the 12,000' is $1.8 M ($1.00/sqft) and 7,000' is $0.7 M ($1.00/sqft). As a percentage of construction costs the operations and maintenance costs are both 1.1%. If the runway is expanded the maintenance costs will be estimated as 3% of the inflation adjusted expansion construction costs plus some additional factor that takes the recurring costs of the initial infrastructure into consideration.

Recurring costs for utilities and insurance are assumed to be negligible.

Planning and Research and Development

These costs are incurred before and after the BCA. Those that occurred before are considered sunk costs and are ineligible for inclusion in the BCA. Costs that occur afterwards are considered to be negligible and are excluded from this Hypothetical Project BCA.

Hard to Quantify Costs

Travel and time costs for General Aviation users that choose to relocate their activities at the new airport. These costs are non-zero, but are assumed to be zero for this thesis.

Benefits and Costs Summary

Table 5.5 summarizes the initial benefits and costs. Benefits begin to accrue in the initial operating period and in each subsequent period are adjusted for inflation and anticipated growth in time saved. Land acquisition is a one-time cost that occurs at the beginning of the evaluation period and is $24.5 M for Alternative 1 and $6.1 M for Alternative 2. Construction costs occur over a three-year period and their constant dollar sum is $162 M for Alternative 1 and $63 for Alternative 2. Initial Operations and Maintenance expenses are $1.8 M for Alternative 1 and $0.7 M for Alternative 2.

Although the Airline and Passenger Savings are $4.8 M and $7.4 M in 2006 (t=0) dollars, their initial appearance in the model is at t=4 when they are $5.4 and $8.3 M.

Table 5.5 - Benefits and Costs Summary

Description	Recurrence time period(s)	Units	Alternative 1	Alternative 2
Benefit		[$ M]		
Airline savings	Annual (t=4,5,…)		8.3	8.3
Passenger savings	Annual (t=4,5,…)		5.4	5.4
Cost				
Land Acquisition	One-time (t=0)		24.5	6.1
Construction	One-time (t=1,2,3)		162	63
Operations and Maintenance	Annual (t=4,5,…)		1.8	0.7

Step H w/out RO Measure impact of alternatives on airport usage

To reduce the complexity of the BCA, this thesis will not include additional details for Step H. FAA Guidelines permit the exclusion of this step: "Because of the uncertainty associated with the data used in an analysis of induced demand, it is left to the option of the airport sponsor whether or not to include this analysis in the BCA" (US Federal Aviation Administration 1999a, p. 7).

Step I w/out RO Compare benefits and costs of alternatives

Benefits and costs have been discounted with the real discount rate set at 7% over a 20-year period and are summarized in Table 5.6 (US Federal Aviation Administration 1999a, p. 77; US Office of Management and Budget 1992, p. 1).

Table 5.6 - Hypothetical Project BCA Deterministic Summary

	Units	Alternative 1 (Base Case)	Alternative 2
PV of Benefits	[$ M]	147	147
PV of Costs		181	67
NPV		-34	80
BC ratio	[no units]	0.81	2.19

Step J w/out RO Evaluate variability of benefit-cost estimates

Select Alternatives with positive BC ratios and evaluate for variability of cost estimates by adjusting one input factor at a time and recording the results as shown in Table 5.7. It is assumed that the step input increase and selected benefits and costs selected are sufficient to test the sensitivity of net NPV and the BC ratio.

Table 5.7 - Variability Analysis of Alternative

	Net Effect on NPV		BC ratio	
	Minus 20%	Plus 20%	Minus 20%	Plus 20%
	[$ M]		[no units]	
Alternative 1				
Passenger savings	-27	27	0.71	0.94
Carrier savings	-20	20	0.64	0.99
Land Acquisition	5	-5	0.84	0.77
Construction	31	-31	0.97	0.67
Alternative 2				
Passenger savings	-27	27	1.99	2.61
Carrier savings	-20	20	1.79	2.67
Land Acquisition	1	-1	2.23	2.16
Construction	15	-15	2.31	2.01

Step K w/out RO Perform distributional assessment when warranted

This Step is included for sequential completeness with FAA Guidelines but is excluded for brevity.

Step L w/out RO Make recommendation of best course of action

Alternative 2 also has the highest NPV, $80 M. Alternative 2 also appears to offer the best match for the current needs and, compared to the other alternatives, has the least sensitivity to fluctuation in land prices. Alternative 2 also has a positive NPV with all of the negative scenarios above both independently ($53, 60, 79, and 75 M) and collectively ($17 M). Assuming there is no compelling reason to select Alternative 1 and that both Alternatives have been evaluated equally, then Alternative 2 would be the recommended choice.

5.C Hypothetical Project BCA with Real Options

The Hypothetical Project BCA is presented with real options using the FAA Airport Benefit-Cost Analysis Guidelines (US Federal Aviation Administration 1999a) known to be used in practice. The BCA with real options emphasizes the differences between the two methods and avoids, where possible, repeating previously introduced information.

Table 4.7 is repeated for convenience as Table 5.8. The RO steps are: 1) Identify sources of uncertainty and flexibility, 2) Select the option strategy for each uncertainty and flexibility pairs, 3) Find the option value in each alternative with embedded option(s), and 4) Rank and compare the NPV and VAR of all alternatives. Steps with a single numerical digit between 1 and 4 refer to the generic real options analysis procedure explained on pages 45 to 52 of this thesis. Steps with a character from A to L are the FAA BCA steps that are explained in Chapter 4. Step G is further subdivided into three steps for consistency with FAA guidelines and is denoted as Step G1, G2 and G3. The introduced notation supplements the FAA BCA guidelines by acting as a very short reference pointer to the full title of each step in 7 or less characters.

Table 5.8 - Mapping of RO steps into BCA Steps

		Complementary Real Options Procedural Steps 1-4				Thesis page #	
		1	2	3	4	w/out	w/
FAA BCA Procedural Steps A-L	A					61	70
	B	✓				61	70
	C	✓				63	70
	D	✓	✓			64	70
	E					64	71
	F					64	72
	G			✓		64	72
	H					68	73
	I			✓	✓	68	74
	J				✓	68	75
	K					69	75
	L				✓	69	75
Thesis page #		45	46	46	52		

Step A w/ RO Define project objectives

The principal project objective is to accommodate a changing mix of aircraft types that are initially known to be not more demanding than the Embraer ERJ145ER but may eventually progress to accommodate the equivalent of a Boeing 777-300 at some point in the 20-year operating period. In this step, there are no differences due to the inclusion of real options.

Step B w/ RO Specify assumptions about future airport conditions

In this step, there are differences due to the inclusion of real options and they are attributable to Step 1.

Step C w/ RO Identify the base case (no investment scenario)

In this step, there are differences due to the inclusion of real options and they are attributable to Step 1.

<u>Alternative 1 (Base Case) – Long Runway without Flexibility</u>

Acquire 2,000 acres to construct a 12,000' runway to accommodate all forecasted demand for the entire operating period.

Step D w/ RO Identify and screen all reasonable alternatives to meet objectives

Two additional alternatives are proposed to meet the principal project objective. In this Step, there are differences due to the inclusion of real options and they are attributable to Steps 1 and 2.

<u>Alternative 2 – Short Runway without flexibility</u>

Acquire 500 acres of land to construct a 7,000' runway to accommodate the initial fleet mix. This runway caps future benefits that would be available if it were extendable to accommodate a larger fleet mix in the future.

<u>Alternative 3 – Short Runway with Flexibility</u>

Acquire 2,000 acres to construct a 7,000' runway initially with the option to expand an additional 5,000'. Acquiring additional land would preserve runway length flexibility and permit a decision-maker, in a future time period when additional details emerge, to expand the runway to a length that would accommodate the different types of air traffic demand.

Step E w/ RO Determine appropriate evaluation period

In this Step, the inclusion of real options retains the original evaluation period and introduces a second evaluation period that commences at a discrete randomly selected time between t=6 and t=13 and ends concurrently with the original time period in t=23. The purpose of limiting the starting period between t=6 and t=13 is so that the expansion occurs after the initial project is complete and costs from the expansion occur early enough to have benefits. If the expansion were to occur beyond t=20 there would be three years of construction costs in t=21, 22 and 23 with benefits occurring in and beyond t=24 (the 21st operating year). The random evaluation period circumvents a problem and weakness of current planning methodologies: the expansion date does not need to be known since the project will accommodate it when needed in the future. To include the possibility that significant services may never be established in the future the model assigns a special condition that sets all expansion benefits and costs to \$0. The probability distribution, $p_{cust}(x)$, is the probability distribution example in Figure 4.7. See Appendix III for further details.

With the Monte Carlo spreadsheet addin, $p_{cust}(x)$ is readily added to the model by highlighting an empty cell and configuring it with a custom probability distribution. The specific parameters used for $p_{cust}(x)$ are in Table 5.9. When i=0 the expansion doesn't occur and when i=6 to 13 the expansion occurs. Both t and i are equal, they are separate to draw the distinction between a time period reference and a randomly generated time period. So, when $p_{cust}(x)$ generates i=6 then the construction will occur 1 year later in t=7. The probabilities are arbitrary and intended to show the value of correctly timing a real option. Expansion Benefits and Costs are triggered by this probability distribution with an "if" statement.

if i=0 there are no additional benefit or costs (no expansion occurs)
if i= 6 to 13 then inflation adjust benefits and costs and insert them in the appropriate year. The benefits will recur until ended at t=23, the construction costs will recur until t=i+3 and the Operations and Maintenance costs will commence at t=i+4 and end at t=23.

Table 5.9 - Custom Probability Distribution Data ($p_{expansion}$)

p	0.60	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
i	0	6	7	8	9	10	11	12	13

Both Alternatives 1 and 2 will benefit in the future when significant services commence. Benefits for Alternative 1(3) will commence 1(4) year(s) after it is determined that significant services will commence. The difference in the commencement of benefits is due the differences in the readiness of the alternatives. Alternative 1 is initially constructed to handle significant services when or shortly after they commence. Alternative 3 requires a delay of up to four years to expand the runway to accommodate the significant services.

Step F w/ RO Establish reasonable level of effort for analysis

As BCA and other planning processes can be a time and resource-consuming, the FAA (like other governmental bodies) attempts to manage those costs in a way that is proportional to the complexity of the investment. However, this step is not relevant for this case study as it is highly dependent on the specific BCA being carried out. It should be noted that RO-analysis does not necessarily require more effort than the standard BCA extra effort. The incremental difference between a BCA with and without RO is minimal—the necessary steps to include RO in BCA are primarily limited to altering the BCA from deterministic to probabilistic projections and identifying alternatives with one or more options. In this step, there are no differences due to the inclusion of real options.

Step G w/ RO Identify, quantify, and evaluate benefits and costs of alternatives

Step G w/ and w/out RO is unchanged with these exceptions (needed to include Step 3): 1) select deterministic parameters become probabilistic. 2) expansion benefits are introduced and 3) the timing of the expansion is now probabilistic instead of unknown.

Benefit Categories and Details

Additional Benefits that would accrue when the future fleet mix emerges are Reduced Aircraft Delay and Reduced Passenger Delay – the same as the initial benefit streams but the annual delay reduction is adjusted by a factor of 5 upwards -- in other words the proportion of aircraft benefiting from the newer airport changes from 1% to 5%.. This increase is due to the a reduction of operations at neighboring metro area airports that is equivalent to the increase in operations at the newly expanded airport – the new airport offloads the existing airports.

Rent Back

Alternative 3 receives rent on the acquired land that is not yet needed, specifically 1,500 acres landbanked for future use. The initial rent is set at $1 M/year and is approximately 5% of the occupied land value at the time it was acquired. The rent back benefit would terminate in the year prior to the commencement of expansion construction.

Reduced Aircraft Delay, Initial Fleet Mix

Annual savings from reduced aircraft operating delay is $7.4 M in 2006 dollars.

Variable operating costs are anticipated to have volatility of 20% and the benefit growth of 2.8% is now represented with the probability distribution $p_{min}(x)$=[2.8, 0.56, -5.0, 20.0] that was defined in Chapter 4 and is referred to as $p_{b,aircraft,i}$.

Reduced Passenger Delay, Initial Fleet Mix

Annual savings from reduced aircraft operating delay is $4.8 M in 2006 dollars.

Variable operating costs are anticipated to have volatility of 20% and the benefit growth of 2.8% is now represented with the probability distribution $p_{min}(x)$=[2.8, 0.56, -5.0, 20.0] that was defined in Chapter 4 and is referred to as $p_{b,passenger,i}$.

Reduced Aircraft Delay, Future Fleet Mix

Same as Fleet Mix #1 but each local commercial aviation operation has delay reduced by 10 minutes AND this benefit only materializes when it is known that an air carrier will establish a hub at the airport. When this benefit does begin it is inflation adjusted for the time period it begins in. In the deterministic model the present value of this benefit stream is $0. In the real options model this benefit begins in a future time period when it is known with certainty that it will occur and is applied to Alternatives 1 and 3.

Variable operating costs are anticipated to have volatility of 200% and the benefit growth of 2.8% is now represented with the probability distribution $p_{min}(x)$=[2.8, 5.6, 0, 20.0] that was defined in Chapter 4 and is referred to as $p_{b,aircraft,e}$.

Annual savings from reduced aircraft operating delay is $37.1 M in 2006 dollars.

Reduced Passenger Delay, Future Fleet Mix

Same as Fleet Mix #1 but each local commercial aviation operation has delay reduced by 10 minutes AND this benefit only materializes when it is known that an air carrier will establish a hub at the airport. When this benefit does begin it is inflation adjusted for the time period it begins in. In the deterministic model the present value of this benefit stream is $0. In the real options model this benefit begins in a future time period when it is known with certainty that it will occur and is applied to Alternatives 1 and 3.

Variable operating costs are anticipated to have volatility of 200% and the benefit growth of 2.8% is now represented with the probability distribution $p_{min}(x)=[2.8, 5.6, 0, 20.0]$ that was defined in Chapter 4 and is referred to as $p_{b,passenger,e}$.

Annual savings from reduced aircraft operating delay is $24.2 M in 2006 dollars.

Hard to quantify benefits

There are anticipated benefits that would accrue when a commercial operator indicates an interest to establish a hub in the future. Although it is not known when this will occur it is thought to be plausible since the proposed location is within 50 miles of a top 10 Metropolitan Statistical area and within 30 miles of an already expansion-constrained and congested Large Hub airport. When this event does occur the proposed General Aviation Airport will be expanded to accommodate the needs of the airline and become a Commercial Services Airport. The present value of benefits that may accrue from new services that may materialize in the future are very uncertain and assumed to be $0 in the deterministic model whereas in the stochastic model they are represent with a probability distribution.

Cost Categories and Details

Costs are categorized as land acquisition, construction and operations and maintenance. Land acquisition discusses the quantity of land to be acquired and the price to be paid. Construction costs are derived from the cost per square foot of similar projects and the proposed runway surface areas. Maintenance costs are estimated with the assistance of data from other operating airports.

Land Acquisition

Alternative 3 proposes to landbank 1,500 of the acquired 2,000 acres. Land cost is anticipated to have a volatility of 50% and, with a mean cost of 10%, is now represented with the probability distribution $p_{max}(x)=[20, 10, 0, 50]$ that was defined in Chapter 4 and will be referred to as $p_{c,land}$.

Construction, Initial

The per square foot cost will be $P_{max}(x)=[10, 1, 0, 20]$ and will be referred to as $p_{c,construction,i}$.

Operations and Maintenance

$p_{max}(x)=[3.0, 1.5, 0, 15]$ that was defined in Chapter 4 and will be referred to as $p_{c,om,i}$.

Hard to Quantify Costs

Travel and time costs for General Aviation users that choose to relocate their activities at the new airport. These costs are assumed to be $0 for the thesis calculations.

Benefits and Costs Summary

Benefits and costs retain the same deterministic data but are now the probability distributions described in the sub-Chapter.

Step H w/ RO Measure impact of alternatives on airport usage

To reduce the complexity of the BCA this thesis will not include additional details for Step H. FAA Guidelines permit the exclusion of this step: "Because of the uncertainty associated with the data used in an analysis of induced demand, it is left to the option of the airport sponsor whether or not to include this analysis in the BCA" (US Federal Aviation Administration 1999a, p. 7). In this step, there are no differences due to the inclusion of real options.

Step I w/ RO Compare benefits and costs of alternatives

In this step, there are differences due to the inclusion of real options and they are attributable to Steps 3 and 4.

Figure 5.3 shows the cumulative probability distribution (and a magnified version) of all three alternatives and their NPV's. Table 5.10 summarizes the Value at Risk

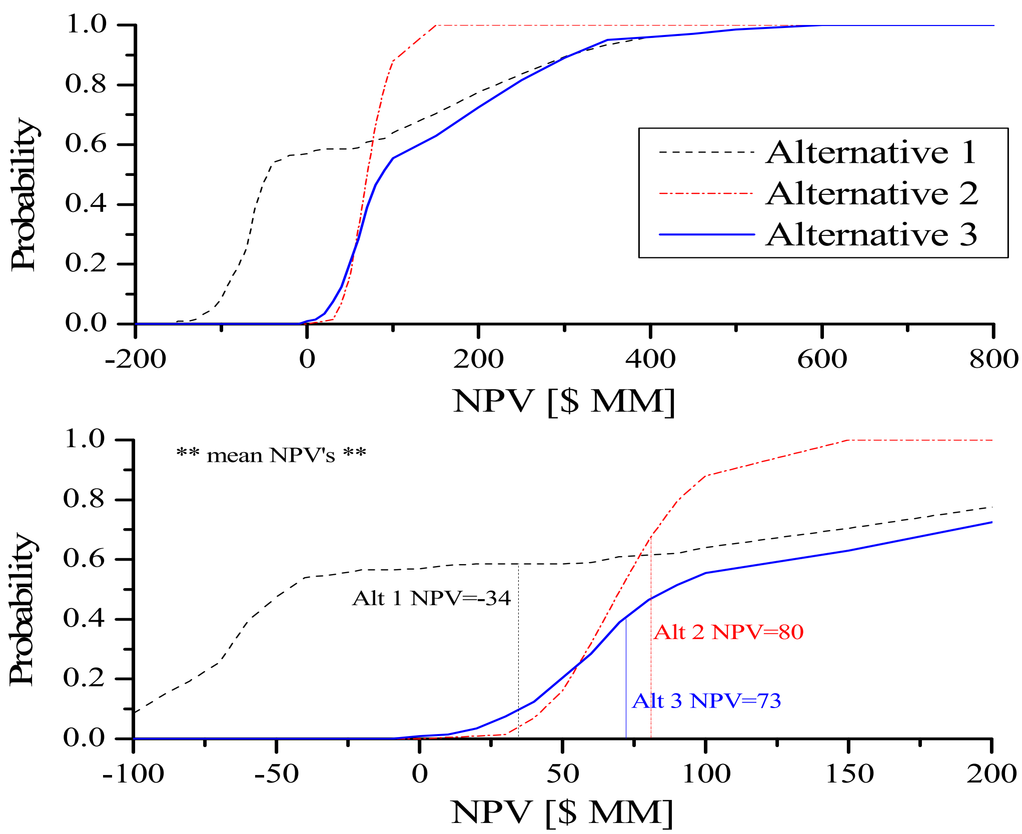

Figure 5.3 - Alternatives 1, 2 and 3 NPV Value At Risk

Table 5.10 - VAR Summary

		Alt 1 (Base Case)	Alt 2	Alt 3
NPV(deterministic)	$ M	-34	80	73
NPV(mean)		54	72	139
NPV(0%)		-158	0	-9
NPV(100%)		541	133	520
Probability of NPV greater than $0 M	%	40	100	98

Step J w/ RO Evaluate variability of benefit-cost estimates

Step. J w/ and w/out RO is different in these ways: 1) the computer software stresses the economic model and then ranks the sensitivities with their respective magnitude. The effect of a change in every model input is measured relative to the output parameter(s) being evaluated. 2) the model output is stochastic, a distribution that includes the original deterministic output and the potential range of outcomes along with their respective probabilities. When the outputs, BC ratios for each alternative, are graphed as a cumulative probability distribution conclusions that would not ordinarily be apparent with deterministic data may emerge. In this step, there are differences due to the inclusion of real options and they are attributable to Step 4.

Step K w/ RO Perform distributional assessment when warranted

As already stated, with real options the distributional assessment is performed as a part of steps G through J. Therefore, no separate step is necessary for the distributional assessment.

Step L w/ RO Make recommendation of best course of action

In this step, there are differences due to the inclusion of real options and they are attributable to Step 4.

Alternative 2 again has the highest BC ratio, 2.19, but has an NPV that is the same as Alternative 3. Alternative 2 appears to offer the best match for the current needs and compared to the other alternatives has the least sensitivity to fluctuation in land prices.

Alternative 3 would be the best choice to make because: 1) it is flexible and can be expanded when the need arises 2) it has the lowest downside risk and the highest upside potential. Although Alternative 3 has the 2nd highest BC ratio and an NPV that is equivalent to Alternative 2 it is the recommended alternative.

6 Conclusion

6.A Case Study Conclusion

The case has demonstrated that real options analysis can be effectively incorporated into existing procedures with currently available software tools and with negligible additional effort. It has also demonstrated that when the future is uncertain that the system should be designed to meet current specifications and also include the flexibility to accommodate changes in the future. When conditions change the flexibility redeemed to match the then current needs.

6.B Research Opportunities

Additional research opportunities to improve the application of real options would be to improve the credibility of using option pricing models that are dependent on factors that are either elusive or absent from non-financial systems.

Examining the flexibility of real options with airport development in the largest MSAs where air traffic is congested and expanding one or more of the existing airports may not provide the best congestion reduction. For example, a real option for the Washington, DC MSA is to expand the local air traffic capabilities by construction a new General Aviation airport in a nearby area where land prices are inexpensive. The new airport is a small initial investment with flexibility that could be expanded in the future when it is appropriate to do so.

7 Acronyms

A/C	Aircraft
AIP	Airport Improvement Program
Alt	Alternative
B	Benefit
BCA	Benefit-Cost Analysis
BC	Benefit-Cost
B-S	Black-Scholes
C	Cost
CBA	Cost-Benefit Analysis
CDF	Cumulative Distribution Function
CIP	Capital Investment Plan
COTS	Commercial Off The-shelf Software
CPD	Cumulative Probability Distribution
CRW	Yeager Airport
DOT	Department of Transportation
F	Fahrenheit
FAA	Federal Aviation Administration (post 1967)
FAA	Federal Aviation Agency (1958 to 1967)
FOIA	Freedom of Information Act
FY	Fiscal Year
GA	General Aviation
GAA	General Aviation Airport
GAO	Government Accountability Office
GPO	Government Printing Office
LOI	Letter of Intent
M	Millions
MSL	Mean Sea Level
MTOW	Maximum Takeoff Weight
NPV	Net Present Value
NM	Nautical Miles
OIRA	Office of Information and Regulatory Affairs
OMB	Office of Management and Budget
OTC	Over-The-Counter
PDE	Partial Differential Equation
PDF	Probability Distribution Function
PV	Present Value
RO	Real Option
ROA	Real Options Analysis
US	United States
USC	United States Code
VAR	Value at Risk
WVPPA	West Virginia Public Port Authority
WWVRA	Western West Virginia Regional Airport
$	United States Dollars

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Appendix I - BCA and FAA Legislation Summary

Summary of Mandates and Orders that Guide FAA Economic Analysis

Entity Sub-Entity Doc. Ref. Number(s)	Document Title	Purpose	Source
Executive Branch			
Office of the President			
Executive Order 12291	Federal Regulation	Facilitated a centralized review of planned regulatory actions that are over $100 Million.	(US Executive Office of The President 1981)
Executive Order 12866	Regulatory Planning and Review	Improved EO 12291 and endorse BCA	(US Executive Office of The President 1993)
Executive Order 12893	Principles for Federal Infrastructure Investments	Clarified infrastructure investment guidelines	(US Executive Office of The President 1994)
Executive Order 13258	Amending Executive Order 12866 on Regulatory Planning and Review	Vice President's role delegated to others and other adjustments to reflect government organization changes	(US Executive Office of The President 2002)
Office of Management and Budget			
Circular A-4	Regulatory Analysis, Memorandum	Provide general guidelines for Regulatory Analysis	(US Office of Management and Budget 1999)
Circular A-11	Preparation, Submission and Execution of the Budget	Guidelines for budget preparation and submission	(US Office of Management and Budget 1999)
Circular A-94	Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, Memorandum	Discounted cash flows, Inflation, Discount Rate, Uncertainty. 'Economic analyses submitted to OMB will be reviewed for conformity with Items 5 to 13 in this Circular'	(US Office of Management and Budget 1992, pp. 1)
Circular A-94, Appendix C	Discount Rates for Cost-Effectiveness, Lease-Purchase, and Related Analyses for OMB Circular No. A-94	Annual source for interest rate data.	(US Office of Management and Budget 2006a)

Summary of Mandates and Orders that Guide FAA Economic Analysis (continued)

Entity Sub-Entity Doc. Ref. Number(s)	Document Title	Purpose	Source
Executive Branch			
Department of Transportation			
Order DOT 2100.5	Policies and Procedures for Simplification, Analysis and Review of Regulations	Governs all DOT rule making	(US Department of Transportation 1980)
Federal Aviation Administration			
N/A	Airport Benefit-Cost Analysis Guidance	BCA guidance for airport sponsors seeking AIP discretionary grants	(US Federal Aviation Administration 1999a)
N/A	FAA Policy and Final Guidance Regarding Benefit cost Analysis (BCA) on Airport Capacity Projects for FAA Decisions on AIP Discretionary Grants and LOI	Announcement of BCA policy and procedures for airport sponsors seeking AIP discretionary grants	(US Federal Aviation Administration 1999c, pp. 70107)
Order 7031.2c	Airway Planning Standard Number One		(US Federal Aviation Administration 1984)
FAA-APO-98-4	Economic Analysis of Investment and Regulatory Decisions	BCA guidance for internal FAA use	(US Federal Aviation Administration 1998, pp. 4-1)
N/A	Economic Values for Evaluation of FAA Investment and Regulatory Decisions	Economic values for use in FAA BCAs	(US Federal Aviation Administration 1998, pp. 4-1)

Summary of Mandates and Orders that Guide FAA Economic Analysis (continued)

Entity **Sub-Entity** **Doc. Ref. Number(s)**	**Document Title**	**Purpose**	**Source**
Legislative Branch			
Congress			
Public Law 89-285	Department of Transportation Act of 1966	Legislation that created and guides the DOT	http://www.access.gpo.gov/uscode/title49/title49.html
Public Law 85-726	Federal Aviation Act of 1958	Legislation that created and guides the Federal Aviation Agency (pre-1967) and Federal Aviation Administration (post 1967)	http://www.access.gpo.gov/uscode/title49/title49.html
Public Law	Airport and Airway Trust Fund Act	Fund aviation activities	http://www.access.gpo.gov/uscode/title49/title49.html

Appendix II - Evaluation Period(s)

	Initial Operating Period (Deterministic)			**Future Expansion (Stochastic)**			
				Earliest		Latest	
t	Land Acq.	Construction	Operating	Construction	Operating	Construction	Operating
Offset	N/A	0	-3				
0	0						
1		1					
2		2					
3		3					
4			1				
5			2				
6			3				
7			4	1			
8			5	2			
9			6	3			
10			7		1		
11			8		2		
12			9		3		
13			10		4		
14			11		5	1	
15			12		6	2	
16			13		7	3	
17			14		8		1
18			15		9		2
19			16		10		3
20			17		11		4
21			18		12		5
22			19		13		6
23			20		14		7

t=0 land acquired
t=1- 3 construction
t=4-23 operating period

Appendix III - Summary of Probability Distributions in BCA w/RO

- The notation p_{bmn} for benefits, p_{cmn} for costs and p_{omn} for others; m indicates the Alternative number (1, 2, or 3) and n indicates the specific benefit or cost.
- The composite notation consolidates 39 probability distributions into 13.

Benefits

Probability Distributions	Composite	Generic PD	Benefit Description	Alt 1	Alt 2	Alt3
$p_{b11}= p_{b21}= p_{b31}$	$p_{b,aircraft,i}$	$p_{min}(x)$=[2.8, 0.56, -5, 20]	Reduced Delay, Initial Fleet Mix (Aircraft)	X	X	X
$p_{b12}= p_{b22}= p_{b32}$	$p_{b,passenger,i}$	$p_{min}(x)$=[2.8, 0.56, -5, 20]	Reduced Delay, Initial Fleet Mix (Passengers)	X	X	X
~~p_{b13}~~= ~~p_{b23}~~= p_{b33}	$P_{b,rent}$	$p_{min}(x)$=[0, 0, 0, 0]	Rent back – no probability description used.			X
p_{b14}= ~~p_{b24}~~= p_{b34}	$p_{b,aircraft,e}$	$p_{min}(x)$=[2.8, 5.6, 0, 20]	Reduced Delay, Initial Fleet Mix (Aircraft)	X		X
p_{b15}= ~~p_{b25}~~= p_{b35}	$p_{b,passenger,e}$	$p_{min}(x)$=[2.8, 5.6, 0, 20]	Reduced Delay, Initial Fleet Mix (Passengers)	X		X

Costs

Probability Distributions	Composite	Generic PD	Benefit Description	Alt 1	Alt 2	Alt3
$p_{c11}= p_{c21}= p_{c31}$	$p_{c,land}$	$p_{max}(x)$=[20, 10, 0, 50]	Land acquisition	X	X	X
$p_{c12}= p_{c22}= p_{c32}$	$p_{c,construction,i}$	$p_{max}(x)$=[10, 1, 0, 20]	Construction, Initial	X	X	X
$p_{c13}= p_{c23}= p_{c33}$	$p_{c,om,i}$	$p_{max}(x)$=[3.0, 1.5, 0, 15]	Maintenance and Operations, Initial	X	X	X
p_{c14}= ~~p_{c24}~~= p_{c34}	$p_{c,om,e}$	$p_{max}(x)$=[3.0, 3.0, 0, 15]	Maintenance and Operations, Expansion	X		X
p_{c15}= ~~p_{c25}~~= p_{c35}	$p_{c,construction,e}$	$p_{max}(x)$=[3.0, 6.0, 0, 15]	Construction, Expansion	X		X

Others

Probability Distributions	Composite	Generic PD	Benefit Description	Alt 1	Alt 2	Alt3
$p_{o11}= p_{o21}= p_{o31}$	$p_{discount}$	$P_{tri}(x)=[7, 4, 10]$	Real interest rate	X	X	X
$p_{o12}= p_{o22}= p_{o32}$	$p_{inflation}$	$P_{tri}(x)=[3, 2, 4]$	Inflation rate	X	X	X
$p_{o13}= p_{o23}= p_{o33}$	$p_{expansion}$	$p_{cust}(x)$= see Table 5.9 on page 71	Randomly assigned expansion time	X	X	X

Appendix IV - General Aviation Operations Estimate

In the FAA's Model for Estimating General Aviation Operations at Non-Towered Airports" two regression equations are recommended to estimate the General Aviation operations. The equations are Equation 9 and Equation 13 (GRA, Inc. 2001).

$$OPS_{EQ9} = 14.449 + 421*BA + 0.001*Pop100 - 12452WACAORAK - 0.64*BA$$
$$+ 31361*Pop25/100 - 52130\%in100mi - 5528FAR139$$
$$= 14.449 + 421*99 + 0.001*10000000 - 12452*0 - 0.64*9801$$
$$+ 31361*0.05 - 52130*0.1 - 5528*0$$
$$= 41{,}776 \text{ annual GA operations with FAA regression "Equation 9"}$$

$$OPS_{EQ13} = -571 + 355*BA - 0.46*BA2 - 40510*\%in100mi + 3795*VITFSnum + 0.001*Pop100$$
$$-8587WACAORAK + 24102Pop25/100 + 13674TOWDUM$$
$$= -571 + 355*99 - 0.46*9801 - 40510*0.1 + 3795*0 + 0.001*Pop100$$
$$-8587*0 + 24102*0.05 + 13674*0$$
$$= 37{,}220 \text{ annual GA operations with FAA Regression "Equation 13"}$$

Variable Name and Definition	Measurement/Units	Source	Eq. 9	Eq. 13
OPS – number of annual operations to expect	Aircraft operations	Equation output (the dependent variable)	41,776	37,220
Pop25 – population within 25 miles	Population	By census tract, U.S. Census	500,000	500,000
Pop100 – population within 100 miles	Population	By census tract, U.S. Census	10,000,000	10,000,000
Pop25/100 Ratio of Pop25 to Pop100	Proportion, between 0 and 1	By census tract, U.S. Census	0.05	0.05
TOWDUM	1 if towered airport, 0 otherwise	TAF	0	0
%in100mi Percentage of based aircraft among based aircraft at GA airports within 100 miles	Proportion, between 0 and 1	TAF and Mapinfo software	0.1	0.1
VITFSnum Number of FAR141 certificated pilot schools on airport	1 if FAR141 certificated pilot school present, 0 otherwise	FAA Flight Standards VITALS database	0	0
WACAORAK	1 if state is CA, OR, WA, or AK, 0 otherwise	Categorical/geographical	0	0
FAR139	Categorical variable, 1 if airport is certificated for commercial air carrier service, 0 otherwise			

Source: (GRA, Inc. 2001)

Appendix V - Runway Length Comparisons

Effective runway lengths at selected altitudes above mean sea level

alt. above MSL	adjustment factor	Altitude Adjusted R/W length					
0	1/1.07^0=1	16000	12,000	10,000	9,000	8,000	6,000
1,000	1/1.07^1=0.93	15,000	11,200	9,300	8,400	7,500	5,600
2,000	1/1.07^2=0.87	14,000	10,500	8,100	7,900	7,000	5,200
3,000	1/1.07^3=0.82	13,100	9,800	6,600	7,300	6,500	4,900
4,000	1/1.07^4=0.76	12,200	9,200	5,000	6,900	6,100	4,600
5,000	1/1.07^5=0.72	11,400	8,600	3,600	6,400	5,700	4,300
6,000	1/1.07^6=0.67	10,700	8,000	2,400	6,000	5,300	4,000

** Rounded to the nearest multiple of 100.

Ratio of runway surface areas based on 1,800,000 sqft (12,000' x 150'). For example, a 9,000' x 200' runway is 1.00 x 1,800,000 sqft and exactly equivalent to the surface area of a 12,000' x 150' runway.

		Runway Length					
		16,000	12,000	10,000	9,000	8,000	6,000
runway width	200	1.78	1.33	1.11	1.00	0.89	0.67
	150	1.33	1.00	0.83	0.75	0.67	0.50
	100	0.89	0.67	0.56	0.50	0.44	0.33
	50	0.44	0.33	0.28	0.25	0.22	0.17

Area ratio of proposed runway to other runways

Select runway lengths at different altitudes:

Denver International Airport (Altitude above MSL = 5,341')
Runway 16R/34L 16,000' x 200'. Runways 17L/35R, 17R/35L, 16L/34R, 8/26 and 7/25 12,000' x 150'

Salt Lake City International Airport (Altitude above MSL = 4,227')
Runways 16L/34R 12,004' x 150', 16R/34L 12,000' x 150' 17/35 9,596' x 150', 14/32 4,892' x 150'

Phoenix Sky Harbor International Airport (Altitude above MSL = 1,135')
Runways 8/26 11,489' x 150', 7L/25R 10,300' x 150', 7R/25L 7,800' x 150'

Washington Dulles International Airport (Altitude above MSL = 313')
Runways 1L/19R 11,501' x 150', 1R/19L 11,500' x 150', 12/30 10,501' x 150'

John F Kennedy International Airport (Altitude above MSL = 13')
Runways 13R/13L 14,572' x 150', 4L22R 11,351' x 150', 13L/31R 10,000 150', 4R/22L 8,000' x 200'

Appendix VI – Hypothetical BCA Explanation of Calculations

Calculations in this thesis were done with Microsoft® Excel and the addin Decisioneering Crystal Ball® (for Monte Carlo simulation). The calculations for Alternative 1, 2, and 3 are documented on the six pages that follow. For consistency the calculation table follows the same pattern regardless of whether data is present or not. A grayed out column indicates that the data is not used, an empty column indicates that the data is probabilistic and is only present when the Monte Carlo simulation is run.

The descriptions (and data type) above the solid line of each calculation table are A) year (an ordinal number), B) discount factor (real number calculated as 1/((1.07)^(year-3))), C) Benefit or Cost (real number), and D) Present Value (real number with units of millions of dollars, calculated by dividing C) by B)). Present Value columns are summed individually and then aggregated to become the Benefit (or cost). These calculations are identical to those in Equations 2.4 and 2.5 on pages 15 and 16.

Benefits for Alternative 1

		Reduced Delay, Initial Fleet Mix				Unused		Reduced Delay, Initial Fleet Mix (probabilistic start date)			
		Aircraft		Passenger				Aircraft		Passenger	
year	discount factor	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV
	1.000										
1	0.935										
2	0.873										
3	0.816										
4	0.763	$8.3	$6.3	$5.4	$4.1						
5	0.713	$8.5	$6.1	$5.5	$4.0						
6	0.666	$8.8	$5.8	$5.7	$3.8						
7	0.623	$9.0	$5.6	$5.9	$3.7						
8	0.582	$9.3	$5.4	$6.0	$3.5						
9	0.544	$9.5	$5.2	$6.2	$3.4						
10	0.508	$9.8	$5.0	$6.4	$3.2						
11	0.475	$10.1	$4.8	$6.5	$3.1						
12	0.444	$10.3	$4.6	$6.7	$3.0						
13	0.415	$10.6	$4.4	$6.9	$2.9						
14	0.388	$10.9	$4.2	$7.1	$2.8						
15	0.362	$11.2	$4.1	$7.3	$2.7						
16	0.339	$11.6	$3.9	$7.5	$2.5						
17	0.317	$11.9	$3.8	$7.7	$2.4						
18	0.296	$12.2	$3.6	$7.9	$2.4						
19	0.277	$12.5	$3.5	$8.2	$2.3						
20	0.258	$12.9	$3.3	$8.4	$2.2						
21	0.242	$13.3	$3.2	$8.6	$2.1						
22	0.226	$13.6	$3.1	$8.9	$2.0						
23	0.211	$14.0	$3.0	$9.1	$1.9						
			$88.8		**$57.8**						

PV Benefit SUM	**$147**
BC ratio	**0.81**
NPV	**-$34**

t=0	land acquired
t=1,2,3	construction
t=4-23	operating period

Costs for Alternative 1

year	discount factor	Land Acquisition Cost	Land Acquisition PV	Construction Cost	Construction PV	Maintenance and Operations Cost	Maintenance and Operations PV	Maintenance (probabilistic start date) Cost	Maintenance (probabilistic start date) PV	Construction (probabilistic start date) Cost	Construction (probabilistic start date) PV
	1.000	$24.5	$24.5								
1	0.935			$32.4	$30.3						
2	0.873			$81.0	$70.7						
3	0.816			$48.6	$39.7						
4	0.763					$1.8	$1.4				
5	0.713					$1.8	$1.3				
6	0.666					$1.8	$1.2				
7	0.623					$1.8	$1.1				
8	0.582					$1.8	$1.0				
9	0.544					$1.8	$1.0				
10	0.508					$1.8	$0.9				
11	0.475					$1.8	$0.9				
12	0.444					$1.8	$0.8				
13	0.415					$1.8	$0.7				
14	0.388					$1.8	$0.7				
15	0.362					$1.8	$0.7				
16	0.339					$1.8	$0.6				
17	0.317					$1.8	$0.6				
18	0.296					$1.8	$0.5				
19	0.277					$1.8	$0.5				
20	0.258					$1.8	$0.5				
21	0.242					$1.8	$0.4				
22	0.226					$1.8	$0.4				
23	0.211					$1.8	$0.4				
			$24.5		**$140.7**		**$15.6**				

PV Cost Sum	**$181**

Benefits for Alternative 2

		Reduced Delay, Initial Fleet Mix									
		Aircraft		Passenger		Unused		Unused		Unused	
year	discount factor	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV	Benefit	PV
	1.000										
1	0.935										
2	0.873										
3	0.816										
4	0.763	$8.3	$6.3	$5.4	$4.1						
5	0.713	$8.5	$6.1	$5.5	$4.0						
6	0.666	$8.8	$5.8	$5.7	$3.8						
7	0.623	$9.0	$5.6	$5.9	$3.7						
8	0.582	$9.3	$5.4	$6.0	$3.5						
9	0.544	$9.5	$5.2	$6.2	$3.4						
10	0.508	$9.8	$5.0	$6.4	$3.2						
11	0.475	$10.1	$4.8	$6.5	$3.1						
12	0.444	$10.3	$4.6	$6.7	$3.0						
13	0.415	$10.6	$4.4	$6.9	$2.9						
14	0.388	$10.9	$4.2	$7.1	$2.8						
15	0.362	$11.2	$4.1	$7.3	$2.7						
16	0.339	$11.6	$3.9	$7.5	$2.5						
17	0.317	$11.9	$3.8	$7.7	$2.4						
18	0.296	$12.2	$3.6	$7.9	$2.4						
19	0.277	$12.5	$3.5	$8.2	$2.3						
20	0.258	$12.9	$3.3	$8.4	$2.2						
21	0.242	$13.3	$3.2	$8.6	$2.1						
22	0.226	$13.6	$3.1	$8.9	$2.0						
23	0.211	$14.0	$3.0	$9.1	$1.9						
			$88.8		**$57.8**						

PV Benefit SUM	**$147**
BC ratio	**2.19**
NPV	**$80**

t=0	land acquired
t=1,2,3	construction
t=4-23	operating period

Costs for Alternative 2

year	discount factor	Land Acquisition Cost	Land Acquisition PV	Construction Cost	Construction PV	Maintenance and Operations Cost	Maintenance and Operations PV	Unused Cost	Unused PV	Unused Cost	Unused PV
	1.000	$6.1	$6.1								
1	0.935			$12.6	$11.8						
2	0.873			$31.5	$27.5						
3	0.816			$18.9	$15.4						
4	0.763					$0.7	$0.5				
5	0.713					$0.7	$0.5				
6	0.666					$0.7	$0.5				
7	0.623					$0.7	$0.4				
8	0.582					$0.7	$0.4				
9	0.544					$0.7	$0.4				
10	0.508					$0.7	$0.4				
11	0.475					$0.7	$0.3				
12	0.444					$0.7	$0.3				
13	0.415					$0.7	$0.3				
14	0.388					$0.7	$0.3				
15	0.362					$0.7	$0.3				
16	0.339					$0.7	$0.2				
17	0.317					$0.7	$0.2				
18	0.296					$0.7	$0.2				
19	0.277					$0.7	$0.2				
20	0.258					$0.7	$0.2				
21	0.242					$0.7	$0.2				
22	0.226					$0.7	$0.2				
23	0.211					$0.7	$0.1				
			$6.1		**$54.7**		**$6.1**				

PV Cost Sum	**$67**

Benefits for Alternative 3

year	discount factor	Reduced Delay, Initial Fleet Mix: Aircraft Benefit	Aircraft PV	Passenger Benefit	Passenger PV	Rent back on excess land: Benefit	PV	Reduced Delay, Fleet Mix 2 (probabilistic start date): Aircraft Benefit	Aircraft PV	Passenger Benefit	Passenger PV
	1.000										
1	0.935					$1.0	$0.9				
2	0.873					$1.0	$0.9				
3	0.816					$1.0	$0.8				
4	0.763	$8.3	$6.3	$5.4	$4.1	$1.0	$0.8				
5	0.713	$8.5	$6.1	$5.5	$4.0	$1.0	$0.7				
6	0.666	$8.8	$5.8	$5.7	$3.8	$1.0	$0.7				
7	0.623	$9.0	$5.6	$5.9	$3.7	$1.0	$0.6				
8	0.582	$9.3	$5.4	$6.0	$3.5	$1.0	$0.6				
9	0.544	$9.5	$5.2	$6.2	$3.4	$1.0	$0.5				
10	0.508	$9.8	$5.0	$6.4	$3.2	$1.0	$0.5				
11	0.475	$10.1	$4.8	$6.5	$3.1	$1.0	$0.5				
12	0.444	$10.3	$4.6	$6.7	$3.0	$1.0	$0.4				
13	0.415	$10.6	$4.4	$6.9	$2.9	$1.0	$0.4				
14	0.388	$10.9	$4.2	$7.1	$2.8	$1.0	$0.4				
15	0.362	$11.2	$4.1	$7.3	$2.7	$1.0	$0.4				
16	0.339	$11.6	$3.9	$7.5	$2.5	$1.0	$0.3				
17	0.317	$11.9	$3.8	$7.7	$2.4	$1.0	$0.3				
18	0.296	$12.2	$3.6	$7.9	$2.4	$1.0	$0.3				
19	0.277	$12.5	$3.5	$8.2	$2.3	$1.0	$0.3				
20	0.258	$12.9	$3.3	$8.4	$2.2	$1.0	$0.3				
21	0.242	$13.3	$3.2	$8.6	$2.1	$1.0	$0.2				
22	0.226	$13.6	$3.1	$8.9	$2.0	$1.0	$0.2				
23	0.211	$14.0	$3.0	$9.1	$1.9	$1.0	$0.2				
			$88.8		**$57.8**		**$11.3**				

	no exp.	exp.
PV Benefit SUM	**$158**	**$158**
BC ratio	**1.85**	**1.85**
NPV	**$73**	**$73**

t=0 land acquired
t=1,2,3 construction
t=4-23 operating period

Note: The two PV Cost Sum values represent the no expansion (left) and expansion (right). Since the expansion is probabilistic, the values are the same prior to and after the simulation.

Costs for Alternative 3

		Land Acquisition		Construction		Maintenance and Operations		Maintenance (probabilistic start date)		Construction (probabilistic start date)	
year	discount factor	Cost	PV	Cost	PV	Cost	PV	Cost	PV	Cost	PV
	1.000	$24.5	$24.5								
1	0.935			$12.6	$11.8						
2	0.873			$31.5	$27.5						
3	0.816			$18.9	$15.4						
4	0.763					$0.7	$0.5				
5	0.713					$0.7	$0.5				
6	0.666					$0.7	$0.5				
7	0.623					$0.7	$0.4				
8	0.582					$0.7	$0.4				
9	0.544					$0.7	$0.4				
10	0.508					$0.7	$0.4				
11	0.475					$0.7	$0.3				
12	0.444					$0.7	$0.3				
13	0.415					$0.7	$0.3				
14	0.388					$0.7	$0.3				
15	0.362					$0.7	$0.3				
16	0.339					$0.7	$0.2				
17	0.317					$0.7	$0.2				
18	0.296					$0.7	$0.2				
19	0.277					$0.7	$0.2				
20	0.258					$0.7	$0.2				
21	0.242					$0.7	$0.2				
22	0.226					$0.7	$0.2				
23	0.211					$0.7	$0.1				
			$24.5		**$54.7**		**$6.1**				

	no exp.	exp.
PV Cost Sum	**$85**	**$85**

Note: The two PV Cost Sum values represent the no expansion (left) and expansion (right). Since the expansion is probabilistic, the values are the same prior to and after the simulation.