Investments Under Uncertainty in Air Transportation: A Real Options Perspective

Bruno Miller[1] and John-Paul Clarke[2]
International Center for Air Transportation
Massachusetts Institute of Technology
Cambridge, Massachusetts

Abstract

The cyclical nature of the aviation industry makes investments in air transportation infrastructure difficult. Given the long lead times and large capital expenditures in the provision of this infrastructure, timing the investments with the market is of critical importance; however, given the technological, market and political uncertainties inherent in aviation, decision-makers face a very challenging task. A flexible strategy for infrastructure delivery is suggested as a means of managing the risk in these type of investments. The central idea is to structure the investment so that it would benefit from the upside potential if circumstances are resolved favorably, but it would be protected from downside losses otherwise. Traditional evaluation techniques, such as the Net Present Value rule or Decision Analysis, have some shortcomings that make it difficult to determine the value of such strategies.

In this paper, an evaluation methodology based on system dynamics and Monte Carlo simulation in a real options framework is utilized to evaluate different flexible capacity delivery strategies. A hypothetical yet common situation of an airport with limited capacity and uncertain demand growth is utilized to illustrate these strategies which vary in terms of the timing of the investment, size of the capital expenditure and time to deliver the capacity expansion. As the airline industry starts a slow recovery from one of its worst crisis in history, flexibility in the structuring of capital investments may be important to ensure a sound return to profitability. The methodology presented here provides a means of identifying and evaluating such strategies.

---

[1] Doctoral candidate. E-mail address: brunom@mit.edu
[2] Associate professor. E-mail address: johnpaul@mit.edu

1. Introduction

Air transportation is a cyclical industry characterized by periods of high growth followed by periods of deep capacity reductions and other desperate measures by airlines to remain operational [Skinner et al, 1999; Stonier, 1999]. Planning in the face of this volatility becomes a major problem for many stakeholders, in particular airports and aircraft manufacturers. Because of the large capital requirements and long lead times generally associated with new runways, passenger buildings or aircraft assembly lines, the timing of these investments is of particular importance: a premature investment may result in unused capacity that sits idle without generating any returns whereas a tardy investment may miss the potential market completely.

A flexible approach for infrastructure delivery is suggested as a means of managing the risk in these type of endeavors. The central idea is to structure the project so that it would benefit from the upside potential if circumstances are resolved favorably, but it would be protected from downside losses otherwise. Traditional evaluation techniques, such as the Net Present Value (NPV) rule or Decision Analysis (DA), have some shortcomings that make it difficult to determine the value of such strategies. In this paper, a new methodology to determine the strategic value of air transportation infrastructure based on Monte Carlo and system dynamics simulation in a real options framework is presented. This methodology is illustrated by considering a simple yet common situation where a service facility (e.g., a runway, a passenger building, etc) has fixed capacity and stochastic demand.

In the next section, the research objective of this work is presented. In section 3, some difficulties with traditional valuation methodologies are highlighted. In sections 4 and 5 a brief overview of financial and real options, respectively, is given. In section 6, the evaluation of real options with uncertain exercise price is introduced. In section 7, the methodology proposed here is explained. In section 8, an airport capacity expansion project is used as an example to demonstrate this methodology. In section 9, numerical results are presented. Finally, section 10 concludes the paper.

2. Research objective

The objective of this research is to develop a methodology to support investment decisions in air transportation infrastructure by determining the value of flexible capacity expansion strategies. Two main hypothesis underlie this work: first, that the value of flexibility arises from the coupling of internal (project) dynamics to external (market) dynamics. This suggests using systems dynamics as a modeling tool. Second, that the value of flexibility also arises from uncertainties related to the technology and market conditions. This merits the use of Monte Carlo simulation to take multiple sources of uncertainty into account.

3. Difficulties with traditional valuation methodologies

Traditional evaluation methodologies, such as the Net Present Value rule and Decision Analysis, have some shortcomings that make it difficult to determine the value of flexibility in the face of uncertainty. For example, NPV considers only one course of action, dismissing from the beginning any flexibility that project managers may have to react as uncertainties get resolved [Copeland and Antikarov, 2001]. DA is an improvement over NPV, because it does allow project managers to choose alternative courses of action as more information is obtained and uncertainties are resolved. In addition, DA models risk explicitly by assigning probabilities to different possible scenarios [Amram and Kulatilaka, 1999]. A serious drawback of DA is its limitation to account for several sources of uncertainty as the decision tree(s) may become very large.

In the past decade, real options analysis (ROA) has emerged as an alternative project valuation technique. It is based on financial options theory, but, instead of finding the value of holding an option on a financial asset, it is applied to “real” projects to estimate the value of flexibility in the face of uncertainty [Dixit and Pindyck, 1994]. ROA is a powerful evaluation technique that circumvents some of the difficulties of more traditional approaches; however, in under to understand real options, it is necessary to explain financial options first.

4. Basics on financial options

Financial options are securities that give you the right, but not the obligation, to buy or sell an asset, at a pre-determined price, within a specified period of time [Black and Scholes, 1973]. The price paid for the asset when the option is exercised is called the "exercise price" or "strike price." The last day on which the option may be exercised is called the "expiration date" or "maturity date." A "European option" can only be exercised on the expiration date; an "American option" can be exercised at any time up to the maturity date.

If you own an option, you are able to defer the decision to fully invest until you have more information about the state of the world. Thus, you can protect your downside losses by not investing if conditions are not favorable, and you maintain the right to invest and reap benefits if conditions are favorable.

The payoff of a European call option, w, on a non-dividend paying stock, S, is shown in Figure 1.[3] If the stock price, S, is less than the strike price, X, the option does not get exercised and the payoff is zero; however, if S is larger than X, the option holder has the option of buying the stock for X and then selling it for S, thus, making a profit of S – X. Mathematically, the payoff of a call option can be expressed as the maximum of S-X or zero, i.e., max[S-X, 0]. This profit must be compared to the cost of obtaining the option to determine the net profit.

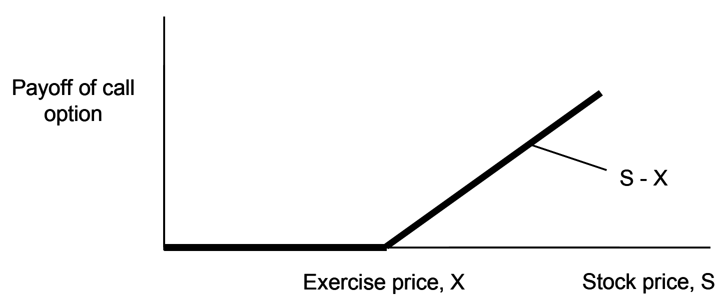

Figure 1: Payoff of a European call option on a non-dividend paying stock, S. ***Source: Authors with information from [Brealey and Myers, 1996].***

[3] This discussion is based on [Brealey and Myers, 1996].

Options are said to be “in the money,” “at the money,” or “out of the money” depending on the cash flows that the option holder would obtain if the option would be exercised immediately [Hull, 1995]. If exercising the option results in positive cash flow, the option is “in the money;” if it results in a zero cash flow, it is “at the money;” and if it yields a negative cash flow, it is “out of the money.” For example, a call option is “in the money” if S > X, “at the money” if S = X, and “out of the money” if S < X.

Options are valuable because the future stock price is uncertain (see Figure 2). In fact, the value of an option increases with the volatility of the stock, because this means that the stock can reach higher prices (it can also reach lower prices, but we are not concerned about this because the option protects us from downside movements).

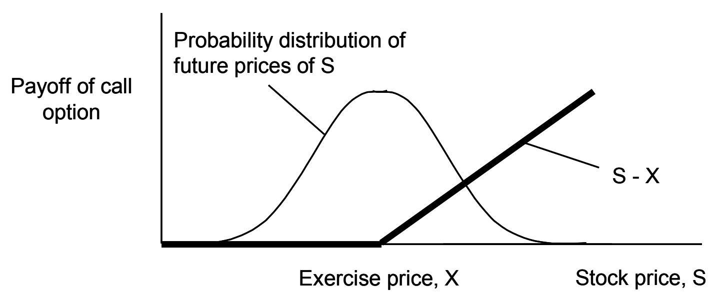

Figure 2: The stochastic nature of stock prices make options valuable. ***Source: Authors with information from [Brealey and Myers, 1996].***

The total value of an option can be considered as the sum of two parts: the intrinsic value and the extrinsic or time value [Hull, 1995]. The intrinsic value is the payoff from exercising the option immediately. For a call option, the intrinsic value is max[S-X, 0] (see Figure 3). The extrinsic or time value is the portion of the option price that is not intrinsic value [Summa and Lubow, 2002]. It arises from the probability that, with time, the intrinsic value of an option will increase. For example, the intrinsic value of an “out of the money” option is zero, but its price is not zero because it has some time value. The person buying that option has the expectation that the option will get “in the money” eventually and thus, gain some intrinsic value.

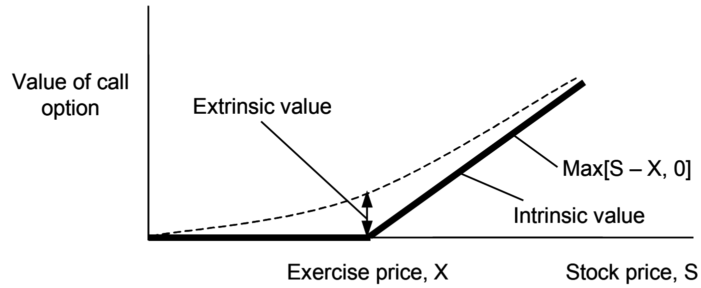

Figure 3: The value of an option consists of an intrinsic and an extrinsic part. The extrinsic or time value is highest when the option is "at the money." ***Source: Authors with information from [Brealey and Myers, 1996; Summa and Lubow, 2002].***

The time value of an option is highest when the option is "at the money" [Summa and Lubow, 2002]. To see the reason for this consider the following: if the option is deep "out of the money," the probability that over time it may get "in the money" is very small. If the option is deep "in the money," there is already great certainty that it will be exercised. Therefore, there is not much value in waiting. In both cases, the price of the option approaches its intrinsic value. If the option is "at the money," however, its intrinsic value is zero but, because there is a high probability that it may expire "in the money", the time value is very high.

5. Basics on real options

Real options analysis (ROA) uses some of the basics of financial options theory to find the value of options in "real" projects. For example, consider a city that is considering building a new airport. Assume further that current levels of demand require only one runway, but there are indications that future demand may grow to levels where a second runway could be necessary. A real option would consist of building one runway and acquiring the land for the second runway now, but not building the second runway until the traffic levels require it.

Ownership of the land for the second runway gives the airport developers the right, but not the obligation, of expanding capacity if and when it is needed. In this manner, capacity can be provided quicker than in a case were one runway was built but no land was purchased, thus increasing the likelihood that the second runway would be better timed with the market. Another approach would be to build both runways now; however, given uncertainties in demand, there is a risk that the second runway may not be needed. The option to build the second runway offers protection against this situation.

Creating and having the option comes at a price: the airport developer must buy a piece of land. This is where ROA can be particularly useful because it can help to determine the value of this option and, hence, indicate the maximum price that an investor should be willing to pay for it.

6. Evaluating real options with varying stock price and strike price

Most traditional financial option methodologies assume that the strike price is fixed a priori and does not change throughout the life of the option. While this may be a valid assumption for financial options, it is not necessarily true for real projects, because the strike price of real options (generally taken to be a cost related to the project, such as capital investments and/or operational or maintenance expenditures) can certainly vary over time.

There are a few examples in the financial options literature that address the valuation of options when the strike price is uncertain. Stanley Fisher [Fisher, 1978] and Avinash Dixit and Robert Pindyck [Dixit and Pindyck, 1994] assume that the strike price can be represented by a geometric Brownian motion (GBM) and use this behavior to derive their analytical evaluation formulae. While GBMs may be appropriate to model the behavior of stock and strike prices for financial options, expected revenues and costs of real projects do not necessarily follow these type of stochastic processes, thus, the work by these authors may not be generally applicable to real options.

An approach from the ROA literature that can be used to evaluate real options with uncertain exercise prices is given by Robert Tufano and Alberto Moel (we will refer to it as the “Tufano-Moel approach” here) [Tufano and Moel, 1997]. Their technique consists of simulating the underlying asset until the end of the life of the project assuming that the real option is always exercised and then finding its present value. This process is repeated thousands of time using Monte Carlo simulation to incorporate multiple sources of uncertainty both on revenues as well as on costs. In this manner, a distribution of net present values for the project with its associated mean is obtained (see Figure 4, left).

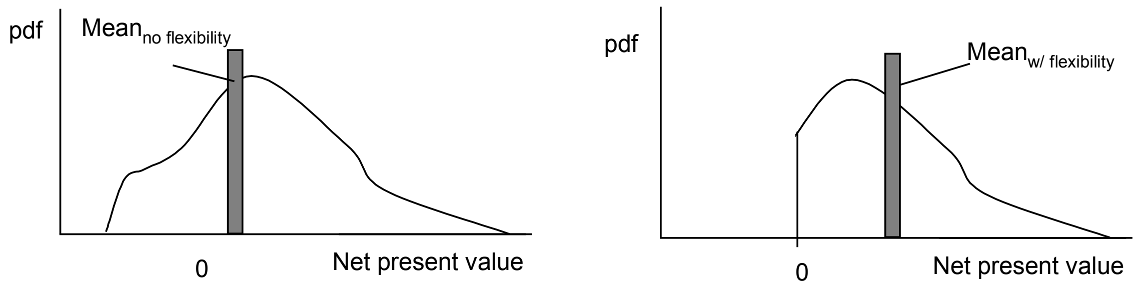

Figure 4: The approach proposed by Tufano and Moel consists of using simulation to determine the distribution of net present values without flexibility and its associated mean (left). Flexibility is simulated by substituting negative NPV values with zero (right). The mean of the truncated distribution is the value of the project with flexibility. ***Source: Authors with information from [Tufano and Moel, 1997].***

The power of real options is that it allows managers to walk away from projects with negative outcomes. Tufano and Moel argue that this can be represented by substituting negative NPVs with zero which essentially truncates the distribution (see Figure 4, right). The mean of this truncated distribution is the value of the project with flexibility. The value of the real option is the difference between the means with and without flexibility.

7. Real options, system dynamics and Monte Carlo simulation

The methodology proposed by Tufano and Moel can be used to find the value of real options when the exercise price is uncertain by simulating the expected net present values. Here, we propose an alternative approach that combines the power of simulation with the simplicity of analytical solutions. As in the case of Tufano and Moel, the methodology developed here assumes a European call-like real option.

First, assume that the probability density function, $f_S(s)$, of the expected revenues from a real project (i.e., the stock price, S) at expiration time T is known. In addition, assume that the cost of exercising a real option on this project (i.e., the strike price, X) at expiration time T is also known (see Figure 5).

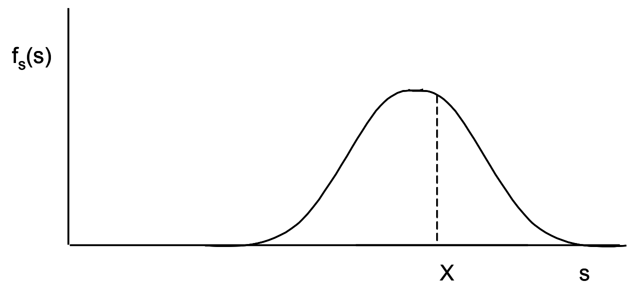

Figure 5: Probability distribution of expected revenues, S, and construction costs, X, at time T.

In this case, the decision-maker would only exercise in those instances when the stock price is greater than the strike price. The value of this option, w, can be calculated as the difference of two terms. The first term is the expected value of revenues given that the revenues are realized, i.e., given that the option is exercised. Since the option would only be exercised if the stock price is higher than the strike price, this expected value can be represented as the expected value of S for values of s > X (see first term in Equation 1). The second term represents the costs associated with exercising the option. It can be computed as the strike price, X, weighted by the probability that it is realized, i.e., the likelihood that the option is exercised. This can be expressed as X times the probability that X will be incurred, i.e., the probability that s > X (second term in Equation 1):

$$w = \int_{s=X}^{\infty} s \cdot f_S(s) ds - X \cdot \int_{s=X}^{\infty} f_S(s) ds \qquad \text{(Eq. 1)}$$

In reality, however, exercise costs can also be uncertain. Therefore, assume that the expected exercise cost at time T can be described with a probability distribution, $f_x(x)$ (see Figure 6):

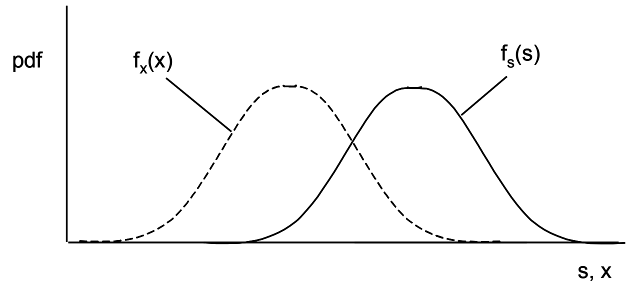

Figure 6: Exercise costs can also be uncertain. Here, they are described by a probability density function, $f_x(x)$.

Consequently, the value of the option, w, is now a random variable dependent on x (see Equation 2):

$$w = w(x) = \int_{s=x}^{\infty} s \cdot f_S(s) ds - x \cdot \int_{s=x}^{\infty} f_S(s) ds \qquad \textbf{(Eq. 2)}$$

The expected value of w can be determined by applying the definition of expected value for continuous random variables (see Equation 3):

$$E[w(x)] = \int_{x=-\infty}^{x=\infty} w(x) \cdot f_x(x) dx = \int_{x=0}^{\infty} f_x(x) \int_{s=x}^{\infty} s \cdot f_s(s) ds dx - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot \int_{s=x}^{\infty} f_s(s) \; ds dx \qquad \textbf{(Eq. 3)}$$

It is worth highlighting two results obtained from Equation 3 if the distributions $f_x(x)$ and $f_s(s)$ do not overlap. First, if all values of x are larger than all values of s (see Figure 7, left), the expected value of w(x) is zero:

$$E[w(x)] = \int_{x=0}^{\infty} f_x(x) \int_{s=x}^{\infty} s \cdot f_s(s) ds dx - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot \int_{s=x}^{\infty} f_s(s) \; ds dx = \int_{x=0}^{\infty} f_x(x) \cdot (0) dx - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot (0) dx$$

$$E[w(x)] = 0$$

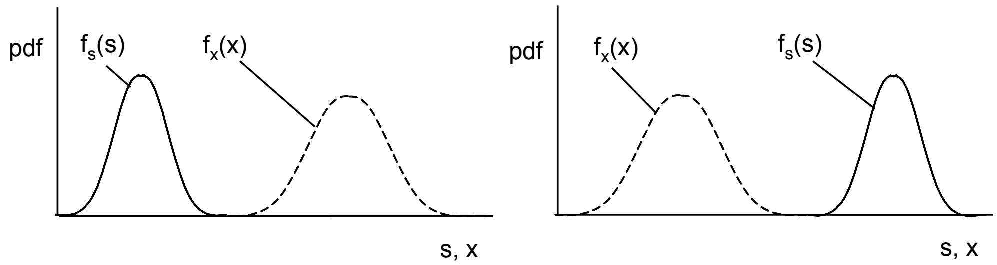

Figure 7: Two limiting cases worth exploring: all values of x greater than all values of s (left) and vice-versa.

Intuitively, since the strike price is always larger than the stock price, the option will never be exercised and its value is zero. This corresponds to the case of a financial option that expires "out of the money." The second point is that if all values of s are larger than all values of x (see Figure Figure 7, right), the expected value of w(x) is the difference between the expected value of S and the expected value of X:

$$E[w(x)] = \int_{x=0}^{\infty} f_x(x) \int_{s=x}^{\infty} s \cdot f_s(s) ds dx - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot \int_{s=x}^{\infty} f_s(s) \; ds dx$$

$$E[w(x)] = \int_{s=x}^{\infty} s \cdot f_s(s) ds \int_{x=0}^{\infty} f_x(x) dx - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot \int_{s=x}^{\infty} f_s(s) \; ds dx = \int_{s=x}^{\infty} s \cdot f_s(s) ds \cdot (1) - \int_{x=0}^{\infty} x \cdot f_x(x) \cdot (1) dx$$

$$E[w(x)] = E[S] - E[X]$$

If all values of s are larger than all values of x, the real option is essentially "deep in the money" and it will be exercised with great certainty. Thus, as in the case of financial options that are "deep in the money," the time value of the option is very small and the price of the option approaches its intrinsic value. In the case of financial European call options, the intrinsic value is max[S-X, 0], which for options "deep in the money" approaches S – X. This is analogous to the above result.

In order to find the distributions of revenues and costs of the real project, a combination of system dynamics and Monte Carlo simulation is suggested. System dynamics is a powerful tool to model the internal dynamics, feedback loops and uncertainties of the project and its behavior given external influences. In addition, system dynamics is flexible enough to allow the simulation of other factors such as competitor behavior, if desired. Monte Carlo simulation can be combined with the system dynamics model to obtain a better representation of the cash flows by including the effects of different sources of uncertainty.

As stated, this methodology assumes that costs and revenues are independent. This can be a reasonable assumption for those systems where, for example, the couplings between the costs of supplying and maintaining the infrastructure and demand are not very strong. In the case where these couplings may be significant, the distributions of S and X would have to represent conditional probabilities.

Another important question regarding this evaluation methodology is related to the choice of the discount rate. The valuation formula from Equation 3 gives the expected value of w at exercise time, T. Thus, to find its value today, it is necessary to discount the distributions of revenues and costs to the present with a risk-adjusted discount rate. In the remaining of this section, the approach used to find the appropriate discount rate is explained.

In any type of investment, an investor should be concerned about two types of risk: a) technical or unsytematic risk and, b) market or systematic risk [Brealey and Myers, 1996]. In terms of technical risk, it is assumed here that it can be accounted for in the calculation of the distributions of revenues and costs with Monte Carlo simulation and that investors are well-diversified. Thus, the discount rate needs only to address systematic risk.

It is standard practice in finance theory to assume that investors have two objectives when making their investment decisions: maximize expected returns and minimize uncertainty (i.e., risk) of those returns [Sharpe, 1991]. A consequence of having these objectives is that investors are urged to diversify by holding more than one asset in their portfolio. The most diversified portfolio that investors can hold is one that includes all traded assets in the economy: the market portfolio. A market index, such as the Standard and Poor's index of the 500 largest companies in the U.S. (S&P 500), can be used as an approximation to the market portfolio.

In addition to risky assets, investors can also hold risk-free securities, such as government bonds. The risk-return curve of a portfolio that includes the market portfolio and a risk-free asset is shown as a straight line in Figure 8:

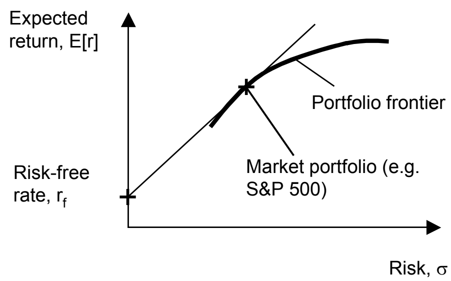

Figure 8: Risk-return curve for a portfolio that includes a risk-free asset and the market portfolio.

In Figure 8, the portfolio frontier represents the efficient set of portfolios that can be constructed with other risky assets in the economy. Notice that for any level of risk, the expected return of the portfolio holding the S&P 500 and the risk-free asset is always equal to or higher than that of any other portfolio.

In order to find the appropriate discount rate for the projects considered in this paper, it is assumed that investors have two investing opportunities: investing in the portfolio with the S&P 500 index and a risk-free asset, or the real project. The compensation (risk premium) that investors would demand for investing in the real project is the difference between the expected return of this portfolio or the expected return of the real project, for the level of risk of the project (see Figure 9):

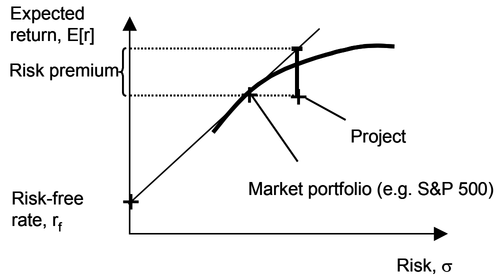

Figure 9: Risk-premium that investors demand for investing in the project.

Thus, the discount rate for the project, r, becomes:

$$r = r_f + Risk\ Premium \qquad \textbf{(Eq. 4)}$$

The expected return and risk of the project can be determined for each time period in the Monte Carlo simulation of the real project. In addition, a separate simulation of the evolution of the S&P 500 index as a geometric Brownian motion can be performed in order to obtain the expected return and risk of this index over time. By using information on future values of the risk-free rate, the discount rate for each period in the life of the project can be calculated.

The main advantage of this approach as opposed to more conventional techniques, such as determining one discount rate with the Capital Asset Pricing Model, is that the discount rate is not limited to one single value, but it varies according to how the project performs financially over time. A potential drawback is that simulating the S&P 500 as a geometric Brownian motion may not capture shocks, such as recessions and market bubbles, and, thus, may not give a completely accurate picture of the behavior of the market; however, the simulation of the market index could be improved by modeling shocks as Poisson arrivals with random magnitude.

8. Example: An airport expansion project

The example of the city with interest in building a new airport with one or two runways mentioned above is used to illustrate the methodology proposed here. In this case, the real option consists of the right, but not the obligation, of building a second runway to obtain the revenues from the demand served by the added capacity. The underlying asset, S, are expected revenues from travel demand served by the second runway. The exercise price, X, are the construction and maintenance costs of the second runway. The maturity of the option is assumed to be 5 years and the cost of the real option is the price of the land for the second runway.

The purpose of the evaluation methodology is to determine whether the value of the real option (building a second runway) is greater than the cost of the real option (buying the land). If it is, then the city should follow this strategy and purchase the land for the second runway. Several different scenarios are considered to analyze the effect of different maturity times, size of the investment and time to deliver the investment on project financial performance and on the value of the real option.

8.1 Modeling the airport expansion project with system dynamics

System dynamics is used to model the airport expansion project (see Figure 10). In this particular example developed by Miller and Clarke [Miller and Clarke, 2003], *Runway capacity* is the limiting factor that leads to C*ongestion*. As demand for air travel (*Aircraft per hour*) increases, the total number of aircraft requesting service on this runway (*Total aircraft*) also increases. Demand is modeled as a mean-reverting stochastic process according to the process outlined in [Dixit and Pindyck, 1994]. If *Runway capacity* is held constant, the increase in demand slowly leads to *Congestion*, which raises the direct operating costs of airlines (*Airline congestion cost*). The higher operating costs are passed on to the passenger in terms of higher air fares (*Air fare impact*) and this leads to less demand for travel (Congestion cost loop). In addition, congestion decreases the level of service by lengthening passenger travel time (*Level of service impact*) which also results in less demand for aviation services (Passenger comfort loop). When the decision to add capacity is taken, i.e., when the option is exercised, a certain amount of capacity (*Capacity increase*) is delivered after a certain period of time (*Years to increase capacity*). The decision to expand capacity is the key managerial intervention in this model. Once capacity is added to the runway, *Congestion* decreases, thus, stimulating demand by reducing the *Air fare impact* and *Level of service impact*. *Delivery Costs* represent the expenditure associated with providing the desired capacity expansion. *Maintenance costs* are recurring costs associated with maintaining the added capacity. The model assumes that congestion occurs only at a given number of *Peak hours* per year.

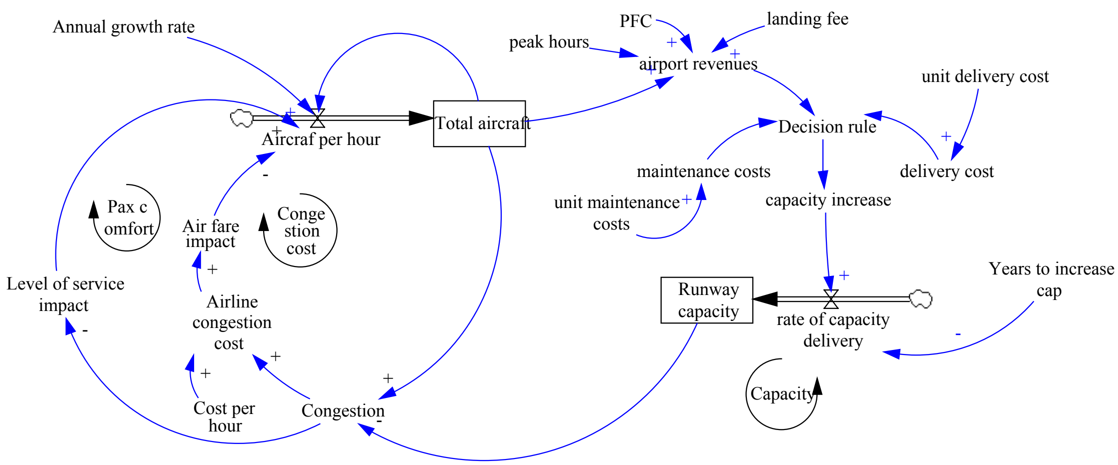

Figure 10: System dynamics model of the hypothetical situation considered in this study.

There are two main outputs from this model. The first are the benefits from the expanded infrastructure accrued to the airport operator in terms of *Airport revenues*. Here, it is assumed that they consist mainly of *Landing fees* paid by the airlines and passenger facility charges (*PFC*) paid by each traveler. The second output are the costs of infrastructure expansion (*Delivery cost)* and maintenance (*Maintenance costs)* of this expanded infrastructure. These outputs are used to calculate the value of the underlying asset, S, and the exercise price, X.

The numbers used to calibrate the model are meant to illustrate a realistic situation but they do not represent an actual airport. The airport in this study is assumed to be a one runway facility that serves primarily narrow-body aircraft. The current runway capacity was set at 40 aircraft per hour. Landing fees were estimated at $200 per aircraft based on data given by [de Neufville and Odoni, 2003] and the typical weight of narrow-body aircraft. It is further assumed that congestion occurs only at peak hours and there are 1000 peak hours in a year. The simulation time period is in years and each run covers 30 years. Demand was calibrated using historical data for air travel demand in the United States between 1979 and 2001 contained in the Form 41 database [USDOT, 1979-2001].

Monte Carlo simulation is used in combination with the system dynamics model to take into account multiple sources of uncertainty. The following variables were assumed to behave randomly (see Table 1):

Table 1: Variables considered for Monte Carlo simulation and their assumed probability distributions.

Variable	**Units**	**Prob. Distr.**	**Max. value**	**Min. value**
Average travel time	Hours	Uniform	2	4
Time elasticity	N/A	Uniform	-1.6	-0.8
Price elasticity	N/A	Uniform	-1.6	-0.8
Unit Maintenance costs	$/(a/c/hr)	Uniform	0.6 M	1 M
Unit Delivery costs	$/(a/c/hr)	Uniform	3 M	10 M

A total of 1000 runs are made in each Monte Carlo simulation.

8.2 Infrastructure delivery strategies

Different capacity expansion strategies were analyzed to determine the variation in the value of flexibility. Three parameters were assumed to define an infrastructure delivery strategy: 1) the maturity of the option, 2) the size of the capacity expansion, and 3) the time to deliver the capacity once the decision to expand has been made. For the maturity time, three values were considered: 2, 5 and 7 years. The size of the expansion was considered to be small (25% of existing capacity), medium (50% of existing capacity) and large (75% of existing capacity). Three times to deliver capacity were assumed: 5, 7, and 10 years. The life of all projects was taken to be 30 years.

8.3 The value of flexibility

Here, we assume that the value of flexibility is the difference between the value of the flexible and the inflexible strategies:

$$\textit{Value of flexibility} = \textit{Value of flexible strategy} - \textit{Value of inflexible strategy} \qquad \textbf{(Eq. 5)}$$

The value of the flexible strategy is calculated with Equation 3. In general, the value of the inflexible project is calculated as the mean of the net present values for each run in the Monte Carlo simulation; however, when determining the value of the flexible strategy, negative expected values for the inflexible strategy are replaced by zero. Following the spirit of real options, an inflexible strategy with a negative expected value would not be undertaken and, consequently, its expected value would be zero. Thus, the appropriate comparison to find the value of flexibility should be between the value of the flexible strategy as calculated with Equation 3 and the intrinsic value of the inflexible strategy, which in this context would be max[$E[NPV_{inflexible}]$, 0]:

$$\textit{Value of flexibility} = \textit{Value of flexible strategy} - \max[\,E[NPV_{inflexible}], 0] \qquad \textbf{(Eq. 6)}$$

Recall that the value of financial options is the sum of the intrinsic value and the extrinsic or time value. Thus, the time value can be expressed as:

$$\textit{Time value} = \textit{Value of financial option} - \textit{Intrinsic value} \qquad \textbf{(Eq. 7)}$$

Thus, the value of flexibility as defined here is analogous to the time value in financial options. The relevance of this point will be clear in the next section.

9. Numerical results

9.1 The value of flexibility: comparison to the Tufano-Moel approach

A comparison of option value between the methodology developed here and the Tufano-Moel approach mentioned earlier is presented in Figure 11:

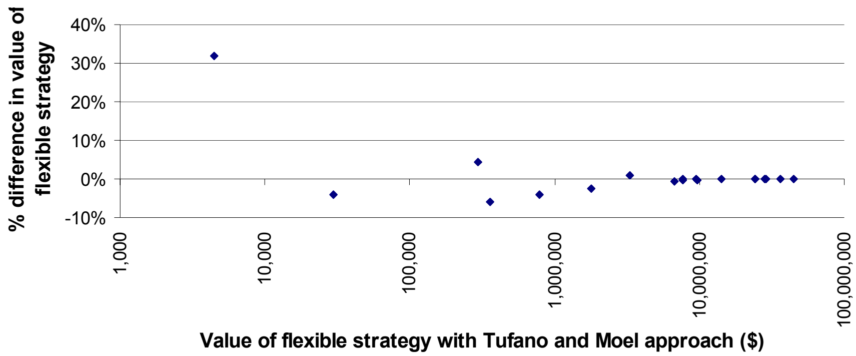

Figure 11: Percentage difference in the value of the flexible strategy between the methodology presented in this paper and the Tufano-Moel approach. Notice that the scale on the x axis is logarithmic.

Both methods agree in the calculation of the value of flexibility, especially as the value of the flexible strategy increases. For lower values of the flexible strategy, the percentage difference between both methods is considerably larger. A reason for the discrepancy is the fact that the distributions for S and X as calculated with the system dynamics and the Monte Carlo simulation are discrete, whereas the evaluation formula given in Equation 3 calls for continuous distributions.

9.2 The value of flexibility in the delivery of airport infrastructure

9.2.1 Strategies with small (25%) capacity increase

Projects that consider a 25% increase in capacity have, in general, a positive expected NPV (see Figure 12). The intuition is that small increases in capacity are sufficient to meet the expected demand. Therefore, there is no need to incur large capital expenditures and the costs can be recovered more rapidly. Another important consideration is the timing of the investment: as the capital delivery is pushed further into the future (in other words, as maturity and/or time to deliver capacity increase), the expected value of the project decreases. Delaying the infrastructure expansion results in the airport not being able to capitalize on the demand that would materialize if the capacity was there. For example, the only case were the project has a negative expected NPV is when the maturity is 10 years and it takes 10 years to deliver the capacity. In this situation, capacity is added so late in the life of the project that there only a handful of periods available to generate revenues and recover the investment.

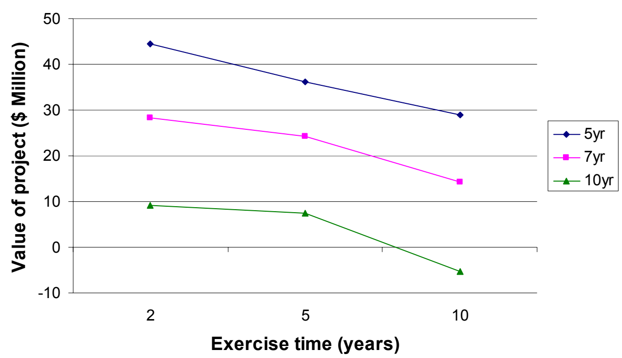

Figure 12: Expected value of projects without flexibility for strategies that consider 25% capacity increase and 5, 7, and 10 years to increase capacity.

The value of flexibility for these projects is minimal (see Figure 13). Since they are very likely to succeed by following an inflexible strategy, having a flexible approach does not improve their expected value.

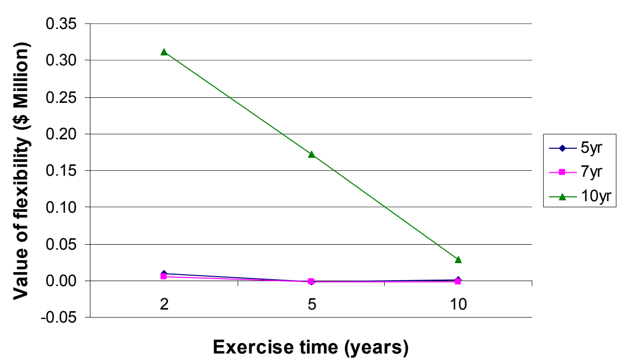

Figure 13: Value of flexibility for strategies that consider 25% capacity increase and 5, 7, and 10 years to increase capacity.

9.2.2 Strategies with medium (50%) capacity increase

Projects that consider a medium capacity increase are not clear winners. Depending on the maturity of the real option and the time to deliver capacity, the expected NPV of the inflexible strategies may be negative, close to zero or positive (see Figure 14). This indicates that the timing of the infrastructure delivery must be considered carefully. In general, early exercise results in too much capacity relative to demand, thus, it is difficult to recover the investment. As the exercise date recedes into the future, demand can grow to levels where the large added infrastructure can be better utilized. Notice, however, that a short time to deliver capacity is always preferable. A long time to deliver capacity may result in the project not being able to generate enough revenues to recuperate costs or to miss the market completely.

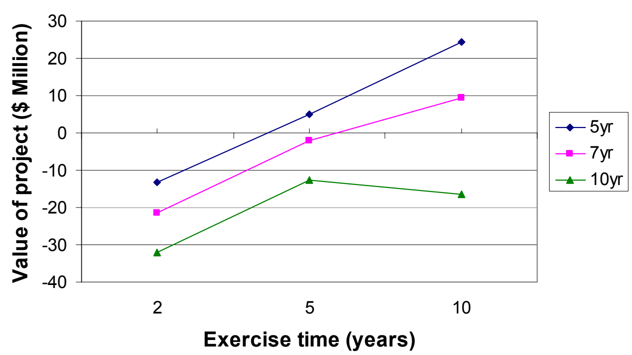

Figure 14: Expected value of projects without flexibility for strategies that consider 50% capacity increase and 5, 7, and 10 years to increase capacity.

The value of flexibility for these cases is higher than for those projects with 25% capacity increase (see Figure 15). In addition, notice that the value of flexibility is highest for those situations where the expected value of the inflexible project is close to zero. Recall the analogy of the value of flexibility to the time value of financial options. As mentioned earlier, the time value of financial options is highest when the option is "at the money." Those projects with an almost zero expected NPV can be considered to be "at the money" or very close to it, thus, their value of flexibility is highest.

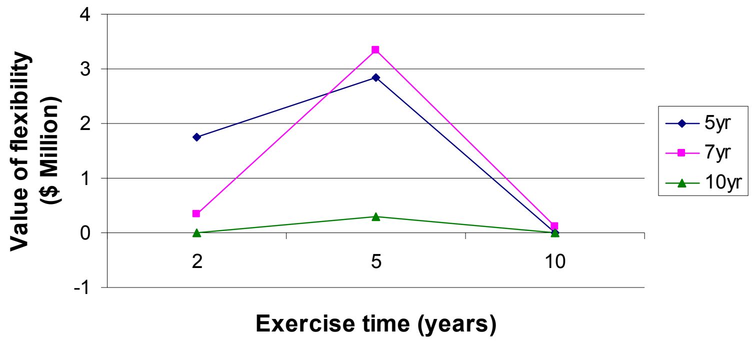

Figure 15: Value of flexibility for strategies that consider 50% capacity increase and 5, 7, and 10 years to increase capacity.

9.2.3 Strategies with large (75%) capacity increase

Strategies with large capacity increase result in projects with negative expected net present values in almost all situations (see Figure 16). In general terms, these strategies lead to excess capacity (over-investment) with a large expenditure that can not be recovered with the expected traffic.

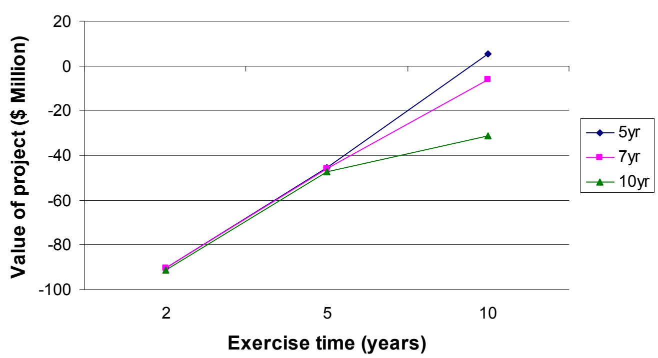

Figure 16: Expected value of projects without flexibility for strategies that consider 75% capacity increase and 5, 7, and 10 years to increase capacity.

The value of flexibility for projects with large negative expected net present value is zero (see Figure 17). This is analogous to financial options deep "out of the money," where the time value of the option is essentially zero. Notice, again, that the value of flexibility is higher for those projects with an expected NPV close to zero.

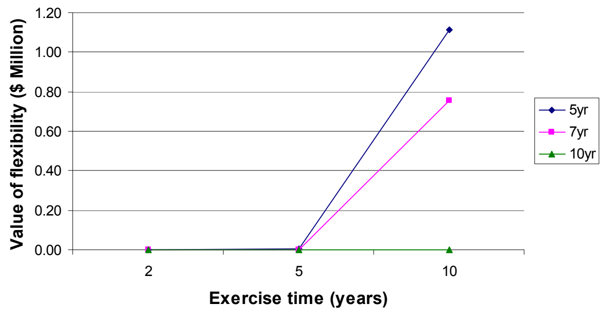

Figure 17: Value of flexibility for strategies that consider 75% capacity increase and 5, 7, and 10 years to increase capacity.

10. Conclusions

10.1 New methodology to determine the value of real options

The methodology developed here can be used to evaluate European call-like real options with uncertain stock and strike prices. Numerical results are in agreement with results obtained using the Tufano-Moel approach which is one of the best examples found in the literature to evaluate European call-like real options with uncertain stock and strike prices.

If the distribution of costs and revenues can be expressed analytically, the methodology developed here can find a closed-form solution for the value of the real-option. A benefit over similar analytical approaches, such as the ones proposed by [Fisher, 1978] and [Dixit and Pindyck, 1994] is that the stock and strike are not restricted to behaving like geometric Brownian motions. With respect to the Tufano-Moel approach, the methodology developed here would have the advantage of not being tied to simulating the behavior of the stock and strike prices.

Another potential advantage of the methodology developed here is the possibility of managing cost in the face of a given demand. For example, if demand is well understood, the formula developed here could be used to find the cost profile that would maximize the value of the project.

10.2 Strategies with small capacity increases have better chances of success

In general, strategies with small (25%) capacity increase are likely to have a higher expected NPV, all else equal. The intuition is that small increases in capacity are sufficient to meet the expected demand in the system modeled here. Therefore, there is no need to incur large capital expenditures and the costs can be recovered more rapidly.

10.3 If capacity increases are large, it pays to wait to exercise

If capacity increases are medium (50%) or large (75%), the project developer is better off delaying the exercise date. In general, early exercise results in too much capacity relative to demand, thus, it is difficult to recover the investment. As the exercise date recedes into the future, demand can grow to levels where the infrastructure can be better utilized.

10.4 Short times to increase capacity are best

Regardless of the capacity increase or the exercise date, a short time to increase capacity results in a higher expected value. Once the decision to increase the capacity has been taken (and the resources committed), the sooner the capacity is in place, the sooner its costs can be recuperated.

10.5 Flexibility is most valuable in uncertain situations

The value of flexibility depends on the performance of the inflexible project. For projects deep "in the money" or deep "out of the money," flexibility is not very valuable because there is little action that a manager can take to improve the project; however, if the project is "at the money," flexibility can be very valuable.

10.6 Implications for the air transportation industry

The results indicate that small infrastructure increases are the best alternative to ensure profitability; however, small capacity expansions may not always be feasible in air transportation infrastructure projects, such as airports. Generally, capital expenditures imply the construction of a whole new runway which adds a considerable amount of capacity to the facility. It is in these cases that flexibility becomes very valuable, because the size of the expansion imply spending a considerable amount of resources that may not be recovered if demand does not materialize. Thus, having the option to walk away if conditions are not favorable can be very valuable.

In addition, a short response time in the capacity delivery is very important. By being able to react quickly to the market, project managers can capture and maybe even stimulate demand that otherwise could be lost by if the response time was slow. Building flexibility into their projects gives management this ability.

11. References

Amram, Martha and Nalin Kulatilaka (1999) *Real Options: Managing Strategic Investment in an Uncertain World*. Boston, Massachusetts: Harvard Business School Press.

Black, Fischer and Myron Scholes (1973) "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy.* Vol. 81, May/June.

Brealey, Richard A. and Stewart C. Myers (1996) *Principles of Corporate Finance.* New York: McGraw-Hill. 5th Edition.

Copeland, Tom and Vladimir Antikarov (2001) *Real Options: A Practitioner's Guide.* New York: Texere.

de Neufville, Richard and Amedeo Odoni (2003) *Airport Systems – Planning, Design and Management.* McGraw-Hill.

Dixit, Avinash K. and Robert S. Pindyck (1994) *Investment under Uncertainty.* Princeton, New Jersey: Princeton University Press.

Fisher, Stanley (1978) "Call Option Pricing when the Exercise Price is Uncertain, and the Valuation of Index Bonds," *Journal of Finance.* Vol. 33, No. 1, March.

Hull, John (1995) *Introduction to Futures and Options Markets.* New Jersey: Prentice Hall. 2nd Edition.

Miller, Bruno and John-Paul Clarke (2003). "The hidden value of air transportation infrastructure." Accepted for publication in *Technological Forecasting and Social Change* (forthcoming).

Sharpe, William F. and Gordon J. Alexander (1991) *Investments*. New Jersey: Prentice Hall. 4th edition.

Skinner, Steve, Alex Dichter, Paul Langley and Hendrik Sabert (1999) "Managing Growth and Profitability across Peaks and Troughs of the Airline Industry Cycle – An Industry Dynamics Approach," in *Handbook of Airline Finance,* ed. by Gail F. Butler and Martin R. Keller. MacGraw-Hill.

Stonier, John E. (1999) "What is an Aircraft Purchase Option Worth? Quantifying Asset Flexibility Created through Manufacturer Lead-Time Reductions and Product Commonality." *Handbook of Airline Finance.* Executive editors: G. Butler and M. Keller. Aviation Week.

Summa, John F. and Jonathan W. Lubow (2002) *Options on Futures: New Trading Strategies.* New York: John Wiley and Sons.

Tufano, Peter and Alberto Moel (1997) "Bidding for Antamina," Harvard Business School Case No. 9-297-054, Rev. Sept. 15.

USDOT: *Form 41*, US Department of Transportation, Bureau of Transportation Statistics, Office of Airline Information, 1979-2001.