# A Practical Method for Valuing Real Options: The Boeing Approach

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Scott Mathews
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# A Practical Method for Valuing Real Options: The Boeing Approach

by Scott Mathews, The Boeing Company, Vinay Datar, Seattle University, and Blake Johnson, Stanford University

The field of real options has been slow to develop because of the complexity of the techniques and the difficulty of fitting them to the realities of corporate strategic decision-making. Such complexity, and the resulting challenge of getting senior management "buy-in," has been a major barrier to wider corporate adoption of real option techniques.

To overcome this barrier, The Boeing Company has invested heavily to develop state-of-the-art methods and tools. The goal is to create a real options approach that uses the language and frameworks of standard DCF analysis—a framework the company's financial analysts and managers are already familiar with and feel comfortable using. The result has been a method of valuation (referred to at Boeing as the "DM" Method[1]) that, while algebraically equivalent to the Black-Scholes formula for valuing financial options,[2] uses information that arises naturally in a standard DCF project financial valuation.

The main advantage of the DM Method is its simplicity and transparency, which allow for more insightful strategic planning and evaluation, and help decision-makers design strategies with high-benefit outcomes that also minimize risks. By contrast, the traditional NPV method leaves decision makers without essential information about the impact of market dynamics and sources of uncertainty.

The DM Method has the look and feel of an extended NPV analysis. Because it is easily modeled in a spreadsheet using off-the-shelf simulation software to incorporate uncertainty and the timing of decisions, analysts rapidly learn the method and are able to benefit from the associated risk analyses. Furthermore, executives quickly begin to appreciate the effectiveness of the DM method in identifying investments that maximize the likelihood of success, thereby limiting downside losses. Finally, the method can be used to give structure to early scenario-based strategic discussions and so provide a way of subjecting problems to quantitative analysis.[3]

## An Investment Decision: The NPV Case

To illustrate how the DM Method works, we first examine a simple investment decision using standard NPV analysis. Boeing currently builds a small experimental unmanned aerial vehicle (UAV), or pilotless drone aircraft, that has a number of possible applications, including the monitoring of electrical transmission and pipe line safety, forest health, and border security. These kinds of monitoring are currently done by trained pilots flying small planes over remote stretches of back country—a monotonous, hazardous, and expensive undertaking. We can envision a new market for a UAV that promises reduced cost and higher efficiencies. But the development of that market depends on advances in the current technologies in aviation control systems, remote sensing, and global positioning.

Of course, the actual business case for the UAV is complex, involving many factors, including critical FAA certification. But we can illustrate the concepts of this paper using a much simplified business case. Table 1 sets forward sample projections of revenues and costs following the standard practice for NPV-type business case estimation using the most-likely scenario. There is an immediate $15 million outlay for R&D engineering efforts in aviation control systems, remote sensing, and global position technology that are expected to take up to two years. After that point, contingent on the success of the R&D efforts and a forecast of a promising market reception, Boeing then expects to spend $325 million to launch the product, a one-time outlay for UAV design, testing, and factory tooling. The estimated operating profit from UAV sales depends on assumptions about product strategy and market reception that are summarized in Table 1.

Based on a corporate hurdle rate of 15%, the project NPV is estimated to be a negative $19 million, which suggests that the project is not worth undertaking. But the manager may override the NPV results because she believes she can flexibly manage the market research and the technology R&D efforts,

1. The method has been patented by The Boeing Company (U.S. Patent 6862579) as the Datar-Mathews Method for Quantitative Real Option Valuation, © 2001, The Boeing Company, All Rights Reserved.

2. Vinay Datar and Scott Mathews, "European Real Options: An Intuitive Algorithm for the Black-Scholes Formula," *Journal of Applied Finance*, Vol 14 (1), 2004.

3. The Boeing Leadership Center has begun exposing the company's financial and engineering managers in the proper use of the DM Method. The aim of the course "Critical Thinking" is to help managers learn to identify, analyze, and manage risk in ways that are consistent with growing the business. In addition, the Global Integrated Systems Engineering (GISE) program, a graduate level interdisciplinary program offered jointly by the University of Washington's College of Engineering and the Business School in collaboration with The Boeing Company, provides instruction in the DM Method as a means to solve difficult engineering and financial tradeoffs. The GISE program emphasizes systems engineering, project management, and finance to produce a new generation of complex systems thinkers who can excel in a global business environment.

Table 1 **NPV Business Case for UAV Project**

| Scenario | Strategy |
|---|---|
| Most Likely | Product sales growth is approximately in line with the market at about 15% per year. Initial sales target will be moderate. |

**Discount Rate Assumptions**

| | |
|---|---|
| Project Risk Rate | 15% |

| NPV Calculations | |
|---|---|
| $PV_0$ Operating Profits | $242 |
| $PV_0$ Launch Cost | ($246) |
| R&D Expenses | ($15) |
| Total Project NPV Value | ($19) |

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Most Likely Op Profits | | $0 | $0 | $52 | $62 | $74 | $77 | $89 | $104 | $122 |
| Launch Cost | | $0 | ($325) | | | | | | | |
| R&D Expenses | ($15) | | | | | | | | | |

and because the market for UAVs might have a plausible, if lower-probability, upside. Some managers might be tempted to declare the UAV project "strategic" and invest anyway in order to preserve the opportunity to explore the market potential. But this would mean sacrificing the authority and discipline that comes from managers' being required to use quantitative methods, and thus defeat the purpose of having any kind of rigorous analysis.

Given the uncertainty of the market and thus of the project outcome, there are good reasons for managers to be skeptical about the recommendation based on the NPV analysis. For starters, while there is likely to be a range of possible operating profit outcomes projected for the UAV project, the mathematics of the NPV method require use of a single value for each time period. (This limiting approach is further reinforced by spreadsheet formatting that constrains each cell to a single value.) As a consequence, low-probability outcomes are eliminated from the analysis, and only the most-likely survives the process.

Further, in this case, and in most NPV-based approaches, all cash flows are discounted at a single project hurdle rate, regardless of possible differences in risk. In sum, the NPV analysis can bias decision-making against projects like UAV with major uncertainties that are expected to be resolved—in this case, within two years. NPV analysis tends to reflect its conservative origins in the banking industry by favoring annuity-like investments. Real options, by contrast, is well suited to evaluating investments with flexibility, critical decision points, and major discontinuities.

## The Datar-Mathews Real Option Method

Many strategy discussions begin with scenario planning exercises designed to embrace new technologies and products. The scenarios are the outcome of the forecasts and insights generated by gatherings of technologists and engineers, program and marketing managers, finance specialists, and senior executives. The typical output from such meetings, more often than not, is a series of scattered notes and drawings, generally providing little coherent basis for meaningful quantitative analysis. Much of the difficulty reflects the challenge of structuring business propositions that incorporate nebulous, disparate-seeming factors such as uncertainty, contingent decisions, probability of success, timing, and risk versus return. The DM Method, and what we call "real options thinking," has the potential to extract significant value from scenario planning by providing a structure that lends itself to quantitative analysis.

In contrast to the NPV approach that aims to reduce all to a single most-likely scenario, the more strategic approach is to stimulate discussions around the various scenarios reflecting different market conditions that could be encountered at the time of product launch. Such discussions also focus on other relevant factors such as the current technology or product readiness, the funding and time required to launch the product, and project contingency plans in the event the engineers are unable to develop the necessary technology or the market outlook turns unfavorable. The underlying reality is that as events unfold prior to the launch date and one or another scenario begins to play out, decision managers have the ability to increase project value by identifying and responding to technology or market opportunities. Unlike the NPV approach, real options analysis is able to capture the value of such flexibility.

The advantage of the real options approach, then, is its ability to take the wide range of "strategic intelligence" produced by the scenario discussions and translate it into a business plan with flexibility and critical decision points. For example, the UAV strategy discussions result in three scenarios similar to those shown in Table 2. Provided with the scenarios, Boeing's marketing department then helps quantify each of them by providing revenue forecasts, while the engineering department provides estimates of one-time

Table 2 **Real Options Business Case for UAV Project**

| Scenario | Probability | Strategy |
|---|---|---|
| Optimistic | 10% probability | Superior product outsells the market with sales growth up to 40% in the first years, then averaging 25% per year; thereafter slowing. Initial sales target is high due to early market spadework. |
| Most Likely | | Product sales growth is in line with the market at about 15% per year. Initial sales target will be moderate. |
| Pessimistic | 10% probability | Intense competition limits sales growth to 5% per year, with a potential market downturn owing to a weak economy. Initial sales are low because manufacturing costs are higher than expected. |

| ($ M) Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Optimistic | | $0 | $0 | $80 | $116 | $153 | $177 | $223 | $268 | $314 |
| Most Likely | | $0 | $0 | $52 | $62 | $74 | $77 | $89 | $104 | $122 |
| Pessimistic | | $0 | $0 | $20 | $23 | $24 | $18 | $20 | $20 | $22 |
| Launch Cost | | $0 | ($325) | | | | | | | |

launch and recurring manufacturing costs.

As can be seen in Figures 1 and 2, the three scenarios result in three operating profit estimates for each year, with the optimistic and pessimistic scenario cash flows each assigned a 10% probability. The three estimates can be viewed as representing the corners of a triangular distribution (shown in Figure 2) that reflects a range of forecasts and thus the uncertainty about annual operating profits.[4] Using Monte Carlo software, we created such a triangular distribution for each year of the operating profit forecast.[5]

The Monte Carlo simulation provides a way of translating the market forecast uncertainties originally envisioned in the scenario discussions into the variability of the project cash flows. The Monte Carlo application works by taking successive random "draws," or "trials," from all the operating profit cash-flow distributions, with the most frequent draws nearest the most-likely values. Each trial is a plausible scenario and is calculated through in Excel, resulting in a complete profit/loss analysis for that one scenario instance. A typical comprehensive simulation analysis consists of hundreds or even thousands of trials.[6]

The output of the simulated operating profits depicted in Figures 3 and 4 underscores the meaning of market uncertainty. The bar graph in Figure 3 shows the Optimal-Most Likely-Pessimistic ranges for each year (with the thicker middle section running from the 20th to the 80th percentiles of the distribution). The Excel NPV Function discounts to the present the operating profit for each trial, and the Monte Carlo simulation software creates a histogram distribution (see Figure 4) for the hundreds of trials. This distribution of discounted cash flows, which is called a Present Value Distribution, represents the range of present values of future operating profits.

Each trial forecasts a plausible UAV business case scenario. But before calculating the net present value, we must determine the appropriate discount rate for the various cash flows within a single trial. Most NPV-based business cases use, incorrectly, a single discount rate (such as 15%) for all cash flows regardless of their different risk levels. With real options, we can use different discount rates that reflect the risk of the different cash flows. The operating profits are subject to market risk and so the appropriate discount rate for these cash flows is the project's required rate of return, 15%.

In contrast, the launch cost cash flow (or "strike price") has relatively low risk because management controls the funds

4. Distributions other than triangular can be used. Most risk distributions are skewed, including the triangular distributions used in the case. A skewed distribution captures the risky project concept of a low likelihood but high consequence phenomenon. A lognormal distribution, used in formal options theory, is a type of skewed distribution, but its defining parameters, such as mean and standard deviation, are more difficult to determine in the context of standard engineering and business practices. The easily comprehensible parameters Max-Most Likely-Min that define a skewed triangular distribution can more or less approximate the formal lognormal distribution without material impact on analytical results. Also note that though there exists the NPV technique of multiple scenario analyses, some of its shortcomings are that 1) there is no understanding of the probability of any one of the scenarios, and 2) there is no way to determine which of the several valuation results ought to apply to the project investment decision at hand.

5. Spreadsheet Monte Carlo software (such as Crystal Ball or @Risk) can be used to build the triangular distributions and add other simulation specific functionality. Monte Carlo software generally includes a correlation function that enables any one distribution to be "co-related" with other distributions. For example, if there is one year of high/low operating profits, then we can forecast, with some degree of predictability, that next year's operating profits may also be high/low. In the UAV project, we estimate the correlation to be about 70% based on historical evaluation of similar projects, and have used this value in the correlation function relating all the years' distributions. If there is little or no correlation in year-over-year operating profits, then the simulation results collapse to a simple average scenario, negating scenario variability, and effectively nullifying any strategic optionality.

6. We recommend about 500 trials for preliminary results and about 2,000 trials for final results. The more complex and uncertain the analysis, the more trials are required. Some analyses requiring substantial precision, such as that illustrated in Appendix II, need upwards of 10,000 trials. Another Monte Carlo function determines how draws are made; we recommend Latin Hypercube to obtain good sampling of all the variable data.

Figure 1 **Real Options Operating Profit Business Case Scenarios**

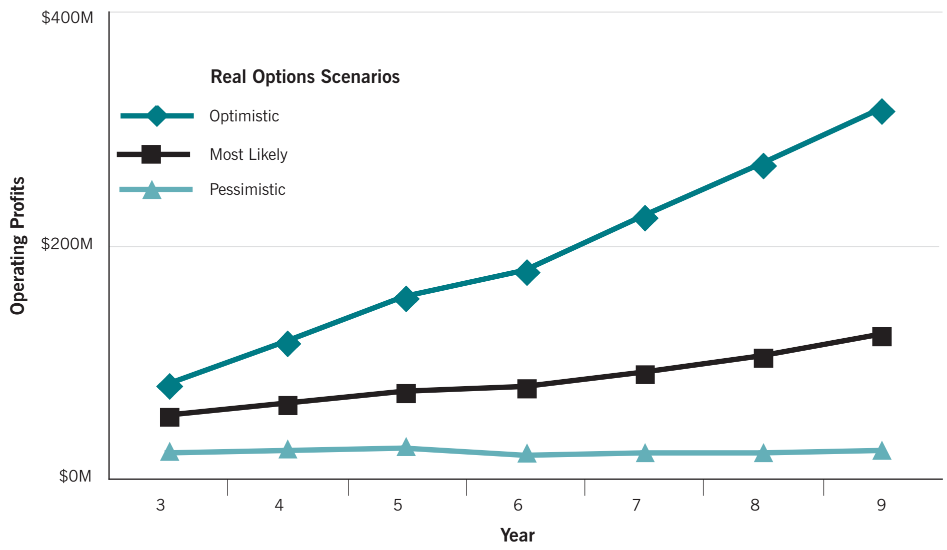
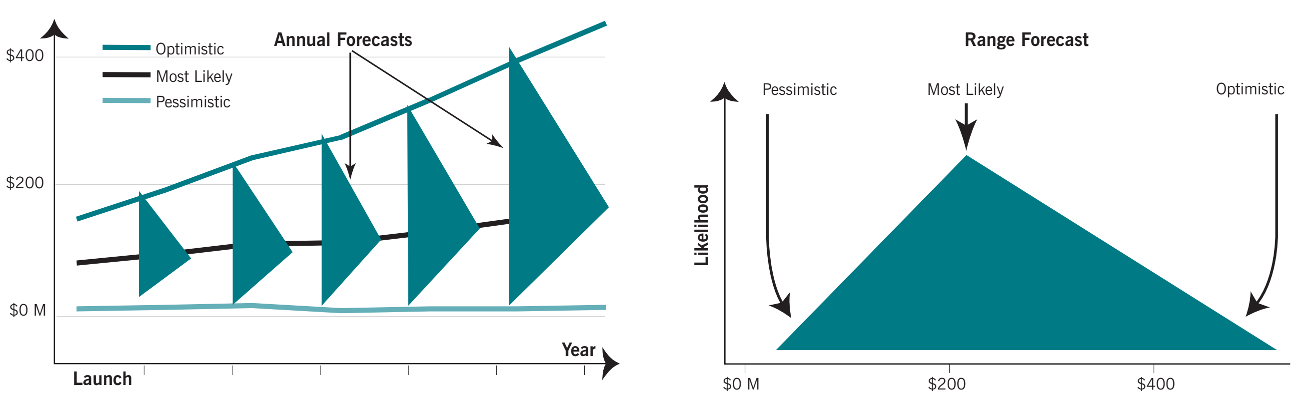



Figure 2 **Modeling Scenarios using Range Forecast Distributions for Operating Profits**




and is expected to incur the launch cost only if there are good prospects for a successful outcome. Consequently, the launch cost discount rate of 5%, termed the investment rate, is set at Boeing's corporate bond rate.[7] By thus applying an observable discount rate, the real options business case is grounded in the realities of the capital markets, putting the resulting profit and loss calculations on par with how shareholders might perceive the value of the same business opportunity, a compelling argument for senior management.[8]

The net profits and losses for all UAV scenarios collectively determine the real option value for the project. The option value can be best understood as the appropriately discounted

7. Within Boeing, the corporate bond term rate is used in option valuation. Applying a bond rate instead of the more standard risk-free rate has little material impact on the valuation and final decision-making process, while significantly improving management understanding. Here the low rate, our least expensive source of capital, can be understood as the resulting benefit of a diversified portfolio effect of a general obligation corporate bond. One view of real options is that it contrasts the value of prospective risky project operating profits against paying off corporate bondholders. For illustration purposes, the risk-free rate can be used to derive a "market-based" valuation of the option.

8. The degree of risk aversion reflected in the option value is a function of the differential discount rates. A risk neutral option valuation occurs when the two discount rates are equal, say 5%. Alternatively, setting the Project Risk Rate to 20% while maintaining the Investment Rate at 5%, will increase the risk aversion, decreasing the option value. DM Method uses risk-averse cash flow values, the same values as directly used and provided by marketing and engineering. There is no need to convert to risk-neutral values and probabilities as required by some other real option methods, a barrier to transparency and intuitiveness. In passing, we note that we could apply, correctly, the differential discount rates to the NPV business case, but the resulting expected loss would be even larger, -$69 million instead of -$19 million.

Figure 3 **UAV Project Cashflows with Uncertainties**

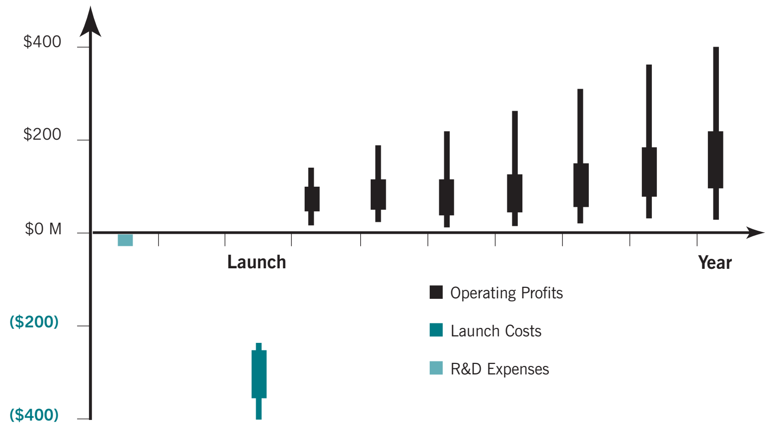
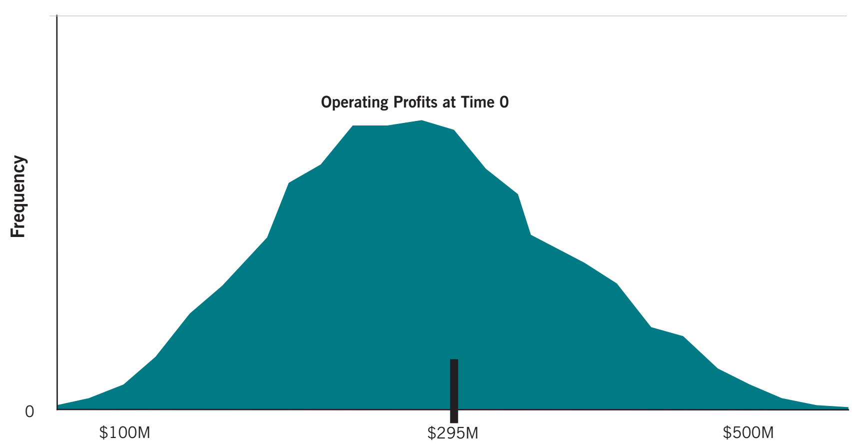



Figure 4 **Present Value Distribution of the Operating Profits**




average net profit, assuming the project is terminated if a loss is forecast. We can see this visually in Figures 5 and 6. The dark shaded section on the right of the present value distribution in Figure 5 corresponds to successful outcomes in which the discounted operating profits exceed the launch cost of $295 million. The area to the left of the launch cost consists of trials in which the cost is anticipated to exceed the operating profits. In these cases, management is expected to rationally avoid the loss by terminating the project.

The net profit—equal to the difference between the operating profit and launch cost in a successful outcome and zero when the project is terminated—also has a distribution. Figure 6 shows this payoff frequency histogram, with the terminated cases (60%) having a zero outcome, while the remaining successful cases yield a range of expected net profits.[9] The average value of this Payoff Distribution is the real option value, approximately $23 million in this example. This value is our best estimate today of the discounted future expected net profit, contingent on rational decision making at the time of launch.

Table 3 summarizes the calculations and shows that the total project value is $8 million—the difference between the $23 million option value and the $15 million R&D cost. Therefore the project is worth undertaking. The formal calculation of the real option value is done using the Boeing

9. The term "non-linear" is often applied to real options. This simply means that the project payoff has two different outcomes: zero for the terminated cases and a positive net profit for the successful cases, reflecting the contingent decision-making. A real option valuation is always positive denoting a rational decision to invest the significant launch costs only if today we forecast a positive risk-adjusted NPV at launch time. A real option valuation does not preclude that conditions at launch time may change necessitating a re-valuation of the prospective project NPV profitability, nor that the launch investment decision itself will be financially risk-free. Conversely, in the capital markets the tactical risk of owing the underlying asset is frequently eliminated by exercising an in-the-money financial option call and simultaneously selling the equivalent shares of stock for a cash settlement.

Figure 5 **Risk-adjusted Operating Profit Outcomes Based on Rational Decision-making at Time 0**

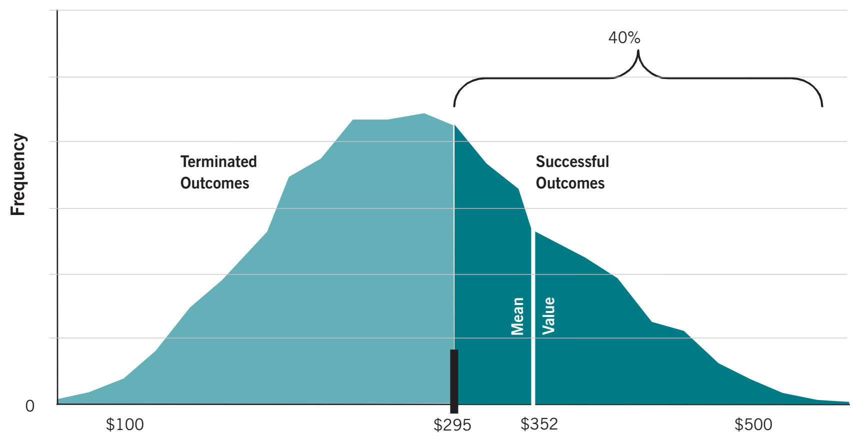
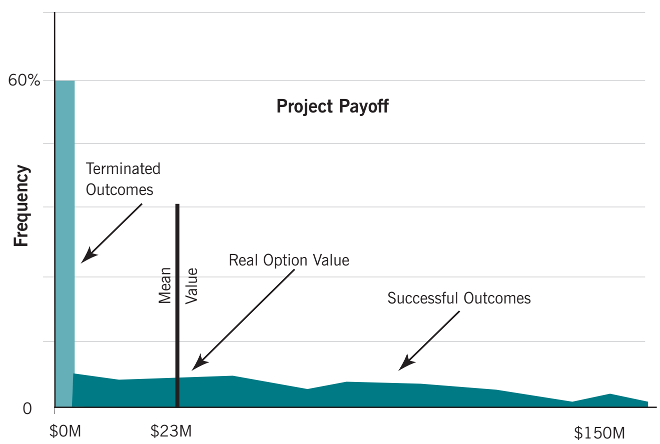



Figure 6 **UAV Project Payoff, or Net Profit, Distribution**




Datar-Mathews Method, which has the following spreadsheet formula:

Real option value =
Average[MAX ($\overline{\text{operating profits}}$ – launch cost, 0)] .

The formula captures the intuition described above.[10] The operating profits are the range of possible discounted values in Figure 4. For each trial, Excel calculates the MAX function, which involves determining whether the discounted operating profit exceeds the launch cost. The function thus has a minimum threshold of zero, which corresponds to the shaded region to the left in Figure 5. Calculating the MAX value for several hundred simulated trials creates the payoff distribution in Figure 6, with the option value equal to the average of all the net profit outcomes.

We can also provide an additional intuitive understanding of real options, which is useful during those strategy discussions, by using an estimator of the real option value that is expressed as a function of successful outcomes in the following formula:

Real option value =
Risk Adjusted Success Probability x (Benefits – Costs).

For example, as reported in Figure 5, the risk-adjusted probability of success is 40%, and the discounted mean value of the successful outcomes ("benefits ") is $352 million.[11] The discounted launch cost is $295 million. Plugging these values into the above formula also yields a real option value of $23 million, the value of the project given contingencies:

10. The overscore bar in the equation represents a distribution—formally a random variable—of the discounted operating profits at time 0.

11. For more on risk-adjusted probability, see Appendix III.

Table 3 **Real Options Business Case for UAV Project**

| **Discount Rate Assumptions** | |
|---|---|
| Project Risk Rate | 15% |
| Investment Rate | 5% |
| **D-M Method Calculations** | **($M)** |
| $PV_0$ Operating Profits | **$242** |
| $PV_0$ Launch Costs | ($295) |
| Project Payoff MAX(OP-LC,0) | **$0** |
| Project Option Value | $23 |
| R&D Expenses | ($15) |
| Total Project Value | $8 |

Real option value = 40% x ($352 – $295) ≈ $23M.

In sum, real options help address contingent strategic investment challenges, those that require preparatory resource allocation in advance of an anticipated use. In this case, our analysis tells us that the UAV project has a contingent present value of $23 million two years prior to launch. And since our engineers have informed us that they need $15 million in R&D funds today to advance the necessary technology to a state of readiness at the time of launch, the UAV project option can be purchased for $8 million less than its estimated value. This is a good deal for shareholders; the real option value exceeds the initial R&D expense request, and we should approve and fund the R&D portion of the project.

Another way of interpreting our findings is that the ability of Boeing's engineers to solve aviation challenges with a high degree of efficiency is a competitive advantage—one that allows us to "buy" the UAV option at below market value. This contrasts with the NPV analysis, which shows a loss of $19 million and the resulting conclusion to abort this business opportunity with no R&D investment. While the outcome of the initial R&D investment will not be known for some time, our expectation is that the R&D will improve our insight into the true value of the project, thereby reducing uncertainty and putting us in a better position to make a correct decision about whether to fund the much larger launch costs. And if the project is terminated prior to launch because of poor forecast projections and no further investments are committed, our loss is limited to the upfront R&D expense.

## Concluding Thoughts

The Datar-Mathews Real Option Method is gaining acceptance among managers at Boeing as a framework for analyzing strategic opportunities with both high payoff outcomes and high risk. We made the point earlier that much of the value of real options resides not in the actual calculation of the option value, but rather in "real options thinking." Because it is a critical but as yet not well articulated part of our decision-making process, applying real options thinking provides a welcome structure to scenario discussions. Moreover, the ability of the DM method to simplify the real option value calculations to familiar NPV techniques and create transparency in the process accelerates managers' adoption of real option thinking. Finally, the DM Method gracefully collapses to an NPV calculation when the uncertainties are inconsequential (the cash flow distributions converge to a most-likely point value) and there are no timed investment decision events.

Real options methods work for strategic decisions because of their ability to simplify and manage complex investment problems. It's generally not possible to know all of the potential factors that might affect the outcome of such investment. But it is sufficient in an uncertain environment to bound the problem, yet still be confident in the decision-making process. By acquiring the initial resources and information necessary for informed decisions, real options allows us to "prune" possible bad outcomes and concentrate our resources on those truly promising opportunities. The DM Method simplifies the calculation behind this thinking.

The simple UAV example in this article presents the underlying intuition and basic methodology of the DM Method. But the method can be extended in a number of ways that enable broader applications. Some examples are the inclusion of a dynamic market demand curve and production variability, and the extension to multi-stage (compound) and American options. Perhaps most promising is the method's ability to show how the option value can increase while simultaneously reducing cost and market uncertainty. Although this might appear to contradict the academic doctrine on options, in reality companies exert considerable effort to reduce costs and market uncertainty, while also counting on obtaining the highest value for its products. The richness of potential applications of the DM method, combined with its intuitive appeal, suggests it can be a powerful strategic planning and decision-making tool.

SCOTT H. MATHEWS is an Associate Technical Fellow at The Boeing Company and is technical lead for the Computational Finance and Stochastic Modeling team for the Modeling and Simulation section within the Boeing research and development division.

VINAY DATAR is Professor of Finance at Seattle University. His areas of interest include finance, international business and foreign exchange risk.

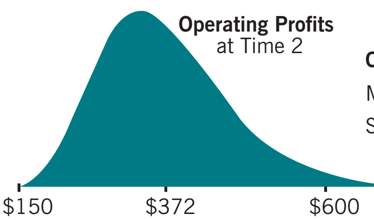
BLAKE JOHNSON is Consulting Assistant Professor in Stanford University's Department of Management Science and Engineering, where his work focuses on quantification and management of risk and flexibility for industrial companies.

Special thanks to Shen Liu at Boeing for helping to prepare the Excel models.

Table 4 **Comparing the DM and Black-Scholes Option Methods in Excel**

| Year | 0 | 1 | 2 | 3 | ...9 |
|---|---|---|---|---|---|
| Operating Profits | | | $372 | | |
| Investment | | | ($325) | | |

| | | |
|---|---|---|
| Time (t) | 2 | |
| Risk Free Rate (Rf) | 5.0% | |
| Discount Rate (Rr) | 15.0% | |




| Operating Profits | |
|---|---|
| Mean | 372 |
| StdDev | 105 |

| **Black Scholes Method** | | |
|---|---|---|
| Asset (S) | $275.58 | **=EXP(-Rr*t)*(Mean)** |
| Exercise (X) | ($294.07) | **=EXP(-Rf*t)*Investment** |
| Sigma | 19.6% | **=SQRT(LN(1+(StdDev/Mean)^2))/SQRT(t)** |
| **Option Value** | **$22.97** | **=Nd_1*S-(Nd_2*(-X))** |
| d1 | -0.10 | **=(LN(S/(-Investment))+(Rf+0.5*(Sigma^2))*t)/(Sigma*SQRT(t))** |
| N(d1) | 0.46 | **=NORMSDIST(d_1)** |
| N(d2) | 0.35 | **=NORMSDIST(d_1-(Sigma*SQRT(t)))** |

| **Datar Mathews Method** | | |
|---|---|---|
| Asset (A) | $275.58 | **=EXP(-Rr*t)*OpProfits** |
| Exercise (X) | ($294.07) | **=EXP(-Rf*t)*Investment** |
| Payoff | $0.00 | **=MAX(A+X,0) or IF((A>-X),A+X,0)** |
| **Option Value** | **$22.97** | **=Average(Payoff)** |

## Appendix I: Extensions to the DM Method

One of the simplest extensions is the conversion of the DM Method formula to an Excel logic function:

Real option value =
Average {if [(operating profits – launch cost)> 0,
(operating profits – launch cost), 0]} .

An advantage of the logic formula is greater clarity of the real option strategy, essentially the logic of business decision-making. In addition, business analysts can capture fairly complex what-if scenarios for "operating profits" and "launch cost" in spreadsheet models. For example, operating profit volatility is more accurately modeled by integrating a dynamic demand curve and production uncertainty.

The DM Method framework can also incorporate additional options. For example, the launch cost, which is fixed for the sample case, can also be a distribution (a "variable strike" option)—one of the most common situations in real options. We can integrate this option together with an exit option to either license or sell the technology developed, say for $5 million, in the event of project termination. The value of the terminated, unsuccessful project is therefore $5 million, not $0. The spreadsheet formula for the complex project option that combines these two features becomes:

Real option value =
Average [MAX (operating profits – launch cost, 5)].

A project type that frequently arises at Boeing is an opportunity to bid on a fixed price proposal, where the uncertainty is the cost ("strike price") of the system. In this case, the traditional option variables are reversed, with the benefit, or proposal price, being the fixed value. The DM Method is able to calculate the option value of the proposal bid opportunity:

Real option bid value =
Average [MAX (fixed price – system costs, 0)].

These are all call options that will pay off only if there is an increase in value. A common put option, which will pay off if there is decrease in value, such as a service guarantee for customer service agreements (CSA), or, for expensive leased assets such as cars and airplanes, a residual value guarantee (RVG). Put options are often used in contingent clauses in contracts to tailor the value to the performance risks of the contract. The DM Method values a put option as follows:

Figure 7 **Operating Profit Outcomes Based on Rational Decision-making at Year 2**

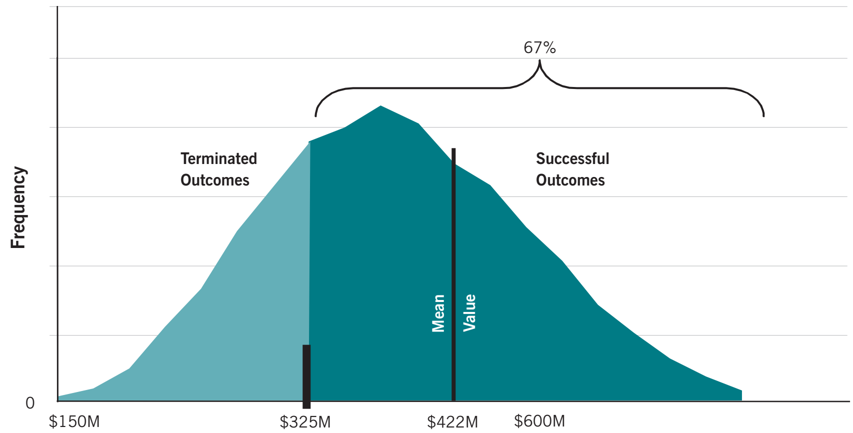
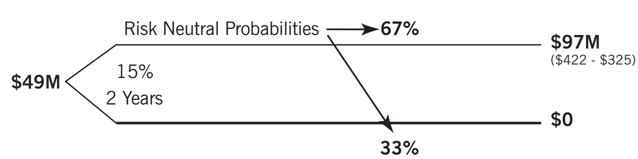



Figure 8 **Decision Tree at Year 2**




Real put option value =
Average[MAX (guarantee value – $\overline{\text{actual value}}$, 0)].

## Appendix II: Comparing the DM Method to Black-Scholes

The DM Method is mathematically equivalent to the Black-Scholes formula under certain assumptions. Table 3 illustrates this with a simple but typical DCF analysis. The DM Method uses the distribution of forecasted cashflows to find the option value, whereas Black-Scholes uses the volatility, $\sigma$.[12] Furthermore, the DM Method implicitly adjusts the discount rate to account for the underlying risk. The option value is easily understood as the expected payoff resulting from rational exercise decisions. The flexibility of the DM Method also allows it to better deal with the real world deviations from the strict theoretical assumptions of Black-Scholes. For example, the DM Method can easily deal with non-lognormal cashflow distributions and random exercise price.

## Appendix III: How Risk Undercuts Decision Trees

Decision trees provide a graphic representation of the possible paths for the project outcome, but they do not correctly value the project. Whereas NPV analysis typically undervalues a project because it does not include the value of flexibility, a decision tree usually overvalues the project because it does not appropriately adjust the investment risk.[13]

To see why, we construct a decision tree for the UAV project. Monte Carlo simulations applied to the information in Table 2 create the distribution for operating profits

12. The DM formula is: $C_0 = E[e^{-\mu t}\bar{S} - e^{-rt}X]^+$,
an expectation where $\bar{s}$ is the random variable for operating profits, $\mu$ and r are the risky-asset and the risk-free discount rates, respectively, and + is the MAX function. The simulation for the DM Method is typically run for 10 – 20,000 trials as it gradually converges on the Black-Scholes value.
The Black-Scholes formula is:

$$C_0 = S_0N(d_1) - Xe^{-rT}N(d_2),$$

where

$$d_1 = \frac{\ln\left(\frac{s_0}{x}\right) + \left(r_f + \frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}}$$ and $d_2 = d_1 - \sigma\sqrt{t}$.

13. Remarks also generally apply to a closely related discipline, decision analysis. Decision analysis practice includes the application of utility curves to assess a project manager's risk aversion and therefore assign an appropriate risk-adjusted discount rate, which can differ from, sometimes substantially, the corporate hurdle rate. However, in my observations the utility curve assessment is very infrequently conducted owing to its subjective nature, which runs counter to the corporate need for intuitive and transparent analysis.

discounted to Year 2, the decision date. As seen in Figure 7, 67% of the outcomes are a success, with a mean operating profit of $422 million and a net profit of $97 million. A simple decision tree with two branches in Figure 8 illustrates the decision outcomes at Year 2. Discounting the net profit at 15% to Time 0 values the project at around $49 million, $26 million higher than the option value.

The different values are a consequence of how the two methods handle risk. A decision tree applies risk neutral valuation. A person who is risk neutral would be willing to pay $49 million for the UAV project two years in advance. However, there is a fair chance that the project will be terminated and the original investment forfeited. A risk averse investor cares about this loss, and the real options method takes this into account. The estimated project value of $23 million effectively lessens the investor's exposure to the amount of capital at risk. The smaller investment positions the investor for a higher rate of return should the UAV project be successful.[14]

The success percentages in Figures 5 and 7 differ because the former is based on the risk averse percentages at Time 0, while the latter shows the risk neutral percentages at Year 2. Time 0 risk aversion can be severe because a substantial sum of money is invested well before the launch opportunity is viable. This translates into a perceived reduction in the chances of success. The DM Method implicitly adjusts the probabilities to account for risk aversion. The intent of the initial investment is to resolve many of the project uncertainties.[15] By Year 2, some of the uncertainty is in the past, and we can examine the launch prospects in a less risky framework. At that time, we can determine whether the project meets our required rate of return of 15% using standard NPV analysis.

Decision trees and binomial lattices have a more practical limitation. They are not easy to implement in spreadsheets, the industry standard for business case models. Most business cases involve dozens, and occasionally hundreds of variables, with multiple sources of uncertainty that can quickly overwhelm a spreadsheet decision tree. Instead, a properly structured spreadsheet-based business case with embedded Monte Carlo simulation adequately recreates the branching of a decision tree.

14. An option's rate of return is given by:

$\mu_{implied} = \frac{\ln(C_T / C_0)}{T}$, where $C_0$ is the option value at Time 0, or $23 million; CT is the project value with rational decision-making at Year 2, or $97 million. $\mu_{implied}$ then equals 72%. Options are risky but highly leveraged investments and therefore are accompanied by a sufficiently high ROI. Note that highly leveraged investments with significant but risky rates of return correspond well with our concept of the nature of R&D investments. Occasionally $\mu_{implied}$ is termed the "rate of learning," again for the nature of leveraged returns on R&D technology investments. $\mu$ is "implied" because the rate of return of the option can only be determined once the option value has been calculated; $\mu_{implied}$ cannot be determined *a priori*.

15. There is a closely related phenomenon on risk aversion and probabilities I observe when I lecture to universities or business groups. I will often offer my audience to 'purchase' a lottery that pays out $100 on a correct call of a coin toss, other wise, $0. I rarely get purchase offers above $40 (or 40%) owing to the risk aversion of the audience, even though the objective probabilities indicate the gamble should be worth $50 (50%), a risk neutral investment. Risk aversion shifts the perceived probabilities.

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