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Business Engineering: A Practical Approach to Valuing High-Risk, High-Return Projects Using Real Options

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Abstract Technologists and engineers endeavor to design and propose leading edge concepts, but the development of these concepts ultimately depends on obtaining funds justified by a business case. Most existing business case tools and methods, which have their origins in the conservative banking industry, tend to favor those project concepts that have secure annuity-like returns such as extensions of existing product lines. This tutorial provides engineers with the business case methods and tools to calculate the value of smaller, more risky projects where new technology or markets are involved, and which potentially offer higher returns in the long run. These straightforward methods and tools have been adopted from sophisticated techniques used in the options markets, where investments in risky securities are routinely traded. We first present an example scenario for a new product and review a typical business case using net present value analysis. Next we develop a "what-if" multi-scenario business case model using Monte Carlo simulation. Then we examine an investment decision using a decision tree to capture scenario flexibility. Finally, we determine a risk-averse investment decision using real options calculated with an intuitive and transparent algorithmic tool. In conclusion we show business engineering as a new approach that provides engineers with investment and risk modeling tools and methods that can be incorporated alongside standard systems engineering design modeling techniques to justify the targeting of project investment dollars to manage risk, shape value outcomes, and make better strategic decisions.

Keywords real options; investments; risk; Black-Scholes; Datar-Mathews method; business engineering; strategic decisions; Monte Carlo simulation; systems engineering; spreadsheet modeling; valuation; capital budgeting; NPV finance

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Too often technologists and engineers endeavor mightily to design and propose leading-edge concepts, only to have them left unfunded and on the shelf as a result of a seemingly injudicious business-case analysis. *Business engineering*[1] is a new approach to provide engineers with much needed financial-investment and risk-modeling tools and methods that can be incorporated alongside standard engineering design-modeling techniques. Business engineering extends engineering, particularly systems engineering risk management, practices to include additional design constraints variables like financial risk and value, and injects new tools such as targeting investment dollars to manage risk, shape value outcomes, and make better strategic decisions. Finally, business engineering provides the vocabulary for engineers to justify investments in leading-edge high-risk, high-return projects.

To provide perspective, it is instructive to understand that financial-analysis techniques have historically undergone cycles of change, just as in engineering fields where new technologies supplant older ones. The earliest approach, called *payback*, simply counted the

[1] Business engineering derives its name from *financial engineering*, where mathematicians and engineers apply their skills to pricing of risky investment contracts in the financial options markets (http://en.wikipedia.org/wiki/computational_finance). Business engineering uses many of the same techniques and skills, but for valuing of investments in risky, but high-return projects within corporations.

number of years of estimated profit required to return the original investment. Starting in the middle of last century following on its successful application within the banking industry, net present value (NPV) was applied to project valuation (sometimes called *capital budgeting*) and became the corporate finance standard, applying discounting techniques for future profit cashflows. NPV remains the standard in most corporate business-case analyses, even though appropriate application within the secure environment of the banking industry imperfectly transfers to riskier corporate project analysis. However, since the mid-1980s, the rise of the importance of the options in the capital markets, and, in particular the creation and wide-spread use of the Black-Scholes formula,[2] has led to a revolution in the way financial analysis is conducted. Option-valuation techniques are well suited to evaluating investments with flexibility, critical decision points, and major discontinuities such as one finds in high-risk, high-return technology projects. The practice of option techniques applied to business-investment decisions is termed *real options* because it applies to real product and technology assets, rather than capital market financial assets.

Real options has, however, been slow to develop because of the complexity of the techniques that have been borrowed from the capital markets and the resultant mismatch to the needs and realities of corporate financial analysis and strategic decisions. Such complexity and the resulting challenge of getting senior-management acceptance, has been a major barrier to wider corporate adoption of real-option techniques.

However, recently Boeing has developed a real-option method of valuation, referred to as the Datar-Mathews (DM) method [3]. Although algebraically equivalent to the Black-Scholes formula, it uses information that arises naturally in a standard project financial valuation, see Datar and Mathews [4] and Mathews et al. [5].

1. An Investment Decision: The NPV Most Likely Business Case

In order to illustrate a real-option valuation, let us first examine a project using a simple business case analyzed from an NPV approach. Imagine Boeing has the opportunity to design and build a small aircraft, somewhat smaller than the size of a 737, specialized for air-freight transportation. There is a rapidly expanding market for high-value goods to be quickly shipped from local airports near a manufacturer directly to one close to consumer-market outlet locations and vice versa. Historically, air-freight planes have been created by converting older passenger planes. Inefficiency in design and weight of the converted air freighters result in the cost of transported cargo, as measured by dollars per ton-mile, not being competitive with freight transported by overland truck. Although a new specialized air freighter might be competitive for transporting luxury goods, it remains a risky proposition because it would compete directly with the inexpensive, albeit inefficient, converted freighters. Furthermore, the air freighter market is difficult to forecast for many reasons; e.g., it is sensitive to business cycles and volatile fuel costs.

The actual business case for the air freighter is complex, involving many factors. However, the concepts presented in this paper can be sufficiently illustrated with a simplified business case. Table 1 sets forward example projections of revenues and costs using a most likely scenario. The engineers and marketing analysts are requesting authorization to spend \$100 M over the next three years. The engineers will focus on a preliminary design, particularly on nonrecurring cost-manufacturing efficiencies, to reduce the freighter's costs to make it as competitive as possible, whereas marketing needs to determine the size and price elasticity of the air-freighter market place. After three years, contingent on the success of the engineering efforts and a promising market forecast, Boeing would have to spend an estimated \$2.0 B to launch the air freighter. These one-time nonrecurring launch costs are intended for final

[2] For a lighter review of the Black-Scholes formula, see http://www.risklatte.com/features/quantsKnow050905.php.

Table 1. NPV most likely business case.

	Year										
($M)	0	1	2	3	4	5	6	7	8	9	10
Target unit price ($)											
Target unit (240) cost ($)	20										
Unit cost ($)					45	33	27	24	21	20	19
Unit quantity					15	30	45	60	60	60	60
Revenues ($)					525	1,050	1,575	2,100	2,100	2,100	2,100
Recurring costs ($)					676	977	1,212	1,412	1,284	1,200	1,139
Most likely op profits ($)		0	0	0	(151)	73	363	688	816	900	961
Launch cost ($)		0	0	(2,000)							
R&D expenses ($)	(100)										

Table 2. NPV most likely project valuation.

Discount rate assumptions	
Project risk rate	15.0%
NPV calculations	($M)
PV_0 operating profits	$1,126
PV_0 launch costs	($1,315)
R&D expenses	($100)
Total project NPV value	($289)

design, manufacturing readiness, Federal Aviation Administration certification and marketing outlays. The estimated unit sales, price, and unit-recurring cost depend on assumptions about product strategy and market reception.

Calculation of the NPV value is straightforwardly based on the most likely value estimates for the business-case variables. Net profits are the difference between the operating profits (sales revenue minus unit-recurring cost {[unit price − unit cost] ∗ unit quantity}) and the nonrecurring launch cost. Using the most likely set of estimated values, and applying the Excel NPV function[3] using the project discount rate of 15% (representing the rate established by management to meet a required rate of return for project investments), the project net present value at Year 0, today, is estimated to be a negative $289 M; see Table 2. Under standard NPV decision making, the finance department's forecast for this project is that it will lose money, and therefore the request for initial funding of $100 M would be denied. Following that guidance, senior management would terminate the air-freighter project and appropriately direct engineering and marketing R&D funding resources to other projects with positive NPV values.

Given the uncertainty of the market and the cost estimate forecast, and thus of the project outcome, we may doubt the conclusion of the NPV analysis. An NPV analysis reduces all available information to a single scenario, eliminating other less probable, although still plausible scenarios. The *what-if scenario analysis*, a commonly used engineering technique, could elicit several plausible, but lower-probability, outcomes.

Because of the singular scenario (or path) focus, the NPV approach also has a tendency to impact project planning by channeling engineering resources early into executing a single track effort well before the resolution of significant project uncertainties. This can lead

[3] According to a financial economic insight, the spreadsheet-based NPV function has the effect of simultaneously summing the cash flow values while adjusting the out-year values to equivalent time- and risk-adjusted values of the target year.

to situations where in spite of good intentions, the project is directed down a course of action that limits its ability to respond with agility to changes in the engineering and technology awareness or market factors that have a potential material impact on the outcome of the project. More realistic project planning incorporates contingency plans under a multi-scenario planning approach in the event of unexpected technology or market developments. Capturing the value of project flexibility in the face of uncertainty requires a different valuation approach.

2. What-If Multiscenario-Modeling Approach Using Monte Carlo Simulation

Monte Carlo simulation can be advantageously applied to making investment and risk decisions for business cases. Just as this technology extends the ability to investigate what-if scenarios on matters of engineering concern, such as performance and operating stability, this same technology can be applied to what-if scenarios for price, unit sales, and cost for the air-freighter business case. In fact, Boeing applies the term "business engineering" to the more advanced models, which combine both the business and engineering aspects of a project. These advanced models effectively automate the what-if scenario analysis by application of Monte Carlo simulation. What is required, is a valuation approach that effectively uses this technology and provides a more useful estimate for the project.

Monte Carlo simulation offers the ability to incorporate into the analysis several scenarios, including those that are plausible albeit lower probability, but potentially consequential to the outcome of the project. A substantial portion of the information about these other scenarios may already be available within the corporation. For example, good engineering practice often includes calculating best- and worst-case performance outcomes for technology and products, which can be incorporated into a business-engineering analysis (see Appendix IV). Additionally, a multiscenario approach includes flexibility and critical decision points for managing the project. The underlying reality is that as events unfold prior to the launch date and one or another technology or market opportunity scenario begins to play out, decision managers have the ability to increase project value by identifying and responding to the changes.

The multiple-scenario deliberations need to focus on the high-level risks and opportunities, those that impact 10% or more of the total value of the project. There are several reasons for this. One is the obvious need to reduce the complexity and quantity of the scenarios. This is in line with standard engineering practices for a first- and second-draft design effort, where the focus is on those components that contribute 10% or more of the targeted function. Furthermore, many of the minor risks can be managed by a good engineering and management team when they become apparent.[4] Finally, the future is not divinable, and the immediate circumstances will predictably change—the project manger simply needs to be sufficiently flexible to respond to unfolding events to take advantage of the opportunities that might arise.

Begin the multiscenario modeling process by envisioning three scenarios: optimistic, most likely, and pessimistic. The most likely scenario is usually the scenario already derived by the finance analysts for the NPV business case. This scenario forecasts the most likely cost and revenue cash flows that would materialize if events play out as a majority of experts expect given both engineering efforts and marketing response.

The pessimistic and optimistic scenarios are derived from deliberations with a similar set of experts (technology, engineering, marketing, finance, and management) but now attempt to reflect key insights to the major project contingencies, the high-level risks and opportunities that potentially impact 10% or more of the value of the project; see Table 3.

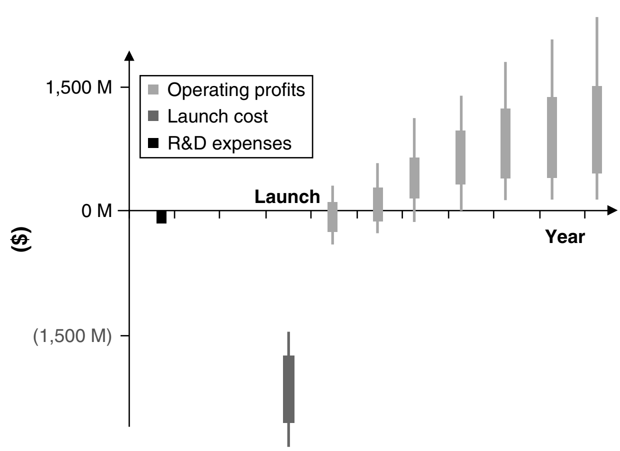
[4] Note this thinking is analogous to how insurance is employed to cover large risks, whereas we accept payment responsibility for minor unpredictable incidents whose costs fall under the insurance deductible.

Table 3. Variables for various scenarios.

Contributor	Variable ($M)	Pessimistic	Most likely	Optimistic
Engineering	Unit (240) cost	$23	$20	$18
Engineering	Launch cost	$2,500	$2,000	$1,500
Engineering	Production ramp	15/Year	15/Year	15–30/Year
Marketing	Unit price	$30	$35	$40
Marketing	Unit quantity	270	330	555
Finance	Discount rate		15% Project; 5% Investment	
Management	Outlook	10%	Most likely	10%
Technology	R&D costs	$100	$100	$100

The pessimistic scenario is determined by estimating cost and revenue cash flows that nine out of ten experts believe will be exceeded; in other words, only one of the experts (10%) believes that the pessimistic scenario will materialize. The optimistic scenario is similarly determined. Only one out of ten experts believe the estimated optimistic cost and revenue cash flows will materialize, whereas the remaining nine believe the actual cash flows will be less; see Figure 1. When ten experts are not available, assemble fewer, e.g., five, but again be sure to survey for the outlying estimates to capture a broad range of possible outcomes. This scenario and probability elicitation method is analogous to a Delphi method for systematic interactive forecasting approach based on inputs from experts. A cat-whisker bar graph illustrates the variability of the cash flows of the optimal, most likely, and pessimistic ranges for each year (with the thicker middle section running from approximately the 20th to the 80th percentiles of the distribution); see Figure 1.

Figure 1. Business-case scenario cash flow variability.



For each of the various scenarios, the marketing specialists can help quantify unit-quantity and unit-price forecasts.[5] Each scenario, i.e., optimistic, most likely, and pessimistic, has a unit-quantity forecast, which corresponds to a plausible strategy within the market. Also, there are three unit-price forecasts, again corresponding to each of the scenarios; see Table 4.

The engineering and technology experts can estimate the nonrecurring launch cost and the recurring manufacturing cost for each unit. Again for each of the three scenarios, there is a range for launch cost, as well as a range for the unit-recurring cost target. The recurring-cost

[5] The relationship of unit price and quantity is described by a demand curve. For a more involved model, the marketing specialists can specify the shape of the market-demand curve and insert it into the model to help derive values for the simulation.

TABLE 4. Optimistic and pessimistic business-case scenarios.

	Year										
($M)	0	1	2	3	4	5	6	7	8	9	10
Optimistic											
Target unit price ($)	40										
Target unit (240) cost ($)											
Unit cost ($)					41	29	24	20	18	16	15
Unit quantity					15	30	60	90	120	120	120
Revenues ($)					600	1,200	2,400	3,600	4,800	4,800	4,800
Recurring costs ($)					609	879	1,419	1,809	2,130	1,945	1,823
Optimistic op profits ($)		0	0	0	(9)	321	981	1,791	2,670	2,855	2,977
Launch cost ($)		0	0	(1,500)							
R&D expenses ($)	(100)										
Pessimistic											
Target unit price ($)	30										
Target unit (240) cost ($)											
Unit cost ($)					52	37	31	27	25	24	23
Unit quantity					15	30	45	45	45	45	45
Revenues ($)					450	900	1,350	1,350	1,350	1,350	1,350
Recurring costs ($)					778	1,124	1,394	1,236	1,142	1,077	1,028
Pessimistic op profits ($)		0	0	0	(328)	(224)	(44)	114	208	273	322
Launch cost ($)		0	0	(2,500)							
R&D expenses ($)	(100)										

TABLE 5. Three business-case scenarios structured for Monte Carlo simulation.

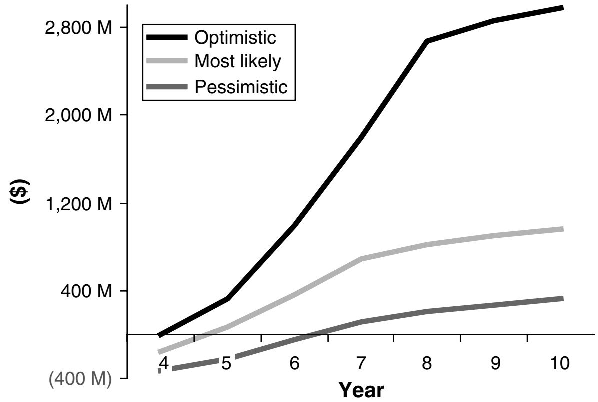
	Year										
($M)	0	1	2	3	4	5	6	7	8	9	10
Operating profits											
Optimistic ($)		0	0	0	(9)	321	981	1,791	2,670	2,855	2,977
Most likely ($)		0	0	0	(151)	73	363	688	816	900	961
Pessimistic ($)		0	0	0	(328)	(224)	(44)	114	208	273	322
Launch costs											
Optimistic ($)		0	0	(1,500)							
Most likely ($)		0	0	(2,000)							
Pessimistic ($)		0	0	(2,500)							
R&D expenses ($)	(100)										

estimate is made for a targeted production unit, typically one in which the manufacturing process is fairly mature. The recurring-cost decreases for each unit produced, following a well-understood manufacturing learning curve.[6] The cost for the remaining units is then projected from the estimated cost target in the learning-curve calculation that reflects the rate of cost reduction.

Quantifying the difference between the unit price and unit cost and multiplying by the unit quantity in the optimistic, most likely, and pessimistic scenarios results in three operating-

[6] The formula used for the unit recurring cost learning curve is $y = Cx^b$. C is the estimated cost of Unit #1: about \$72 M in the most likely case example. x is the number of units. b takes the form of (LOG(0.85)/LOG(2)), where 0.85 is a typical rate of learning. We assume in this case that the target unit cost corresponds to the cost of producing the 240th unit ($y = \$20$ M). The formula can be interpreted as each doubling of unit quantity decreases cost by 15%.

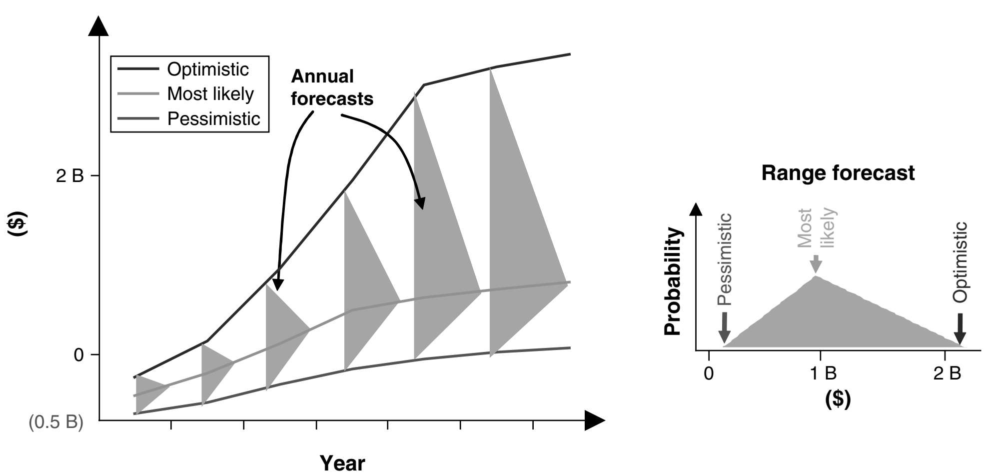
FIGURE 2. Air-freighter operating-profit scenarios.



profit cash-flow estimates for each year of the business case; see Table 5. The three operating-profit cash-flow estimates span nearly the entire range of plausible outcomes for each of the forecast years, encompassing a one-in-ten probability on the pessimistic, or low, forecast and a one-in-ten probability on the optimistic, or high, forecast; see Figure 2.

The three estimates for each year can be viewed as representing the corners of a triangular distribution that reflects a range of forecasts and thus serves as a proxy for the variation of the annual operating cash-flow forecasts at the launch date,[7] as can be seen in Figure 3. Using Monte Carlo software, it is relatively straightforward to construct a range forecast triangular distribution for each year of the operating profit forecast.

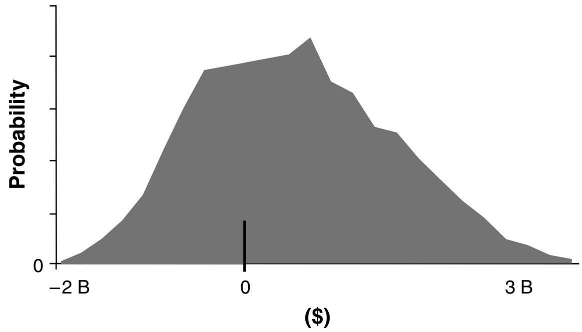
FIGURE 3. Fitting range forecast distributions to scenarios.



Using the corporate hurdle or project discount rate of 15% and applying at Year 3 the NPV function together with the Monte Carlo simulation of the multiscenario operating profit yields a frequency distribution of the total range of value of the air freighter operating

[7] 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 Max, Most Likely, and Min parameters that define a skewed triangular distribution can more or less approximate the more formal lognormal distribution without material impact on analytical results.

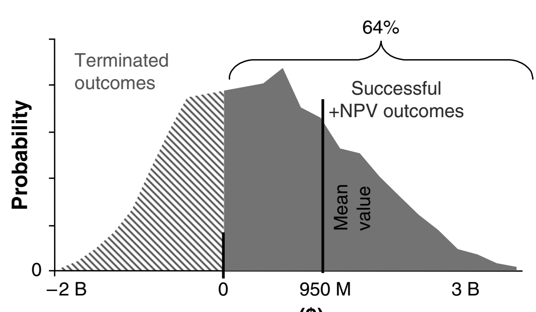
FIGURE 4. Net profits present value distribution forecast at Year 3.



profits "present valued to Year 3." The forecast of the Year 3 launch cost also includes a range because of uncertainty of the many engineering and technology issues that comprise the launch cost (see Appendix IV). The Year 3 net profits are calculated by taking the difference of the operating profits and the launch cost even though both are distributions.[8] The Monte Carlo simulation provides the functionality to carry out the calculation by taking successive draws from the operating-profit and launch-cost distributions. The resulting difference calculated at each trial is the net profit for a single scenario instance. A complete simulation of hundreds of scenario trials creates a net profit present value distribution at Year 3; see Figure 4.

Year 3 is a critical decision point when the discretionary, substantial, and irreversible nonrecurring cost must be invested in order to launch the project. Only by committing the substantial launch cost investment will the corporation be able to produce the air freighter and obtain the resulting operating profits. The investment decision is irreversible because once the launch cost has been expended, those funds cannot be retrieved. The investment is discretionary because there is the option of either expending the launch cost and proceeding with the air-freighter project, termed *exercising the option*, or not expending the launch cost and terminating the project, termed *abandoning the option*.

FIGURE 5. Year 3 rational decision forecast.



Of course, the corporation will expend the launch cost if and only if at the time of the decision, Year 3, the present value of the operating profits exceeds the launch cost. In other words, if at Year 3 the forecasted discounted cash flows indicate a positive NPV, then it would be rational to invest the launch cost and initiate the project. It is important to note that each scenario in the simulation is treated as a potential cash-flow forecast. Based on these forecasts, the present value distribution at Year 3 indicates there is a 64% probability of a positive net profit, and a resulting expected (or mean) net profit of $950 M; see Figure 5.

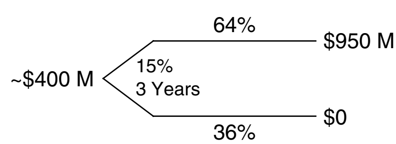
[8] The launch-cost-range estimate does not require discounting because it is already estimated at Year 3 value.

For the remaining 36% of the scenarios it is not financially rational to invest the substantial launch costs because of anticipated negative net profits, a loss for the corporation. Therefore, the corporation would choose not to expend the launch costs, effectively abandoning the air-freighter project, and resulting launch-cost and operating-profits cash flows would be zero.

3. An Investment Decision: Using Decision Trees to Capture Flexibility

Decision trees were developed to address some of the shortcomings of the NPV approach by providing a method to realize the value of flexibility within a project. To create a decision-tree valuation for the air freighter begin by analyzing the Year 3 net profit distribution derived by the what-if multiscenario approach above.[9] The simplest decision tree is constructed with two branches illustrating the decision outcomes at Year 3 and then discounting the results to Year 0. Discounting the net profit at 15% to Year 0 appears to value the project at around $400 million; see Figure 6.

FIGURE 6. Decision-tree valuation technique.



Unfortunately, using the expected value of the decision-tree outcomes leads to a project valuation that is normally too high. This is because the expected value will often implicitly account for too little risk aversion. In other words, if appropriate firm decision making reflects risk aversion, a decision tree using expected values would have you overpay for the air freighter project.

To see this point in a slightly different way, consider that the decision tree is constructed such that it captures the net profit investment perspective at Year 3. However, decision tree analysis incorrectly commingles the operating profits and the launch costs when net cash flows are discounted back to Year 0. Discounting these cash flows by the same rate is almost always incorrect. The correct discount rate for a cash-flow stream should reflect the riskiness of the individual stream being discounted. And in most projects, the launch costs and the operating profits will have very different risk levels. In this case, there is no easy way to calculate a single, appropriate risk-adjusted rate for the net cash flow. Therefore, decision-tree analysis using expected values and a common discount rate does not work well for project valuation.[10]

In Boeing's DM method, an adjustment for risk aversion is included by using a different discount rate for the launch cost outflow and the prospective operating cash inflows. The operating profits are discounted by the market rate (15% in this case); the launch cost is discounted by the corporate bond rate (perhaps 5%) to reflect its relatively lower risk. This adjustment for risk aversion can be ratcheted up or down by changing the differential between the discount rates used for the two flows.

Some final comments about decision trees and a related older real option technique called *binomial lattices*. Although they provide a simple graphical representation of project

[9] It is not possible to accurately construct a decision tree directly from the initial information of the three scenarios. Though the information appears to be linear (probabilities and profit values), in actuality the total impact of the correlated, skewed, and the occasional nonlinear relationships are only revealed by the combinatorial effects of the Monte Carlo simulation.

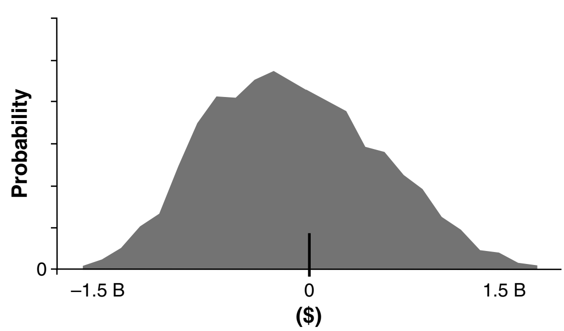
[10] Although it is possible to determine the appropriate risk-adjusted discount rate, it involves certainty-equivalent or risk-neutral probabilities, which are not easy to calculate.

decisions and uncertainty, decision trees and lattices have numerous shortcomings when modeling any realistic business case. Neither trees nor lattices are well accommodated in spreadsheets, the industry standard for business-case models. Most business cases involve dozens, and occasionally hundreds of variables, with uncertainties such as recurring and nonrecurring costs, schedule, technology readiness, market demand, production rates, and competitive threats. In attempting to represent all these branch uncertainties, decision trees quickly become unmanageable and also have difficulties in representing cross-influences, the so-called *joint probabilities*, among the branches. Finally, assigning the many and varied branch probabilities (or u, d parameters in a binomial lattice) is highly problematic within a business context requiring transparency and intuitiveness. In actuality, a properly structured spreadsheet-based business case with embedded Monte Carlo simulation adequately recreates the "bushy" branching of a decision tree or lattice (each trial generates a branch or path) although providing substantially more functionality as well as a bridge to system-engineering risk modeling.

4. An Investment Decision: Using Real Options for Flexibility and Risk Aversion

Real options can calculate the fair value for the air-freighter project given flexibility in project planning and investment risk aversion. A real-option approach will more appropriately value a risky project by accounting for the risk aversion of the potential loss of an up-front investment. The real-option approach discounts to Year 0 the operating-profit cash flows at the hurdle rate, and the launch-cost cash flow at the investment rate.[11] The net profit, the difference of the two discounted cash flows, is simulated and calculated at Year 0. The result is the Year 0 net profit present-value distribution for the hundreds of cash-flow scenario trials as can be seen in Figure 7.

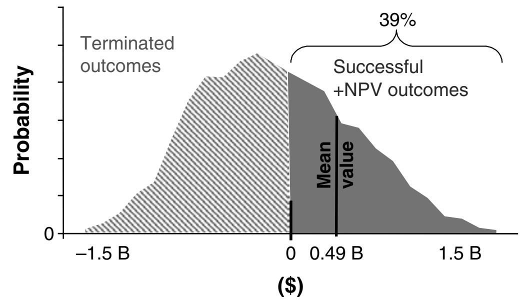
FIGURE 7. Year 0 net profit present-value distribution forecast.



The project manager needs to be financially rational on a risk-adjusted basis for the investments in the air-freighter project; see Figure 8. The solid shaded section on the right tail of the present-value distribution corresponds to the 39% probability of a successful, pos-

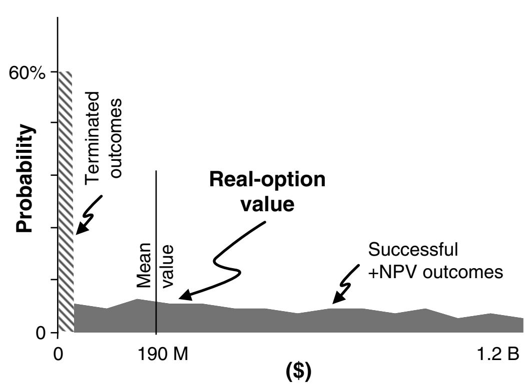
[11] Within Boeing, the corporate bond term rate is used in option valuation to discount the so-called private risk, or internal diversified risk. Applying a bond rate, as opposed to the more standard risk-free rate for option pricing, results in a valuation approximation that has little material impact on the final decision-making process, although appealing to management intuition. Here the low rate, the 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 provides a "corporate-based" valuation that contrasts the value of prospective risky-project operating profits against paying off corporate bond holders. By applying an observable discount rate, the real-options business case is grounded in the realities of the capital markets. Thus, the resulting profit and loss calculations are placed on a par with how shareholders might perceive the value of the same business opportunity—a compelling argument for senior management. For illustration purposes, the risk-free rate can be used to derive a "market-based" valuation of the option. To read more about market- and private-risk dual-discount approach, see Mello and Pyo [6]. See also http://investmentscience.com/Content/newsArticles/news3.html.

FIGURE 8. Year 0 risk-averse rational-decision distribution.



itive NPV forecast in which the discounted operating profits exceed the launch cost.[12] The cross-hatched shaded section on the left tail of the present-value distribution represents the probability of those trials in which the discounted launch costs are anticipated to exceed the operating profits. Being risk averse in these cases, the project manager would rationally choose to avoid the loss by terminating the project, and there would be zero launch cost or operating-profit cash flows. Essentially, the project manager enhances the total value of the project by taking the appropriate action contingent on information revealed during the pre-launch period.

FIGURE 9. Year 0 payoff distribution.



The real-option value can be understood simply as the average net profit appropriately discounted to Year 0, the date of the initial R&D investment decision, contingent on terminating the project if a loss is forecast at the future launch decision date. This payoff calculation also has a distribution; see Figure 9. The payoff distribution illustrates the 61% probability of plausible scenario trials that are terminated with zero cash flow, whereas the remaining successful cases yield a range of expected net profits. The average value of this payoff distribution is the real-option value, approximately \$190 M in this example. The real-option value is the best estimate today of the discounted future expected net profit, conditional on risk-averse rational decision making at the time of launch.

[12] Here we are estimating the probability of a successful outcome of the project, meaning a risk-adjusted positive NPV value given the uncertainty of the launch-investment decision. A real-option valuation does not preclude that conditions at launch time may change necessitating a re-valuation of the prospective project profitability, nor that the launch decision will be financially risk free. A real-option valuation calculates the risk-adjusted probability of a positive NPV at launch time—a rational, but not risk-free financial decision. Exercising a real option on a project nearly always exposes the owner to a tactical decision of whether to invest the significant launch costs in the risky underlying project asset. On the other hand for financial options exercising an in-the-money call and simultaneously selling the equivalent shares of stock for a cash settlement eliminates tactical risk of owning the stock.

The formal calculation of the real-option value is done using the DM method. The spreadsheet DM method formula is as follows:

$$\text{Real-Option Value} = \text{Mean}[\text{MAX}(\overline{\text{Operating Profits}} - \overline{\text{Launch Cost}}, 0)]^{13}$$

The formula, which is a combination of Excel and Monte Carlo functionality, captures the intuition described above. The "operating profits" and "launch cost" are the present-value distributions. The payoff distribution is created by simulating several hundred scenario trails, and calculating the MAX value, with a zero threshold for terminated projects representing no cash flow. The option value, \$190 M, equals the mean value of this payoff distribution.

A real-options approach provides justification for contingent strategic R&D investments. Strategic investments allocate resources in advance of an anticipated use. The air-freighter project has a strategic value of \$190M three years prior to launch. Project management can justify investments up to this amount in technology, engineering, and marketing R&D in advance of the launch. In this case, the project engineers and market analysts need \$100 M in R&D funds today. Because the real-option value exceeds the initial R&D expense request, the project manager should approve the R&D portion of the project and fund this initial effort; see Table 6.[14] These funds will enable the engineers to advance the necessary technology to a state of readiness in preparation for, and effectively reducing the uncertainty of, the launch decision. Marketing analysts will be able to survey customer interest in the air freighter to gauge market interest further reducing uncertainty. Contrast this result with that of the NPV approach which would terminate the project even before initiating the R&D effort. The NPV approach fails to justify strategic investments, which leave us unprepared should the plausible but lower probability market opportunity actually materialize.

There is an intuitive understanding of real options, which is useful during those multi-scenario strategy discussions. An estimator for the real-option value can be expressed as a function of successful launch outcomes in the following formula:

$$\begin{aligned}\text{Real-Option Value} &= \text{Risk-Adjusted Success Probability}\\ &\quad \times (\text{Operating Profits} - \text{Launch Costs})\end{aligned}$$

For example, in Figure 8 the risk-adjusted probability of success is 39%, and the appropriately discounted mean net profits value (operating profits − launch costs) of the successful outcomes is ∼\$0.49 B. Using these values in the above formula produces a real-option value of the project given its contingencies:

$$\text{Real-Option Value} = 39\% \times (\$0.49\text{ B}) \approx \$190\text{ M}$$

5. Concluding Thoughts

Much of the value of real options resides not in the actual calculation of the option value, but rather in what is termed "real-options thinking." Because options are a critical but as yet not well articulated way of how project managers conduct their decision-making process and implement project planning, applying real-options thinking provides a welcome structure to scenario discussions. The real-options planning, approach contrasts with that of NPV-driven planning, which tends to commit large dollar amounts up front to a single course of action.

The value of a real option-driven approach to project planning is tied to two key factors—an initial investment directed to uncertainty reduction followed by a contingency-based

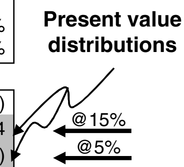
[13] The overscore bar in the equation represents a distribution—formally a random variable—of the discounted cash flows at time 0.

[14] The air-freighter project option can be purchased for \$90 M less than its real-option value, a good deal for the shareholders. The engineers' ability to solve aviation challenges with a high degree of efficiency is a competitive advantage, which allows the corporation to "buy" the air-freighter option below market value.

Table 6. Air-freighter project value using real options.

Discount rate assumptions	
Project risk rate	15.0%
Investment rate	5.0%

DM real-option calculations	($M)
PV_0 operating profits	$734
PV_0 launch costs	($1,728)
Project payoff	$0
Project option value	$190
R&D expenses	($100)
Total project RO value	**$90**



course of action. The first factor in the real-options-driven planning is targeting the small (relative to the launch cost), risk-averse investment toward engineering and marketing initiatives that reduce uncertainty prior to the launch commitment. The net result is at the downstream decision point of the irreversible launch investment, the project manager will be able to better determine which project scenario (optimistic, most likely, or pessimistic) is being born out in reality. Once the path or scenario is identified, there is a contingent course of action associated with the scenario that preserves the original intent of the option valuation; see Table 7. If the pessimistic scenario is actualized, then conserve the substantial launch-cost investment, terminate the project immediately, and perhaps sell off any derived patented assets. If it is the optimistic scenario, then invest the launch cost and garner the expected operating profits. If the actuality is the most likely scenario, then it may be worthwhile to delay the launch, perhaps invest additional R&D funds to preserve the opportunity and attempt to reduce the uncertainty further in order to make a clear decision at a later date.

Distinguishing between strategic and tactical investment decisions provides further rationale for using real options. Strategic decisions involve an investment commitment that is risky because the benefits are uncertain and because resources are allocated and information acquired ahead of the decision. Having the option to cancel the project if warranted significantly reduces the corporate exposure to the launch investment decision risk. This risk-lowering practice enables companies to take on smaller, higher-risk but potentially higher-return projects while maintaining fiscal responsibility. In comparison, tactical decisions are made by fully committing whatever resources and information are on hand at the decision moment. The launch commitment at Year 3 is a tactical decision, where the substantial investment is irreversible and—without the benefit of prior R&D—largely uncertain. A simple NPV analysis is typically used to help make tactical decisions, but generally is not appropriate for strategic decisions that involve phased investments made under uncertainty.

Real-options methods work for strategic decisions because of their ability to simplify and manage complex investment problems. It is 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 remain 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 scarce

Table 7. Course of action at launch date contingent on scenario outlook.

Scenario	Contingent course of action at Year 3
Pessimistic	Terminate program
Most likely	Delay launch, additional R&D investment
Optimistic	Launch immediately, receive operating profits

investment resources on those truly promising opportunities. The DM method simplifies the calculation behind this strategy.

Business Engineering

Historically, business managers tend to throw their needs, including financial goals, "over the wall" to systems engineering in the form of a requirements document. However, what is really needed, is a working relationship between business and systems engineering. Technology, products, and services are best designed with a strong understanding of the business process context. A concurrent business-engineering practice is one in which engineering and business work jointly to simultaneously design both the business process and the technology solutions to support it. Such a practice enables a dialogue around and trade-off between business and technology considerations, fostering greater levels of innovation and optimization. Business engineering applies advanced investment and risk modeling and simulation technologies to trades of system-engineering performance and business objectives to support key strategic decisions (see Appendix IV).

Business engineering helps determine optimal solutions to system performance, cost-effective product design and production, and business objectives. Risks are elicited by simulation trade-study models, which provide project management with key insights to control identified risk drivers in a staged process of project development. The methods and tools used in business engineering, algorithms such as uncertainty modeling and real options, provide a mathematical foundation for a scientific and "engineering-like" approach to risk identification and quantification of impact. The methods enhance the level of engineering managers' confidence in risk reduction through targeted allocation of risk mitigation and reserve funds. The resulting approach closely reflects how savvy project managers already flexibly balance technology and cost, and schedule risks and opportunities.

Appendix I: DM Method Extensions

The simplest DM method extension is the conversion to an Excel logic function.

$$\text{Real-Option Value} = \text{Mean}\{\text{if}[(\overline{\text{Operating Profits}} - \overline{\text{Launch Cost}}) > 0, \\ (\overline{\text{Operating Profits}} - \overline{\text{Launch Cost}}), 0]\}$$

Part of the advantage of the logic formula is improved clarity of the real-option valuation. Additional advantages can accrue to business analysts that would prefer to capture the intuitive appeal of logic for strategic business decision but also realize that "operating profits" and "launch cost" could be modeled by fairly complex spreadsheet scenarios. For example, operating profit volatility can be more accurately modeled by integrating a model of a dynamic demand curve and production uncertainty.

There are additional options within the DM method framework. For example, launch cost, which in the example above is a range value (a type of option termed *variable strike*) can also be a fixed cost. A fixed cost (termed a *strike price*) is the most common type of financial option. Another example is an exit option either to license or sell the technology developed, e.g., for \$50 M, in the event the project is terminated. The value of the terminated, unsuccessful project is therefore \$50 M, not \$0. Combining these two options, the spreadsheet formula for the complex project option becomes:

$$\text{Real-Option Value} = \text{Mean}[\text{MAX}(\overline{\text{Operating Profits}} - \text{Launch Cost}, 50)]$$

A project type that frequently arises at Boeing is a fixed-price government-project bid where the uncertainty is the one-time cost of the system. In this case, the traditional option variables are reversed with the benefit being a fixed value. The DM method is able to calculate the option value of the bid opportunity.

$$\text{Real-Option Bid Value} = \text{Mean}[\text{MAX}(\text{Bid Price} - \overline{\text{System Costs}}, 0)]$$

The option types above are termed *call options*, meaning investing in an opportunity that potentially will pay off if there is an "upside" increase in value. There is another option type termed the *put option*, which is an option that will potentially pays off if there is a "downside" turn of events. Insurance is a type of put option, where in the event of a loss, a policy holder receives a pay out from his/her insurance company. Another type of put option commonly used in a business environment is a service guarantee, such as customer service agreements (CSA), or, for expensive leased assets such as cars and airplanes, a residual value guarantee (RVG). Put options often are used in contingent clauses in contracts to tailor the value to the performance risks of the contract. Put options are also the basis for hedging strategies in which an option investment premium is paid to purchase a guaranteed protection level (a "deductible" in consumer insurance) in the event of a worst-case loss outcome. The DM method is easily extended to value a put option as follows:

$$\text{Real-Put-Option Value} = \text{Mean}[\text{MAX}(\text{Guarantee Cost} - \overline{\text{Loss}}, 0)]$$

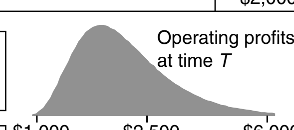
Appendix II: Comparing the Dathar-Mathes Method and the Black-Scholes Formula

The DM method can be shown to be mathematically equivalent to the Black-Scholes formula given certain assumptions. These two are mechanically different representations of the same underlying economics. Table A.1 illustrates a very simplified, but typical discounted cash flow (or NPV) analysis set up. The DM method[15] uses the distribution of forecast

Table A.1. Black-Scholes compared to Datar-Mathews method.

($M) Year	0	1	2	3	…10
Operating profits				$2,500	
Investment				$2,000)	

Time (t)	3
Risk-free rate (R_f)	5.0%
Discount rate (R_r)	15.0%



Operating profits	
Mean	$2,500
StdDev	$1,000

Black-Scholes formula		
PV_0 Asset (S)	$1,594.07	=EXP(-Rr*t)*(Mean)
PV_0 Exercise (X)	($1,721.42)	=EXP(-Rf*t)*Investment
Sigma	22.2%	=SQRT(LN(1+(StdDev/Mean)^2))/SQRT(t)
Option value	**$194.50**	=Nd_1*S-(Nd_2*(-X))
d_1	−0.01	=(LN(S/(-Investment))+(Rf+0.5*(Sigma^2))*t)/(Sigma*SQRT(t))
$N(d_1)$	0.50	=NORMSDIST(d_1)
$N(d_2)$	0.35	=NORMSDIST(d_1-(Sigma*SQRT(t)))

D-M method		
PV_0 Asset (A)	$1,594.07	=EXP(-Rr*t)*OpProfits
PV_0 Exercise (X)	($1,721.42)	=EXP(-Rf*t)*Investment
Payoff	$0.00	=MAX(A+X,0) or IF((A>-X),A+X,0)
Option value	**$194.50**	=Average(Payoff)

[15] Datar-Mathews formula: $C_0 = E[e^{-\mu t}\bar{S} - e^{-rt}X]^+$, an expectation formula where $\bar{S}$ is the random variable for operating profits, μ 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.

cash flows to calculate the option value, whereas Black-Scholes[16] uses a value of sigma σ. Further, the DM method implicitly adjusts the discount rate to account for the underlying risk. The option value is easily understood as expected pay-off resulting from rational exercise decisions. The DM method provides a better estimate of option value when the strict theoretical assumptions of Black-Scholes are compromised in real life. For example, the DM method can easily deal with triangular (non-lognormal) cash-flow distributions and random exercise price.

Appendix III: Comparing Financial Options and Real Options

The history of options is quite colorful and surprisingly a lot longer than most people think (Chance [2]). Although it is not known exactly when the first option contract traded, the Romans and Phoenicians used contracts similar to options in shipping. In Holland, trading in tulip options blossomed during the early 1600s. In 1670, the Royal Exchange in London became the first exchange for trading options. In the United States, the Chicago Board of Trade (CBOE) began exchange trading in 1848. CBOE estimates that in 2006 it traded more than \$15 trillion in options, a value larger than the U.S. economy. Fischer Black and Myron Scholes first published an option pricing model in 1973. The term "real option" was coined a few years later by Professor Stewart Myers of MIT.

Real options are derived from the mathematics financial options and practices of options trading in the options markets. Here is a brief comparison of the variables:

Financial options	Real options
Usually exchange traded	Not usually traded
Contract with contingencies	Strategy with contingencies
Underlying is a stock	Underlying is a product/project
Premium payment	R&D investments
Strike or exercise price	Non recurring investment
"Exercise" an option	Commitment to production or bid
Time to exercise	Time to commitment
Payoff is stock or cash	Payoff is product operating profits
Variance of stock (sigma)	Variance of operating profits
Mathematics correctly prices contingent investment securities	Mathematics correctly prices contingent investment strategies

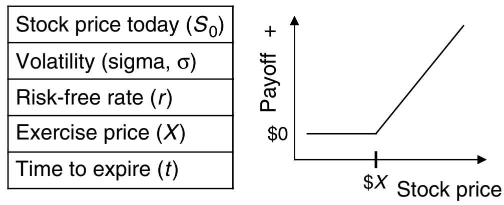
The most simple option is a so-called European call option that can be exercised only on a specified date. The option value is calculated based on five parameters, four of which are known, the exception being the volatility parameter. The option contract specifies the exercise price ($\sim$ \$2 B for the air-freighter example) to purchase the stock. Should the stock price on the exercise date t exceed the exercise price, then the option is "in-the-money." The option holder can either purchase the stock at the exercise price or settle for a cash payoff, the difference between the current stock price and the exercise price. If the stock price falls below the exercise price on date t, then the option expires and the payoff is \$0; see Figure A.1.

Appendix IV: Extensions to Systems Engineering

The launch cost can be simply modeled as a triangular distribution with Min-Most Likely-Max range values of \$1,500 M, \$2,000 M, and \$2,500 M, respectively. In reality, the launch cost is comprised of many cost elements, and each element having a range estimate. In order

[16] Black-Scholes formula: $C_0 = S_0 N(d_1) - Xe^{-rt} N(d_2)$, where $d_1 = (\ln(S_0/x) + (r_f + \sigma^2/2)t)/\sigma\sqrt{t}$ and $d_2 = d_1 - \sigma\sqrt{t}$.

FIGURE A.1.



to better estimate the true launch-cost range a more detailed launch "cost risk" model is constructed; see Table A.2. The estimates of the cost elements are correlated to a physical system engineering design variable (Max Take Off Weight, MTOW), which itself is a range estimate. Similarly, a MTOW detailed system "engineering risk" model could be constructed using comparable concepts, but related to performance instead of business.

TABLE A.2. Launch-cost risk estimate detail.

Nonrecurring cost/ risk estimate System engineering element	Simulation distribution	Range estimate			MTOW correlation
		Low	Most likely	High	
Max take off weight MTOW (lbs)	195,000	125,000	195,000	245,000	—
Structures	$760,000,000	$500,000,000	$760,000,000	$825,000,000	0.65
Systems	$695,000,000	$545,000,000	$965,000,000	$965,000,000	0.45
Propulsion integration	$130,000,000	$85,000,000	$130,000,000	$165,000,000	0.20
Manufacturing operations	$190,000,000	$100,000,000	$190,000,000	$245,000,000	0.20
Certification and testing	$135,000,000	$125,000,000	$135,000,000	$250,000,000	0.25
Marketing and overhead	$90,000,000	$50,000,000	$90,000,000	$125,000,000	0.10
Total nonrecurring cost/risk	$2,000,000,000				
Cost risk mean	$1,993,331,574				
Cost risk Stdev	$147,314,693				

A simulation creates the launch-cost distribution; see Figure A.2. The distribution statistics, mean and standard deviation, enable us to create a launch-cost lognormal distribution that more accurately captures the launch-cost range estimate. However, the superimposed triangle approximates the simulation distribution and can be applied, e.g., to a less complex model, such as in Table 5, without material impact on analytical results.

FIGURE A.2. Launch-cost detail distribution.

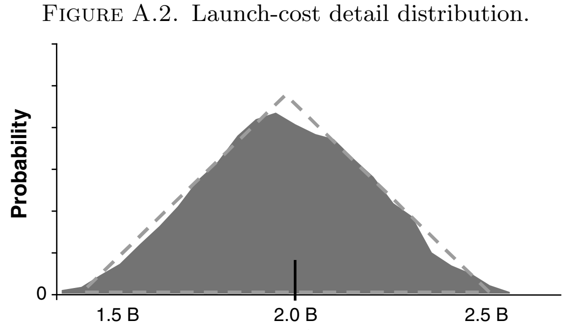
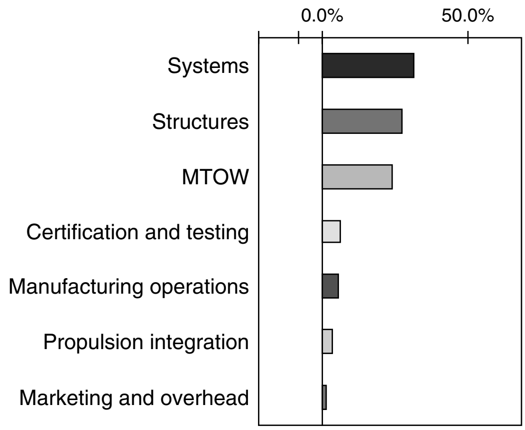


FIGURE A.3. Launch-cost elements sensitivity (contribution to variance).

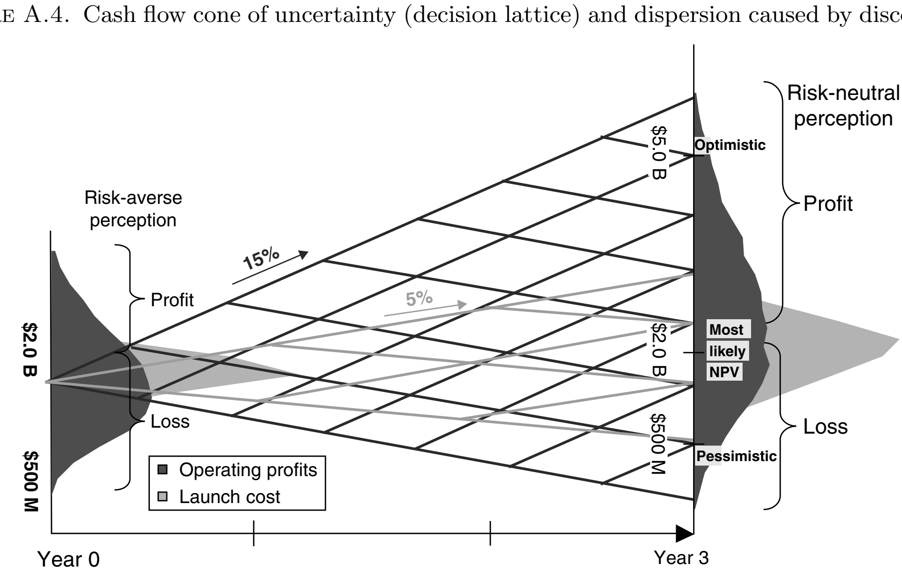


Monte Carlo simulation software provides a sensitivity analysis showing those elements that most contribute to the launch-cost variance (Figure A.3). The principal launch-cost risk drivers are systems, structures, and MTOW. Therefore, much of the $100 M requested R&D funds ought to be directed toward reducing risk and uncertainty in these areas.

Appendix V: The Big Picture

Why do the "success" probabilities in Figure 5 and Figure 8 differ? Figure 5 illustrates the risk-neutral probabilities at Year 3, whereas Figure 8 illustrates the risk-averse probabilities at Year 0. At Year 0, the manager may be quite risk averse because $100 M, a substantial sum of money, is to be invested well before the launch opportunity is viable. This risk aversion translates into a perceived reduction in the chances of success. The DM method implicitly adjusts the probabilities to account for risk aversion by appropriate use of differential discount rates. The intent of the $100 M investment is to resolve a number of the project risks. With some of the uncertainties literally behind by Year 3, launch prospects can be examined in a less risky framework and will have a different perspective on the success rate. At that

FIGURE A.4. Cash flow cone of uncertainty (decision lattice) and dispersion caused by discounting.



time it can determined whether the project meets the 15% required rate of return on the investment of the $2 B launch cost; see Figure A.4.

One can argue that the Year 3 outlook will change because of the $100 M investment and the resulting learning. Of course, the model simply attempts to value the project today given the best projections of the future. However, the project outlook should be updated as risks are mitigated and there is a better understanding of the market. At each funding period, or stage gate, the worthiness of the project should be updated with this new information. A more sophisticated multistage model sets expectations for risk reduction and value enhancement contingent on funding.

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