# Opportunity Engineering

# (Real Options)

We define an opportunity as a set of possible events whose outcomes are uncertain and that have a range of consequences we can affect through an investment or action.

In the world of investment trading, financial options fit this definition. A financial option is a contract that provides its holder the right to purchase a stock at a specific (strike) price at a future date. If the price of the stock at that date is higher than the strike price then the option holder can exercise the option and sell the stock for a profit. Such a contract has value. Loosely, its value is the expected present value of the profit gained from exercising the option when the future stock price is greater than the options strike price.

Determining an opportunity's value is, of course, central to its intelligent use. Robert Merton and Myron Scholes, received the 1997 Nobel Prize in economics for developing with Fischer Black the mathematical solution to the option valuing problem, the Black Scholes formula. The use of that formula and the theory behind it has allowed the options market to blossom in this past decade.

The source of an option’s value is derived from the change in information about the stock price between the time that the option is purchased and when it is exercised. In the stock options case, the future stock price is only partially known at the option purchase date, while at the option’s exercise, the stock price is fully known. This information change coupled with the choice of exercising the option produces its value. In the charts below the stock price has a lognormal distribution with a mean of $10.00 and a standard deviation of $2.50. With an option strike price of $10.00, the option contract has a value of $1.44.

The chart to the left depicts the distribution of future stock prices at the time of the stock option's purchase. The chart to the right shows the distribution of stock prices

greater than $10.00, the strike price, at the time of option exercise. By exercising the stock option when the stock price is higher than its strike price a return is generated.

 Program Termination Option

We can apply the financial stock option concept to a project investment by considering the option's stock price less its strike price to be equivalent to the project's cash flow. Such an application is called a real option. The "option" in both the financial and real cases is to choose to, or not to, exercise the follow-on investment at the exercise date. At the stock option exercise date, the decision to exercise is easily made. It depends only on the stock price at that time and the strike price. For the project option, the decision is more difficult. First, it is not a single decision, but rather a sequence of investment continuation decisions, followed, possibly, by an irreversible program termination. Second, the Net Present Value (NPV) merit depends, not on a known payoff, but rather on an uncertain cash flow, to be realized, perhaps, many years into the future. These additional issues create a more difficult decision problem.

With a partially unknown future NPV, a decision to continue investing must be based on an estimate, an estimate that is in error at least to some degree. If, for example, the decision terminates a program whose future NPV would have been positive, not only will that fact never be known, the program's positive NPV will not be realized. Conversely, if the decision continues a poor program to the next gate the additional investment is, in a sense, wasted. However, despite the additional decision complexity and estimation uncertainty, an expected NPV profit maximizing solution is possible. By employing the principle of Dynamic Programming[[1]](#footnote-1)• the optimal sequence of decision criteria can be efficiently determined from all possible such sequences.

The NPV of the future cash flow is, of course, a problem of estimation. For a well-planned project, the continuing investment produces information relevant to predicting the program's future cash flow, e.g. the product is designed in increasing detail, its scheduled milestones become history, its number one cost is realized, etc. As these events take place, the future cash flow can be more accurately predicted and thus better decisions made. However, the estimation improvement is gained at a significant cost, the cost of continuing program investment. Thus the statistical efficiency of the estimation method in transforming cost history into information relevant to the prediction of its future cash flow can, by impacting the decision, significantly contribute to the program's expected NPV and success.

Consider a project with the option to be terminated without penalty. The project is a low earth orbit commercial communications satellite constellation. The optimization problem is to: Create a plan and a sequence of termination criteria that maximizes the expected NPV of its cash flow at the appropriate risk-adjusted discount rate[[2]](#footnote-2)\*. The project's cash flow uncertainty results from both uncertain revenues and expenditures. The expenditures are generated by a combination of uncertainties. The cost of the design and manufacture of the satellites is uncertain. It is of a new design with state of the art technology and has not been manufactured before. The vehicles to launch the satellites are fixed price, but their potential loss due to launch failures generates some launch vehicle and satellite quantity uncertainty. Further, design progress, satellite manufacturing completions, and launch failure recovery delays, cause the revenue inception date to be variable. The revenue price parameter is also uncertain. The communication constellation's intended market is currently unaddressed, and consequently, there is considerable uncertainty in the eventual price of service and thus the revenue stream. The program, having recognized this, has assigned a team to resolve the revenue parameter's uncertainty. The evolution of the revenue parameter estimate is seen below in the price evolution chart.

To examine the ramifications of a termination option on this project's NPV a thousand scenario simulation was executed. Below are graphs of expenditures, the revenue parameter, and the NPV of cash. Both a sample and the expected value are shown.

Cost - Expected Value and Variation:



Revenue - Price Expected Value and Variation:



Combining the cost and revenue and discounting the resultant cash at the appropriate risk rate we have on the left fifty of the thousand discounted cumulative cash flow scenarios. To the right the cumulative expected NPV cash stream.



The graph to the left shows the net present value of each scenario's cash flow as it evolves in time. The NPV for each scenario can be seen at the 2011 date. The expected NPV cash flow is shown on the right. It is positive, at $268M, and has a return on investment rate of 17.6%. From the scenario chart it can be seen that many of the cases making up the expected value have a negative NPV. If they could be terminated with a low sunk cost the expected value would increase.

A more detailed examination of the cash flow scenarios illustrates a problem.



The cash flow cumulative NPV outcomes are not completely predictable from the early stages of investment. Even if the termination decision were delayed into 2004 we find that some of the extreme low value NPV states turn around and become good programs. Also, from the chart it can be seen that any program continued much beyond January 2003 has a positive balance-to-go NPV. (The difference between the cumulative value in January 2003 and that at 2011 is the balance-to-go NPV.) Thus a decision to cull a negative balance-to-go NPV scenario must be made before that date.

The financial objective is to improve the expected value of the plan's NPV. The expected value is of all scenarios, both those that are completed and those terminated. Thus, it is advantageous to terminate bad programs as early as possible, minimizing their sunk cost. However, making the decision early with relatively less NPV relevant information risks terminating what would otherwise be a successful program. Making the decision late, risks continuing expenditures on a program that will ultimately be unprofitable. Creating the best plan requires that both the balance-to-go estimate maximize NPV relevant information and that the NPV information be utilized in an optimal decision procedure.

For the purposes of this illustration, program reviews are held at 6-month intervals. At each review, a prediction, by a multiple regression, of the at-completion program NPV is made. The regression uses as independent variables the cumulative cost and revenue states at the review point. From these predictions and the dynamic programming algorithm, an optimal termination criteria sequence is determined.

Below are scattergrams of 1000 estimated versus simulated balance-to-go NPVs at four review points.





At 6/2001 the multiple regression predicts for each scenario a NPV of $262M, while the simulated NPVs range between -2B and +7B, hence the vertical scatter. At this point, the regression provides no information distinguishing between the good and bad program scenarios. The cross correlation between simulation and estimate is only .008. In 6/2002 the situation is much different. The correlation is .375 and increases to .77 in December 2002. Thus a program termination decision based on the NPV estimate in June 2001 has a 50-50 chance of being in error, while a decision in December 2002 is likely to be correct.

Below is the initial state of the program, January 2000, followed by its state after each program review.



By including the option to terminate, the program's NPV is increased by 13.9%, or $37M. This improvement includes the sunk cost of terminated programs. Two-thirds of the terminations occurred on or before June 2002, within two years of the program's inception. In the following 6 months, an additional 7.2% are terminated with 79% of the scenarios surviving thereafter to program completion.

In summary, if a program plan has the option to be terminated, includes cash flow NPVs that are potentially negative, and those cash flows can at least be partially predicted as the program is executed, then the program has an option value. That value is a consequence of the termination option plan and is properly part of the plan's financial assessment. Of course, not all option plans have the same value. A plan's option value can be used to distinguish the better plans from the worse. Issues of estimation accuracy, planned program review dates, and the timing of the development of information relevant to the at-completion NPV, can be examined and utilized to design better and potentially more successful program plans.

Program management has other options available to it. The remainder of this paper will address two of them.

 WBS Sequence

The developmental phase of a program can be viewed as an effort to create the information and the associated decisions necessary to produce a successful program. Alternative timings of uncertainty resolving activities can impact NPV predictions and, through the termination decision criteria, the expected program NPV. Some of these timing alternatives may be substantially better than others. By evaluating a range of plans for a key NPV-related developmental activity the better plans can be identified. For the low earth orbit satellite communications example modeled in this paper a major determinant of its financial success is the revenue received for the communications service. In the simulations discussed a market analysis group produced a service price estimate evolution culminating in the simulation’s revenue stream. Since this revenue stream is a major contributor to NPV variation, its early and accurate prediction could have a significant effect on the expected NPV. However, such a better and earlier price estimate may require an earlier investment in the market analysis activity or a larger investment.

To determine the value of an alternative phasing of market analysis activity, the simulation was rerun twice, first with the market analysis effort scheduled one year earlier and second with it one year later. The simulation with the market analysis one year later is intended to describe a program plan that waits for the market response to the delivered product to determine its price, while the earlier determination simulates a plan requiring, for example, a small-scale market experiment. The price estimate evolutions and the NPV cash flows are shown for these simulations below.

Market analysis beginning June 2000.



Market analysis beginning June 2001



Market analysis beginning June 2002



For the three simulations, all parameters other than the phasing of the market analysis activity were held constant. As a result, the three cash flows are nearly identical. A close examination reveals that the program with the earlier phased market activity has a slightly larger early cumulative investment than the others.



The relationship between estimated BTG and simulated BTG differs between alternative plans. The early plan has more revenue-related information available for use in the BTG estimate, early on, than the other plans. Thus, the ability of the estimator to predict the program's eventual NPV with lower levels of sunk cost is increased.

The scattergrams of actual versus estimate for the three plans are shown below.



As can be seen from these scattergrams the revenue-related information in the early plan allows the estimator to predict the program's eventual BTG NPV significantly better than the later plans. This earlier prediction of BTG NPV allows this plan to cull poor scenarios sooner.

The survival statistics for the three plans:

The early market analysis plan.



The base line market analysis plan.

The late market analysis plan.



The earlier market analysis in conjunction with the termination option increased the NPV by $218M over a plan without terminations, this is $185M NPV more than the baseline plan with terminations and $198M NPV more than the late market analysis. This improvement, over the baseline plan, was realized by the termination of an additional 19% of the initiated programs, most of those by December 2001, 6 months into the program's primary design effort. The NPV preference of the early market analysis plan would exist even if the resources expended on it were increased by up to the $185M advantage it holds.

Thus the relative timing of resource expenditures, in this case, the market analysis activity, can have a significant effect on the plan's NPV. The evaluation of decision options, not only removes a possible understatement of the plan's NPV, but also provides the financial evaluation necessary to distinguish the better and more competitive plans from the poorer ones. The implementation of better-planned programs increases their value and likelihood of success.

Design Options

Decisions made between alternative design options are a fundamental part of the developmental process. The traditional engineering risk mitigation planning process creates plans to reduce the negative consequences of high-risk events on product performance. Often these plans are held in reserve in anticipation of the negative event, while in other cases the risk mitigation plan resources are expended in parallel. In either case, the focus is on the mitigation of a small number of significant negative events. The failure of a hardware component has a different impact than do cost or schedule deviations. For the integrated systems of the aerospace industry, component failures tend to generate a complete system failure to a greater degree than, for example, the failure of a 2X4 wall stud. The mitigation of the cost and schedule consequences of these few catastrophic events is critical to the success of an aerospace program. Thus the importance of risk mitigation planning to the aerospace development process. In contrast, the option paradigm includes all consequences, both those for the worse and those for the better. It seeks to distinguish the good from the bad as early as possible and exercise the option to choose the better course. Well-planned design options can thus yield value.

To focus on the design issue and avoid the additional simulation scenarios needed to stabilize the results, the constellation's revenue is included but without variation as in the preceding studies. The satellite's design is made up of ten activities: power, structures, command and control, thermal control, payload, antenna, systems engineering, solar panels, and price. For the purposes of this illustration, a power system design alternative is modeled. The power system, at 100 pounds, comprises a comparatively small proportion of the satellite’s total satellite weight, 1050 pounds. An alternative power system design activity is also planned, its weight's expected value is 80 pounds. The alternative requires technological advancement. The outcome of that advancement is described by the uncertainty in both the cost and weight estimates. The estimate's standard deviation, about the 80-pound weight, is 40%, while the "mature" technology has a standard deviation of only 10%. A choice is to be made between the two designs one year into a planned two-year developmental effort. If the advanced technology's estimated weight is 10 pounds less than the mature approach, at the time of the decision, the advanced approach ss implemented and the mature technology effort is canceled. Otherwise, the advanced approach activity is canceled.

The following charts show a sample of the evolution of the power system's weight for the mature technology independent of any advanced power system activity.



In contrast, the following charts show a sample and the expected value evolution of a program plan with both the mature and advanced power system design activities and the option to choose between them.



In this plan, a decision is made in June 2002 to continue only one of the design activities. Those mature technology activities with weight statuses of more than 10 pounds over the advanced approach at the decision date are terminated, with the corresponding opposite decision taken for the advanced activity. Examining the charts, we see that some of both mature and advanced technology activities end in June 2002. From the expected value chart to the right, we see that the decision to select the lower-weight alternative design causes the average weight of the mature technologies to be lower than their average would be without the advanced technology design option. The decision process culls out mature technology scenarios when their weight migrates upward more often than when they migrate downward. Similarly, the mean of the advanced technology weight is reduced. Due to its greater uncertainty, the reduction is substantially greater. Also, the average for all program scenarios dropped some 25 pounds. This drop is greater than the reduction in weight that would have been expected, 20 pounds if the advanced technology approach had been chosen initially and the mature design effort had not been carried on in parallel. In practice, this effect might be attributed to competitive motivation. These results are, however, due solely to the options process.

Other design option plans can be examined. Making the decision earlier, but with the same resource plan, would reduce the "wasted" effort incurred by carrying on both design activities so far into the program. Also, the decision's impact on other integrated design and manufacturing efforts would be lessened with an earlier decision.

The following charts show the evolution of the power system weight for the two design efforts, with choice made in December 2001, 6 months earlier than above.



For this option plan, the program average drops 19 pounds, 6 pounds less than making the decision 6 months later. On the sample chart, we see that some of the advanced technology scenarios chosen for implementation migrate upwards approaching the 100-pound average of the mature technology. These events occur because at an earlier date less is known about their eventual weight and thus mistaken decisions are made. Also, notice that the expected values of both technologies are higher with this earlier decision than with the decision taken six months later. Although the advantages of the advanced technology solution exist independent of the accuracy of that knowledge, as this example shows, there is merit to expending the effort to firm up the advanced technology design prior to making the selection.

The following charts show the evolution of the power system weight for the two design efforts with another option plan. In these scenarios, the decision is made, as above, in December 2001, but the advanced technology effort is pre-implemented, 6 months earlier than the remainder of the program. This case begins to simulate the merits of an IR&D program.



For this plan, the program expected value drops by 23 pounds, close to the reduction realized in the original plan. An examination of this sample chart shows that some of the chosen mature scenarios migrate upwards above the 100 pound expected value. These events occur because at the date of this decision less is known about the mature technology's eventual weight, and so, choices to implement it are more often in error. This plan, pre-implementing the advanced technology activity, yields results close to the original approach but with increased expenditure on the advanced technology and a lower expenditure on the mature technology.

The termination option, the phasing of uncertainty resolution activities, and the timing and effort applied to alternative design options are each program management activity potentially crucial to the success of a developmental aerospace program. These examples illustrate the role the option paradigm can play in the successful planning and management of such programs.

1. • Bellman's principle of Dynamic Programming, dynamic programming methods assume the principle of optimality, each part of a globally optimal solution is itself an optimal solution to its corresponding partial problem [↑](#footnote-ref-1)
2. \* The appropriate discount rate is related to the systemic risk of the class of investment. Systemic risks are those not diversifiable by an investor. For many real investments the systemic risk level is low because the investor can eliminate them by diversifying his portfolio. [↑](#footnote-ref-2)