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**Options Theory as a Framework
for Decision-Making in R&D Investments**

by

H. Bruce Lounsbury, B.Sc.Hons.(Eng), P. Eng

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of:

MASTER OF MANAGEMENT STUDIES

Carleton University,
Ottawa, Canada.

April 21, 1992.

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for Decision-Making in R&D Investments"**

submitted by H. Bruce Lounsbury, B.Sc.Hons.(Eng), P. Eng.
in partial fulfilment of the requirements for
the degree of Master of Management Studies

Thesis Supervisor

Director, School of Business

Carleton University

May 21, 1992

Abstract

If North America is to retain or, in many cases, regain its competitiveness in world markets it is important to be able to effectively evaluate and undertake long range projects such as Research and Development. The similarity between R&D and stock market options may provide the basis of an evaluation tool that will improve our ability to examine these types of expenditures. It is hypothesized that by considering long term opportunities, such as R&D, as methods of creating strategic options for the company, representation of the true value of these opportunities will be obtained. Several authors have described the theoretical link of options pricing and the evaluation of long range investments. The research in this thesis tests that link empirically by building and testing a decision making aid based on the option analogy for use in evaluating R&D opportunities in the petrochemical business. It is found that the construction of a decision support tool using the options framework is possible and that the necessary information and resources to use the tool exist within the company under study. The results of the analysis of R&D programs in this manner provides new and useful information to the company, especially in the area of sensitivities of the R&D program's value to changes in different input parameters to the evaluation. It is also found that significant education and training of management

and staff of the organization would be necessary to implement this tool within the company under study because of the newness and relative complexity of the concepts employed.

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I also want to thank my wife Susan for her help as expert chart and figure drawer, proof reader and listener. Her support has not only improved this thesis but made the whole two years of my return to the academic world possible.

Statement of Confidentiality

For reasons of confidentiality, the names of its representatives and technical details of the R&D programs examined have been excluded from this thesis. The information obtained and the results from the research has not been altered by these exclusions.

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The Options Analogy as a Framework for Decision-Making in R&D Investments

1.0 Introduction

Adequate commitment to research and development is vital to the long range success of most businesses and industries. It is through the development of opportunities for the future that long term success can be obtained. In their landmark article "Managing our way to economic decline", Hayes and Abernathy (1980) argue that a reduced commitment to R&D is both a cause and a symptom of North America's failure to remain competitive in world markets. Hayes and Abernathy contend that much of the blame for this should be put on the management and evaluation techniques employed by modern North American managers; techniques that favour quick pay off and short term projects.

Mitchell and Hamilton (1986) characterize two evaluation techniques that are currently used to justify R&D expenditures; strategic justification (necessary cost of business, corporate positioning) and discounted cash flow. Both of these techniques are shown to have weaknesses when evaluating R&D expenditures in competition with other business opportunities. Modification of net cash flow calculations through the use of decision trees and Monte Carlo simulation have been proposed but although these techniques have been available for over 25 years, they have not come into common

usage for R&D evaluation (Kester 1984). As Kester points out this is likely because even for simple evaluations, these techniques require an unwieldy number of cases to be calculated making them impractical for normal use.

To this list should be added a developing group of hybrid evaluation techniques such as multi-attribute analysis and calculation of cost of intangibles. With these methods both tangible (numerically quantifiable) and intangible costs and benefits are detailed and then compared using weighted scoring systems or by a subjective valuation of intangible items. Two weaknesses are apparent in these techniques. Firstly they are subjective and can be manipulated by the user to produce results that reflect the user's opinions (Gerwin 1990). Secondly, they are effective for comparing similar projects but are less reliable when evaluating dissimilar projects or when comparing against projects with traditional discounted cash flow calculations such as conventional operating investment opportunities.

In light of the weaknesses in the existing techniques, Mitchell and Hamilton (1988) present the concept of viewing R&D investment as a method of creating options for the company. Their analysis illustrates the similarity between stock options and R&D programs and encourages managers to view R&D in that context. R&D commitments, unlike operating investment opportunities, are not expected to create positive value on their own; rather they create the opportunity to make

further investments in the future, investments that may generate positive returns. Like a stock market call option that entitles the holder the right (not the obligation) to acquire an asset in the future at a fixed price, R&D gives the company the option to invest in the future to operationalize new technology if conditions at the time warrant the investment. The fundamental feature of R&D investments that can be captured by regarding them as options is that decisions to optimize the outcome will be made in the future when more is known about how events may unfold. This is in contrast to traditional evaluation techniques that require the investor to make forecasts of future events and to chart a course of action based on these forecasts. The option analogy provides the investor with a skewed set of potential outcomes where decisions can be made to take advantage of favourable future events and the investor's exposure can be limited for unfavourable outcomes, improving upon his or her potential value.

The analogy between R&D expenditures and stock market options is further supported by a sensitivity analysis involving several external factors. As is outlined in Figure 1 (adapted from Mitchell and Hamilton 1988), R&D programs are affected in similar ways as options when changes are made in underlying factors that affect their value. The purchaser of call option has a maximum down side risk of the price of the option even though the price of the underlying stock is much

Figure 1

COMPARISON OF R&D TO OPTIONS

	Call Options	R&D Program
DOWNSIDE RISK	limited risk	limited risk
VOLATILITY	value ↑	value ↑
TIME INCREASE	value ↑	value ↑
INTEREST RATE INCREASE	value ↑	value ↑

higher. As the initial exposure in an R&D program is only the cost of the R&D, rather than the entire investment required to operationalize the technology, down side risk is known and limited to the cost of the R&D.

Uncertainty or volatility may intuitively reduce the value of many opportunities; however for both options and R&D, volatility increases the chance that more extreme favourable outcomes will result and therefore increases their value.

Longer time horizons give a larger window for favourable conditions to occur. This increases the likelihood that the option will be 'in the money' thus increasing its value. Longer time horizons also give a greater opportunity for technology developed by an R&D program to become profitable, increasing the value of the R&D.

Finally, while higher interest rates may make it appear to be more costly to undertake investments they actually can increase the value of options and R&D through greater reward for deferring the major investments into the future. This analysis provides strong support for considering R&D as a method of creating strategic options.

Mitchell and Hamilton (1988) conclude that R&D can best be viewed as a method of creating options for future investment for a company. The literature on this new approach to R&D decision-making seems to end with a description of the similarities between option purchases and investment in R&D. What this study seeks to add to our knowledge, is the next

apparent step: to operationalize the analogy by using the options analogy as a framework to value R&D programs for investment purposes. The research modifies and employs well developed options pricing theory towards the construction of a decision support tool for evaluating R&D expenditures. This tool recognizes the unique characteristics of R&D expenditures and provides output that can be compared with, and augment, traditional net cash flow calculations for investment decision making purposes.

2.0 Literature Review

Building on an analogy first drawn by Myers (1977), Kester (1984) developed the idea of viewing long range investment opportunities as options rather than net cash flow commitments. He correctly pointed out that the impact of factors such as uncertainty and interest rates influence the value of options in the opposite way than they do traditional net cash flow calculations. He also showed that many long range investment opportunities more closely resemble options than they do short term investment opportunities and encouraged managers to recognize the 'option value' of some of their projects in the capital budgeting process. An important observation that was made in Kester's analysis is that in times of high uncertainty and rising interest rates, traditional wisdom would indicate caution and reducing commitments to long range projects. Using the option analogy

we conclude, however, that this is the time to invest in option type projects as they offer the company the best opportunity to adapt to future events and maximize corporate value.

The negative reaction to the ideas of Myers (1977) and Kester (1984) often fall into two categories (Trigeorgis and Mason 1987). The first is that the option analogy adds no more knowledge than a well performed decision tree analysis. While an extensive decision tree analysis may recognize many of the potential outcomes that may exist for a proposed investment, and therefore capture much of the option value, this type of analysis would require a large number of cases to be run. Although the use of a computer application would reduce the processing time required, the cost in time and resources for data gathering and manipulation for this analysis would be large and, as Kester (1984) contends, therefore it is impractical for normal use. The second criticism is that the options analogy is too complex for practical application. There may be some element of truth in this contention but no research is cited to lend support to the argument. The area of practical applicability of the options analogy is the subject of this research and part of the findings of this work relates directly to this issue.

Authors such as Majd and Pindyck (1985), Baldwin, Mason and Ruback (1984), McDonald and Siegel (1985) and Myers and Majd (1983) use option pricing theory in considering the value

of tangible assets and in investment decisions surrounding these assets.

Brennan and Schwartz (1986) extend Kester's work by using options pricing theory to assign values to hypothetical mining operations, showing that the value of a mine, viewed as an option to produce a commodity, can be greater than the value assigned under traditional discounted cash flow evaluation. The enhancement in value arises from the recognition of management's ability to optimize the operation in the future by adjusting production to take advantage of actual conditions.

Furthering the application of valuing natural resource assets using options pricing, Mann, Goobie and MacMillan (1991) value an oil sands development (based on an actual project). They find that although the project has a expected present value that is negative and therefore is not a good investment at this time, the option to invest in it in the future is worth over 7 million dollars. For this reason the company should be willing to commit funds to research and necessary programs to keep the opportunity open.

The extension of the options analogy to Research and Development is mentioned by Kester (1984) but it is Mitchell and Hamilton (1988) who firmly link R&D opportunities to options. They compare the characteristics of both options and R&D and note that the impact of changes in external factors (such as risk and time) on the value of R&D and options is

similar. Their analysis of current methods for justifying R&D expenditures shows a need for a method that can recognize the strategic or option value of many R&D projects. While providing strong support for the use of the analogy, they do not operationalize and test the link using real R&D opportunities. It is in this niche that the research in this document falls. Building on the work of Mitchell and Hamilton, an evaluation tool based on a framework derived from the similarity of options with R&D opportunities is investigated with real life examples. Accordingly, this research should be of interest to academics seeking to refine the application of options pricing to investment decision making as well as to businesses involved in planning and evaluating R&D opportunities.

3.0 Research Problem

The research problem addressed is to develop and test the implementation of a decision-making aid based on options theory for use in evaluating research and development investments in the petrochemical industry.

4.0 Research Design

The proposed research took the form of a pilot study into the development of a decision-support tool. Existing research has highlighted the potential usefulness of options pricing theory in considering investment decisions on research and

development expenditures, but practical application of the theory has not been documented. It is therefore appropriate to conduct a pilot study in the development of a decision support tool and test its usefulness in real life applications. The support of a major Canadian corporation involved in Research and Development was obtained for this work. Testing of the model was done with the assistance of management in the corporation using real investment opportunities from the current planning cycle.

4.1 Development of the Analogy

The analogy drawn by previous authors likens an R&D opportunity to a stock market call option. To further develop the analogy and explain its application in this research, the aspects of a stock market option need to be discussed first. The features of R&D opportunities can then be explored, looking specifically at how they fit into the option analogy. The differences between stock market options and R&D opportunities can then be reviewed and the impact these differences have on the model can be discussed.

When an investor acquires a stock market call option, he or she has acquired the right to make an investment at some time in the future, to purchase a share of the stock, if and only if, the investor wishes to make the investment in the future. This investment would presumably be made if the value of the stock was greater than the investment required to

technology is made, it is assumed that it will be made using traditional discounted cash flow analysis. The expected value of the implemented technology discounted to t_2 (V_2), based on forecasts of annual net cash flows will be compared to the cost of implementing the technology (C_2). If V_2 is greater than C_2 , the company can expect to make a gain by exercising their option to invest. In this case, the value that they would assign to the option to implement the technology would be the gain that they would expect to make. If C_2 is greater than V_2 , the company would not exercise their option to invest. The value of the option to invest at t_2 is the greater of zero or the expected value of the implemented technology (V_2) minus the cost of implementation (C_2).

Prior to the time that the decision to implement the technology is made, there is uncertainty as to what the expected value of the implemented technology (V_2) will be. A forecast of V_2 , which will be called V_1 can be made at a time prior to the decision to implement. This forecast will have a distribution based on the range of possibilities for V_2 . The company will develop a current forecast of the expected value of the implemented technology based on likely forecasts of input variables which we will call the current outlook (O_1). An outlook using the most optimistic assumptions (H_1) and an outlook using the most pessimistic assumptions (L_1) will also be developed. By imposing a beta distribution on the range of forecasts, the distribution of V_1 can be

Figure 2

OPTION VALUE - ASSUMING CERTAINTY

Figure 3

OPTION VALUE PRIOR TO EXPIRY

reflects the uncertainty surrounding the stock price at expiry; uncertainty that could cause the stock price to be higher than it currently is and therefore make the option more valuable (see Figure 3). In options analysis, the movement of the stock price from its current level is considered to be a random walk consisting of small incremental increases or decreases in the price that could occur with equal probability. This leads to a distribution of possible stock prices at expiry that is normal with an expected value that is the current stock price (see Figure 4). The volatility of the stock, determined from historical price movements, provides a measure of the standard deviation of the stock price at expiry (the standard deviation of the normal curve that represents the stock price at expiry). As can be seen in Figure 5, even when the current stock price is less than the exercise price, the distribution of possible stock prices at expiry result in some outcomes where the stock price at expiry is greater than the exercise price. In these cases the investor would exercise the option and make a gain equal to the difference between the stock price and the exercise price. The possibility that this will occur and the gain that could be made if it did, form the basis for the option premium shown in Figure 3. If the uncertainty did not exist, we would know that the stock price at expiry would be the same as the current stock price and the value of the option could be calculated with certainty. The ability of the option holder

Figure 4

STOCK PRICE MOVEMENT

Figure 5

STOCK PRICE AT EXPIRY AND EXERCISE PRICE

to optimize the future decision regarding the exercise of the option, allows the investor to gain an advantage from the uncertainty in the stock price and creates the option premium.

The value of an option described above arises from two features; the stochastic nature of the movement of the price of the stock, within a certain distribution and the fact that the decision to invest to acquire the stock is made in the future when there is no uncertainty about the price of the stock.

If an investor were to consider purchasing an option, he or she would be concerned with the difference between the value of the option as described above and the cost to acquire the option (market price of the option). If the price of the option was less than its value, the investor would be motivated to acquire the option. Similarly, in evaluating R&D opportunities, we will be looking for R&D programs where the value of the options created by the R&D are greater than the cost of the R&D.

A corporation considering an R&D expenditure expects to obtain the right to certain technology that may be developed. The corporation, once it has the technology, then has the option to spend an additional amount to implement the technology (or use it in other ways) within the time that the opportunity continues to exist. This is shown on the time line presented in Figure 6. At the point in time in the future when the decision regarding implementation of the

Figure 6

TIME LINE FOR TECHNOLOGY IMPLEMENTATION

V_2 = expected discounted cashflow of implementing the technology

V_1 = forecast of V_2 made at time t_1 discounted to t_1 (a random variable)

C_2 = cost of implementing the technology at time t_2

C_1 = forecast of C_2 made at time t_1 (discounted to t_1)

distribution of V_1 is determined using:

O_1 = current outlook for V_2 at time t_1

H_1 = outlook for V_2 at t_1 . using optimistic assumptions

L_1 = outlook for V_2 at t_1 . using pessimistic assumptions

technology is made, it is assumed that it will be made using traditional discounted cash flow analysis. The expected value of the implemented technology discounted to t_2 (V_2), based on forecasts of annual net cash flows will be compared to the cost of implementing the technology (C_2). If V_2 is greater than C_2 , the company can expect to make a gain by exercising their option to invest. In this case, the value that they would assign to the option to implement the technology would be the gain that they would expect to make. If C_2 is greater than V_2 , the company would not exercise their option to invest. The value of the option to invest at t_2 is the greater of zero or the expected value of the implemented technology (V_2) minus the cost of implementation (C_2).

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obtained. This procedure is explained in detail in Section 6.1.

To examine the value of the option to implement the technology, let us first look at the case ignoring the uncertainty in the forecast of V_2 . Without uncertainty, V_1 becomes equal to V_2 , discounted to t_1 . The value of the opportunity to implement the technology then becomes the greater of zero or the difference between the known V_1 and C_1 .

If we allow uncertainty to be recognized, the value of the option depends on the distribution of V_1 . As shown in Figure 7, the value of the option to implement the technology depends on the probability that V_1 will be greater than C_1 . This calculation is explained in detail in Section 6.1. The value of the option to implement the technology includes the option premium that results from the uncertainty in V_1 .

A comparison of the terms used in stock market option analysis and those used for R&D in this research is shown in Figure 8. As terms such as the expected discounted cash flow of implementing the technology (V_2), the cost of implementing the technology (C_2) and the current outlook for V_2 (O_1) have been defined, they have direct equivalents in stock market option terminology. Other terms such as the distributional forecast of V_2 at time t_1 (V_1) have no direct equivalent but can be expressed as a combination of stock market option terms. As will be discussed later in this section, the chance

Figure 7

RELATIONSHIP OF V_1 AND C_1

Figure 8

COMPARISON OF OPTIONS AND R&D TERMS

R&D Term	Stock Market Option Equivalent
Cost of R&D	Cost of Option
Chance of Success of R&D	no equivalent
V2: Expected Discounted Cash Flow of Implementing Technology	Stock Price at Expiry
O1: Current Outlook for V2 at time t1	Current Stock Price
Distribution of V1	Current Stock Price and Volatility
C2: Cost of Implementing the Technology	Exercise Price
C1: Forecast Cost of Implementing the Technology; made at time t1	Exercise Price Discounted to Current Date

of success of the R&D has no equivalent in stock market option terminology.

The use of V_1 (the forecast of V_2 at time t_1) as the stochastic variable in the option analysis can be justified in the following manner. At the time the decision to implement is made, the amount the firm would be willing to pay for the technology (and hence the value of the option to implement the technology) is determined by the difference between the cost to implement (C_2) and the forecasted value of the implemented technology (V_2). Uncertainty in the events following implementation are considered in the evaluation techniques used to determine V_2 (eg. the risk adjusted hurdle rate used in the discounted cash flow calculation). The ultimate value of the implemented technology will be determined by the events that unfold after implementation but the value of the option to implement the technology was set at the time the decision to implement was made. In this sense, it is analogous to an investor acquiring an option on a stock, exercising the option and then holding the stock. The value of the option was established by the exercise price and the price of the stock when the investor exercised the option. The changes in the value of the stock after the decision to exercise reflect the decision to hold the stock, not the value of the option. Similarly, the changes in the value of the implemented technology after the decision to implement has been made reflect the decision to implement. Although the company

holding the option to implement the technology may not have the ability to exercise their option and then sell the implemented technology (like an investor who can exercise the option and then sell the stock), the analogy still holds. As long as the calculation of the value of the option to implement the technology accurately considers the evaluation that will be used in making the decision to implement the technology, the value of the option will accurately represent the value of the opportunity to implement the technology. Concerns about uncertainty in the outcomes after the decision to implement is made should be addressed in the techniques used to evaluate the decision to implement the technology.

There are differences between an R&D investment and stock options that must be recognized and allowed for in the construction of the model. When an investor purchases a stock option, he or she is certain that they have acquired an option to exercise. A company investing in R&D faces the risk that the R&D may not be successful and the option to exercise may never exist. This primary risk must be recognised and incorporated into the value of the R&D separate from the calculation of the value of the option. The way this is done is through the use of a decision tree (see Figure 9). The primary branch of the decision tree is based on the success of the R&D. If the R&D is successful, the technology is developed and the option to implement exists. If the R&D is

Figure 9

EVALUATION PROCESS SCHEMATIC

unsuccessful, no option exists and the cost of the unsuccessful R&D is lost.

The time aspect of a stock option is well defined in the option contract but may be less clear as it applies to implementation of R&D technology. The time that the opportunity to implement the technology disappears may depend on many factors such as the development of newer technology, competitors in the industry, licensing agreements or market changes. The model must be able to perform sensitivity analysis to determine the importance of the time estimates to the value of the R&D program.

The exercise price of a stock market option is fixed and defined in the option contract. With R&D, the cost to implement the technology (C_2) is not known with certainty. C_1 , (the forecast of C_2 that is made at the time t_1), is used to calculate the value of the option to implement the technology. As C_2 may ultimately be different than our forecast, it will be important to understand the sensitivity of the value of the R&D to changes in C_1 . (In this research, the estimate of the cost to implement the technology (C_1) is not considered to be stochastic but rather variations in this cost may be investigated using sensitivity analysis. The possibility of treating both the cost to implement and the value of the implemented technology as stochastic variables is something that could be addressed in further research as stated in Section 8.4.

A stock market option provides the holder with the opportunity to purchase a single asset at the exercise price. The holder of a technology option as a result of a R&D program may hold several different options as illustrated in Figure 9. The technology may create a set of options that include the opportunity to implement the technology as well as options to enhance the technology, spin-off benefits that can be applied to other products and the option to market the technology with or without implementing it. Each of these opportunities may create a separate option value for an R&D program and should be included, as applicable, into the total value calculated for the R&D program.

Lastly, the movement of a stock price on the market has been characterized as a 'random walk', giving rise to a normal distribution of probable outcomes for the future stock price. The distribution of V_1 will be determined by the range of possible outcomes of implementing the technology (O_1 , H_1 and L_1). Since this distribution could quite likely not be normal, a beta distribution has been selected. This allows skewed distributions of V_1 to be incorporated into the analysis.

Previous authors (Mann, Goobie and MacMillan 1991, Ross 1991) have used the options pricing model as presented by Black and Scholes (1973) as the framework for valuing investment decisions. The differences between stock market options and R&D opportunities as outlined above seriously

restrict the range of R&D programs that are appropriate for application of the Black and Scholes model. The Black and Scholes model is based on the concept that it is possible to duplicate an options contract by creating a portfolio of debt and shares in the underlying stock. The amounts of shares and debt depend on the exercise price of the option relative to the current price of the stock, the volatility of the price of the stock, the time to expiry of the option and risk-free interest rate. The further assumption made is that as both the options and the underlying stock are traded on the market, the efficiency of the market will ensure the option is priced correctly relative to the equivalent portfolio of debt and the underlying stock. It is therefore possible to estimate a current value for the option based on the features of the option contract, the current price and volatility of the underlying stock and the risk-free interest rate, assuming the random and normal movement of the underlying asset price.

Except in specific circumstances, in R&D we do not have an option that can be expressed in terms of an opportunity to acquire a quantity of a single commodity. We most likely will not be able to assume that an efficient market exists to establish a market value for the option and the underlying asset (the technology). We may also wish to include a skewed distribution of forecasts of the expected value of the implemented technology. We do, however, have the ability to determine V_t , which is the distributional forecast of the

expected discounted cash flow of implementing the technology. We can therefore calculate the value of the option using techniques that are based on options theory but do not require invoking the assumptions made by Black and Scholes.

4.2 Simplified Example

To illustrate the basic process, an hypothetical example will be presented with simplifying assumptions made regarding the calculation of values.

A company has the opportunity to invest in an R&D program that would lead to a more efficient process for the production of polyethylene (PE). The R&D is estimated by the researchers to have a 50% chance of success (chance of developing the technology) and if successful would lead to an increase in the yield of PE at the company's plant. The company estimates that the technology must be implemented within 3 years due to expected changes in the PE market. Using traditional net cash flow analysis, the implementation of the technology has an current outlook (O_1) of 1.9M\$ if implemented in 3 years. The outlook using optimistic assumptions (H_1) is 3.4M\$ and the outlook using pessimistic assumptions (L_1) is 0.4M\$. These values establish a range of forecasted values of the implemented technology that was discussed in the previous section. They will be used to determine the distribution of V_1 .

The option to implement is assumed to be the only opportunity that exists for this technology. The cost of the R&D program is 50k\$ if successful but the research will be aborted at a cost of 30k\$ if the program is not proceeding well. The cost to implement the technology in three years, discounted to the current time (C_1) is 2M\$. Should the company undertake the R&D?

Figure 10 shows the relationship between V_1 and C_1 . A number of the possible outcomes of V_1 are greater than C_1 . In these circumstances, the company would wish to exercise the option to implement the technology in order to achieve the gain in present value. As discussed in the previous section, the value of the option is a function of the probability that V_1 will be greater than C_1 . Using the technique described in detail in Section 6.1 we can perform the calculation and determine that the value of the option to implement the technology is 130k\$.

We now know that the option to invest in the technology, if the R&D is successful is worth 130k\$. Figure 11 shows a representation of the decision tree that is used to derive the value for the R&D program. The R&D program has a cost of 50k\$ so the net value of the successful R&D is 80k\$ (130k\$ - 50k\$). There is a 50% chance that the R&D will succeed and that the option will exist, so the risked value of the option is 40k\$ (.50 x 80k\$). There is also a 50% chance that the R&D will not be successful and the company will lose the 30k\$ they

Figure 10

DISTRIBUTION OF V_1

Figure 11

SIMPLIFIED EXAMPLE

invested in the R&D. The risked cost of this is 15k\$ ($.50 \times 30\text{k\$}$) which must be subtracted from the value of the successful option to give the net risked value of the R&D program of 25k\$ ($40\text{k\$} - 15\text{k\$}$). The company can now compare other investment alternatives and decide if it wants to invest in an R&D program with a net positive value of 25k\$.

If the uncertainty in V_1 had been ignored (such as in a traditional discounted cash flow analysis), the value of the opportunity to invest in the technology would have been calculated to be O_1 minus C_1 which is -100k\$. The net risked value of the R&D program would have been -90k\$.

This analysis provides an estimated value for the R&D program relative to the do nothing case. That is, either the investment in the R&D program is made as assumed or no investment in the area is made by the company. If other investment opportunities are available (such as investing in facilities without making the R&D investment), the other opportunities would have to be independently evaluated and compared to the net risked value of the R&D program.

5.0 Methodology

The research consisted of four steps as outlined below.

5.1 Evaluation Framework

The first step was the preparation of a framework for the evaluation of the decision support tool. This framework concentrated on assessing the strengths, weaknesses and requirements of the decision support tool and the attributes and requirements of the business environment in which the tool would be used. Early preparation of this framework reduced the bias in the evaluation that could result from deciding on evaluation criteria after the model had been built and was running.

The two main areas of evaluation were the cost and ease of use of the model and format/usefulness of results. Evaluation of the cost and ease of use of the model concentrated on the availability of the necessary resources to perform the options pricing model evaluations. The fit of the model with available information, skills, hardware, money and time was evaluated according to the framework in Appendix 1 by the researcher and the corporate contact. The format and usefulness of the output of the decision support model was evaluated by a representative group from the sponsoring corporation consisting of representatives from senior, middle and front line management in the R&D division. The group was asked for feedback in the areas outlined in Appendix 2. To

assist in the analysis, quantitative testing of the performance of the model as outlined in Section 5.4 below was conducted.

General comments on the strength of the option analogy and therefore the applicability of the model in different business circumstances are also provided.

5.2 Knowledge Building

The second step was one of knowledge building, both of the intricacies of option pricing theory and the characteristics of petrochemical R&D as performed by the sponsoring corporation. Discussions with other researchers currently involved with examining the use of options pricing in investment decision making helped refine the requirements of the application that was to be built. Information from the R&D planning process in prior years within the sponsoring corporation provided typical projects that would need to be evaluated and highlighted information that was available for analysis. Methods of estimating variance or volatility within the business environment (an important input to the options pricing model) were investigated with experts in the area of statistics and with the corporate contact. The methods ultimately selected for estimating variance were considered to be the best compromise solution that was analytically sound, straight forward enough to be used by researchers who are not experts in statistics and suitable for the information

available within the sponsoring corporation.

The ability of the model to perform sensitivity analysis was deemed to be particularly important so additional effort was committed to detailing the types of sensitivity analysis that would be required.

5.3 Model Construction

With the knowledge developed above, the decision support tool based on the analogy between stock market options and R&D investments was constructed. The tool is PC based using available commercial software (Windows and Microsoft Excel) and was designed specifically for the sponsoring corporation in the petrochemical industry. The model follows the simplified flow chart in Figure 12. In its completed and tested state the model should be easily adaptable to other companies in similar businesses and to other industries within the limits of the option analogy. The model is interactive with the user, prompting the necessary inputs and will perform primary data manipulation so that input information can be entered in its available form rather than in the form required by the model. Output information includes the calculated net risk value of the R&D program and the sensitivity of the calculated value to changes in the input variables. The model can also solve for any one variable among the inputs given a minimum acceptable net risk value for the R&D program (e.g. with a certain minimum program value, and all other input

Figure 12

SIMPLIFIED FLOWCHART OF MODEL

variables, the user is able to calculate the maximum R&D program cost that would be acceptable). This allows for the determination of boundary conditions for variables that are unknown or difficult to determine for a particular program. Numerical testing of the model to verify accuracy of the calculations and initial program debugging was carried out as part of the design and construction phase of this research.

5.4 Evaluation of the Use of the Model

The final step in this research was the evaluation of the use of the decision support tool using real life examples provided by the sponsoring corporation. The evaluation should attempt to examine two critical areas: our ability to operationalize the analogy in a model that can be used in business and the accuracy of the model in determining the value of an R&D program. The ideal test in this situation would be to introduce the analogy and the model into a corporation and evaluate a number of R&D programs using the model to determine if the model can be effectively used (ie. are resources and information available so that the model can be used). Then over the next few years, data would be collected to determine the ultimate profitability of each program. The evaluations of the programs performed using the model could then be compared with the actual profitabilities to determine the model's ability to predict the value of the R&D programs. The number of R&D programs evaluated would need

to be large enough to allow statistical testing of the results of the analysis.

In the research presented in this thesis, the time and resources to perform the evaluation described above were not available so modifications to the procedure were made. R&D programs to be evaluated were drawn from the 1992 planning cycle of the sponsoring corporation. Selection of one or two example programs from each of the business divisions in the corporation provided seven cases that were evaluated by the researcher and the corporate representatives using the option analogy decision support tool. This allowed an assessment to be made of whether the model could be used in a corporate setting. The results obtained from the model were examined by representatives of the sponsoring corporation. A subjective evaluation of the usefulness and validity of the results was obtained.

As well, two projects from the past that were successfully implemented by the company were also examined. In these cases, the researcher and corporate contact worked with those involved in the projects to recreate the outlook at the time that the R&D projects were undertaken. The model was used to evaluate the projects at that point in time and the results were compared to the actual outcome of the investments made.

While this historical testing of the model is by no means a conclusive test of the program, it does provide some insight

insight into the ability of the model to fairly represent the value of a proposed R&D program.

6.0 Results of the Research

The results section will be divided into five areas encompassing the building of the model, the numerical testing of the model, evaluation of actual projects using the model, the evaluation of the use of the options analogy and evaluation of the use and results of the model.

6.1 The Model

The first result that can be reported is that it was possible to build a decision support tool for evaluating R&D investments using the framework provided by the options analogy. A complete copy of the model is included in Appendix 4.

The decision support tool as described in Section 5.3 was constructed using MicroSoft Excel 3.0 in a Microsoft Windows operating environment on a DOS based personal computer. The Excel spreadsheet package was selected because of its ability to use Macro activating buttons (used to move within the model and cause calculations to be performed), the iterative problem solving package it contains (used to solve for the option value of the technology) and the desire to use a software package that was currently used and supported by the sponsoring corporation.

The complete list of terms and definitions used in the model are included in Appendix 3.

The model first requests the user to input basic data about the proposed R&D program (R&D cost, chance of success, the time until the technology will be available and the cost of aborting the R&D program if it is unsuccessful). The cost of the unsuccessful R&D program was included separately from the cost that would be expended to complete the successful R&D program. In many cases the R&D program can be discovered as unsuccessful before the entire R&D cost is expended, reducing the cost of failure. Entering the R&D costs into the model in this way captures that savings in the calculated value of the R&D program.

The model then requests the user to verify a variety of default values for the company. These include after tax rates for the various cash flow components used in the calculations, the long term after tax average cost of capital and the after tax corporate hurdle rate. The after tax cost of capital reflects the company cost of capital including industry risk but excluding project specific risk. This rate is used to discount costs and revenues in the period when the option to exercise or invest in the technology is open to the company. As the company has not decided to make the major investment in the implementation of the technology but has the option to invest if conditions become favourable, project specific risk should not be included. As the R&D program and the option to

invest in the technology usually stretches years into the future, the long term average cost of capital is used in most cases. The corporate hurdle rate includes the cost of capital and a risk adjustment appropriate to the projects that the company undertakes. This rate is used to discount costs and revenues after the decision to exercise the option has been made. After this point, the cash flows are no longer contingent on the decision to invest and therefore a discount rate including project risk should be used. This treatment of risk adjusted discount rates is generally consistent with that used by other researchers in this field (Mann, Goobie and MacMillan 1991, Brennan and Schwartz 1986).

The model then requests the user to input data about each of the optional uses for the technology that is to be developed by the R&D. Analysis of past and current R&D opportunities from the sponsoring corporation led to a classification of four general types of option value for a technology: option to implement the technology as developed by the R&D program; option to improve the technology with further R&D investment before implementing; option to transfer the technology to a new area for implementation; and the option to sell the technology. For each of the optional uses of the technology, the investment necessary to exercise the option (used to calculate C_i for implementing, improving, transferring or selling the technology) and the outlooks necessary to determine the distribution of V_i are requested

(H_1 , O_1 and L_1). Separate spreadsheets to calculate H_1 , O_1 and L_1 are provided on request of the user. It is expected that all optional uses for the technology will either fit into one of the four general types used in the model or will be able to be modelled using one of the four formats.

The distribution of V_1 is assumed, for the purposes of this model, to be either a normal or a beta distribution. To allow for a skewed distribution of outcomes, the beta distribution was split at the current outlook (O_1) and a separate variability was calculated for V_1 greater than O_1 and V_1 less than O_1 (see Figure 13). This split is based on two assumptions: that O_1 is the median of V_1 and that the distribution of V_1 greater than and less than O_1 have the characteristics of a beta distribution. These assumptions were judged to be reasonable for most of the R&D projects that were candidates for review, and were consistent with the information that was available from the sponsoring corporation. The investigation of other probability distributions are beyond the scope of this study.

The distribution of V_1 can be determined in the model in one of two ways. The user can directly input the forecasts of the annual net cash flow components for each of H_1 , O_1 and L_1 and let the model determine the distribution of V_1 . The user can also input only the forecasts for O_1 and specify high and low ranges for all of the input variables used to calculate O_1 . The model will then determine H_1 and L_1 and determine the

Figure 13

DETERMINATION OF THE VARIABILITY OF V_1
(From modified Beta distribution)

σ'_L = Low side variability

σ'_H = High side variability

distribution of V_1 . These calculations are performed on spreadsheets resident in the model that are selected by the user. Copies of the spreadsheets are included in Appendices 5 and 6.

The model then calculates the value of the option to employ the technology for each optional use. The methodology is based on the analysis provided in Cox and Rubinstein (1985) where the value of an option is determined to be the present value of the difference between the future price of the stock and exercise price of the option for the set of outcomes when the future price of the stock is greater than the exercise price. Translating this to the R&D analogy, the value of the optional use of the technology is equal to the probability that V_1 will be greater than C_1 multiplied by the conditional value $V_1 - C_1$ when V_1 is greater than C_1 . This can be seen graphically in Figure 14. The probability that V_1 will be greater than C_1 is represented by the shaded area. The conditional value $V_1 - C_1$ when V_1 is greater than C_1 is represented by the difference between the average value of V_1 within the shaded area minus C_1 . The product of these two numbers is the value of the option of that use of the technology.

The method used in the model to approximate this calculation is shown in Figure 15. The Excel program uses a quasi-Newton iterative process (Person 1991) to approximate the average value of V_1 in each of the shaded areas. The

Figure 14

DETERMINATION OF THE VALUE OF THE OPTION

$\bar{V}_s$ = expected value of V_1 given $V_1 > C_1$

$\square$ = probability that $V_1 > C_1$

Figure 15

OPTION VALUE CALCULATION USED IN THE MODEL

= probability of V_1 being in area A

$\bar{V}_a$ = average V_1 in area A (estimated)

= probability of V_1 being in area B

$\bar{V}_b$ = average V_1 in area B (estimated)

average value of V_i for each shaded area, minus C_1 , is multiplied by the probability represented by that shaded area and then totalled to give the value of the option to use the technology.

The model then passes the option values through to the summary portion of the report where the value of each of the options is combined with the basic data about the R&D program to obtain a net risked value for the R&D program. This is done using a decision tree analysis as outlined in Figure 9. The results section of the model includes a sensitivity analysis of the net risked value of the R&D program to changes in the basic data about the program and the total value of all of the options.

As well as the main model, two other modules were constructed for performing sensitivity analysis of the values obtained. Appendix 7 contains a module that calculates the sensitivity of the value of any single optional use of the technology to the parameters used to derive that value. Appendix 8 contains a model that will establish the minimum or maximum for the input parameters, assuming that at least a fixed minimum net risked value for the R&D program input by the user, must be achieved.

6.2 Numerical Testing of the Model

The purpose of the numerical testing of the model was to verify the ability of the model to accurately calculate an option value, given a certain set of inputs. This testing did

not examine the use of the model to evaluate an R&D program, but only the ability of the model to estimate an option value consistent with the options analogy.

Two different numerical tests were performed on the model; a numerical verification of the calculations performed by the model using detailed manual analysis and a comparison of results of the model to the Black and Scholes model in calculating the value of stock market options under very restricted conditions.

As a result of limitations of the Excel software package, it was possible to use only two divisions in the iterative process (Figure 15) to calculate the option value of an opportunity to employ the technology developed by the R&D program. It was a concern that using this approximation to calculate the option value would introduce significant error into the results. A comparison of the model output to the results generated by a detailed calculation of the value of the option employing 20 areas was performed. To improve the accuracy of the model, a correction factor was calculated and incorporated into the model. The comparison of the option values calculated by the model and those obtained from the detailed manual calculation for a range of input values are shown in Table 1. The error in the model ranges from -2.0% to +0.9% and the absolute value of the error averages 0.9%. This is judged to be sufficiently accurate as the potential error in the input variables to the model (estimates of R&D costs,

Table 1

Comparison of Model to Detailed Calculations

Test #	Current Outlook	High & Low Side Variability	PV Cost to Implement Technology	Calculated Option Values			% Difference (corrected model vs. manual calculation)
				Model (uncorrected)	Model (corrected)	Manual Calculation	
1	100	30	80	24.61	24.61	24.39	+0.9%
2	100	30	90	17.66	17.66	17.65	+0.1%
3	100	30	100	12.00	12.00	12.12	-1.0%
4	100	30	110	6.26	7.83	7.79	+0.5%
5	100	30	120	3.63	4.54	4.56	+0.4%
6	100	30	130	1.95	2.44	2.49	-2.0%
7	100	30	140	0.44	0.55	0.56	-1.4%

Average Absolute Error =

0.9%

chance of success and forecasts of future costs, revenues and investments) are expected to contain much greater than 1% error. A detailed example of the manual calculation is included in Appendix 9.

The Black and Scholes option value model holds several restrictive assumptions as discussed in Section 4.1 that make it unusable for calculating option value of R&D developed technology but it is an accepted method of determining the value of stock market options. The model for evaluating the option value of R&D technology is developed from the basic principle of option valuation. In restricted circumstances it could be used to value stock market options and should yield results similar to that of Black and Scholes. By holding the time to expiry to one period and setting the risk-free rate to 0, a substitution of values from Black and Scholes into the R&D model can be made (stock price = current outlook (O_1); exercise price = cost of implementation (C_1); variance = variability of V_1). The results of this substitution are shown in Table 2. The selection of stocks and variances for this test was taken from Stoll (1969). The difference in calculated option value between Black and Scholes and the model range from -3.2% to 2.1% and the absolute value of the difference averages 1.5%. The relatively close agreement of the two methods of calculating the value of a stock market option adds credibility to the calculations performed by the model.

Table 2

Stock Market Option Value Calculations

Company	Stock Price	Variance	Exercise Price	Calculated Option Values		% Difference (model vs. B & S)
				Model	Black & Scholes	
U.S. Steel	44.01	9.50	40	6.04	5.96	+1.3%
St. Oil of N.J.	67.46	8.21	65	4.60	4.59	+0.2%
Chrysler	43.79	18.25	40	9.05	8.97	+0.9%
G.M.	81.84	10.96	80	5.42	5.36	+1.1%
G.E.	99.23	10.48	95	6.64	6.55	+1.4%
N.Y. Central	73.72	10.73	80	1.96	2.00	-2.0%
R.C.A.	51.05	10.07	55	2.40	2.48	-3.2%
Gen. Dynamics	57.62	14.86	60	5.01	4.92	+1.8%
Anaconda	87.00	9.90	95	1.49	1.51	-1.3%
Western Union	97.00	15.35	40	5.80	5.68	+2.1%
Average Absolute Difference =						1.5%

6.3 Evaluation of Real R&D Opportunities

In order to evaluate the operation of the model in real life conditions, data from nine actual R&D projects was supplied by the sponsoring corporation. A list and description of the projects is included in Figure 16. Seven of the projects were from the current (1992) planning cycle and two were historical projects from previous years for which actual results were available. The selected projects represented a wide range of different types of analysis that would need to be performed in the R&D division in any year. Evaluation of the seven current projects was carried out and sensitivities of the net risked value of the R&D were investigated. Table 3 outlines the results of the evaluations. Summary sheets for each of the projects can be found in Appendix 10. Using the model, it was possible to calculate a net risked value of the R&D program for each project and identify parameters to which the net risked value was particularly sensitive. The projects varied from being marginal to very valuable and were sensitive to different parameters depend on the particular situation. Evaluation of the use of the model and utility of the results will follow in Section 6.5.

Evaluation of the historical projects involved discussing the projects with those involved at the conception of each project and attempting to recreate the expectations for the project at that time. The model was then used to estimate a

Figure 16

SELECTED PROJECTS

Project	Description
A	New PlasticProduct Development
B	Environmental Clean-up
C	Petrochemical Process Analysis
D	Plastics Catalyst Development
G	Catalyst Test Facility
H	New Plastics Application
I	New Catalyst Development
E	Historical Analysis
F	Historical Analysis

Table 3

Results of Project Analysis

Project	Total R&D Cost (k\$)	Net Risked Value of R&D (k\$)	Sensitivities
A	11,350	2,000	very sensitive to R&D and implementation costs
B	830	8,800	insensitive to changes in parameters
C	570	5,780	sensitive to chance of success
D	800	1,360	sensitive to chance of success and option value
G	100	246	moderately sensitive to all variables; several options
H	150	3,200	insensitive to changes in parameters
I	800	5,100	very robust to changes; many options

net risked value for the project based on that information. This value was compared with the actual value realized by the development and utilization of the technology. The results of the comparison are shown in Table 4. The first project had an expected R&D cost of 200k\$ and an actual R&D cost of 500k\$. The model estimated a value of 35k\$ for the project and the actual value has been calculated at 144k\$. Although the costs and values changed significantly from those originally expected, the model fairly represented the relative value of the project. Unfortunately, actual data for the second project was not available so comparison could not be performed. The evaluation does however confirm the positive value of the project and supports the decision that was made to proceed with the R&D for this project.

6.4 Evaluation of the Use of the Option Analogy

After an initial presentation of the options analogy as a method of evaluating R&D investment opportunities to a selection of senior, middle and front line management at the sponsoring corporation, a short questionnaire testing the participants opinion of the options analogy was circulated. A copy of this questionnaire is included as Appendix 11. The compiled results of the responses regarding understanding and appropriateness of the analogy are shown in Table 5. Generally there was a high level of understanding of the analogy and a strong feeling that the analogy represented an suitable way to consider the value of R&D. There was also a

Table 4
Results of Analysis of Historical Projects

Project	Forecast Cost of R&D (k\$)	Net Risked Value			Actual Value of R&D (k\$)	Comments
		Actual Cost of R&D (k\$)	of R&D Estimated by Model (k\$)			
F	200	500	35		144	fairly represented project value
G	50	-	77		-	actuals unavailable

Table 5

Results of First Questionnaire
 (following presentation on options
 analogy for R&D evaluations)

	Number of Respondents Indicating:		
	High	Medium	Low
Understanding of the Analogy	10	1	1
Appropriateness of the Analogy	11	1	0
Appropriateness of Building a Decision Support Tool Based on the Option Analogy	11	1	0

strong feeling that it was appropriate to build a decision support tool based on the options analogy. These results indicated an acceptance of the concept of using the option analogy for evaluating R&D investments within the R&D part of the sponsoring corporation in spite of the apparent complexity of the analogy and option valuation process.

6.5 Evaluation of the Use and Results of the Model

The evaluation of the model and its results will follow the format developed in Section 5.1 and included in Appendices 1 and 2. These evaluations were assisted by questionnaires completed by a group of senior, middle and front line management that attended a presentation on the model and results of the analysis of the projects, and by the staff who supplied the data for the evaluation of the projects. These questionnaires are included as Appendices 12 and 13.

6.5.1 Cost and Ease of Use of the Model

The summary of the analysis of the cost and ease of use of the model is presented in Figure 17. The first area of interest is the availability of input information. The model requires basic information about the R&D program such as cost of the program, chance of success and cost of a failure. This information was generally available although estimates of the chance of success had to be made for some projects by the representatives of the sponsoring corporation. The corporate default information regarding discount rates and after-tax rates for cash flow components was all available from central

Figure 17

COST AND EASE OF USE OF THE MODEL
(from Appendix 1)

Characteristic	Model	Business
Input Information	Basic information on R&D program	Currently available
	Corporate default information	Currently available
	Optional uses of technology	Available or can be developed
	Investments to utilize tech. (C)	Can be generated
	Outlooks for value of utilizing technology (O, H, L)	Can be generated
Human Resources	PC literate professional who understands option analogy, option value calculation and business aspects of utilization	Available in central specialist group
Hardware	DOS based PC with 386SX processor or better	Current PC and network systems are adequate
Time for Evaluation	Data gathering = 2 man-hrs Evaluation time = 1.2 man-hrs	Minimize time spent (1 man-day maximum)
Cost of Evaluation	No additional costs other than time spent	Minimize cost Use existing resources

corporate groups. The actual optional uses for the technology (other than the primary purpose) has not been developed within the existing organization. The process of gathering data for this research allowed some of the options to be identified and explored. The data regarding the investments and costs required to utilize the technology in the future (C_1) was not available but could be estimated by the researchers and business contacts involved with the R&D projects. There was a feeling of high uncertainty around these estimates. Similar to the costs, the outlooks for utilizing the technology were not available but could be estimated, allowing for a fair degree of uncertainty. In general, the data required for using the model was either available or could be estimated by those involved with the R&D or their business contacts within the organization.

The human resource requirements to use the model became apparent when the model was being introduced into the sponsoring corporation's organization. Initial objectives were to establish the model as a widely available tool within the organization but it was evident that in order to effectively use the model as a decision support tool, the user required a set of skills that would not necessarily be available in all members of the staff of the R&D division. The user needed to be knowledgeable in the operation of a personal computer, specifically with the Windows operating environment and Excel. These skills were required to access

and manipulate the model. The user needed to be familiar with option value calculations and the option/R&D analogy to be able to interpret the results of the model and effectively use the sensitivity modules to gain the greatest amount of knowledge about the R&D programs. Finally the user needed to be familiar with the business aspects of the implementation of technology to be able to assess the opportunities that are created by the technology resulting from the R&D program. Without these skills the model become a 'black box' that could have been used to generate answers but without the understanding necessary to properly interpret or assess the credibility of the results. These skills were only available in a central specialist group within the research and development division that had responsibility for the business aspects of the R&D effort.

The hardware necessary to support the decision support tool is a DOS based personal computer with a minimum of a 386SX processor. The sponsoring corporation's current standards for personal computers and local area networks met this requirement. No changes in computer hardware were seen to be necessary as a result of the adoption of this model.

The time required to perform an analysis of a project using the model was divided into two parts: data gathering and evaluation time. The data gathering time included the time to obtain available information and to make estimates where information was not already in existence. The

evaluation time included time spent to prepare the data for entry, enter the data into the model, processing time, printing out and initial analysis of the results. The actual times for each of the projects for these two functions are shown in Table 6. The average time taken for data gathering was 2 man-hours (1.6 to 2.4 man-hours). The average time for analysis of the data was 1.2 man-hours for a total of 3.2 man-hours.

As the model made use of existing resources and skills within the corporation, the major cost of performing an evaluation of an R&D program was the manpower required to gather data and run the model.

The sponsoring corporation's objective was to minimize the cost and the amount of time necessary to perform a project analysis.

6.52 Format/Usefulness of Model and Output

The summary of the format/usefulness of the model and output is presented in Figure 18. The assessment of the usability of the model led to the conclusion that is a tool that is appropriate for use by a trained specialist rather than for the general population of the organization. The concept of the option analogy was well understood but the actual calculation of an option value and the mathematics involved in the model were not as easily grasped by laymen. Also the use of this model required some familiarity with its operation on the part of the user. It was doubtful that a

Table 6

Time Required for Project Analysis

Project	Data Gathering Time (man-hours)	Evaluation Time (man-hours)
A	1 - 2	1.5
B	0.5	1.75
C	-	1
D	4 - 5	1.25
E	2	2
F	1 - 2	0.75
G	1 - 2	1.75
H	-	0.5
I	2 - 3	0.75
Average	1.6 - 2.4 (2.0)	1.2

Figure 18

FORMAT/USEFULNESS OF THE MODEL AND OUTPUT
(from Appendix 2)

Characteristic	Evaluation
Usability of the Model	Appropriate for trained specialists Mathematics not understood by laymen
Form of Results	Need to be interpreted before presentation to staff Model provides value of R&D Model provides sensitivity analysis Flexibility of sensitivity analysis is important
Confidence in Results	Confidence in input data must be ensured Laymen unsure of what R&D value represents Sensitivity information well understood and trusted
Utility of Results	Greater understanding of sensitivity of value of R&D Developed new optional uses for technology Consideration of business aspects of technology
Utility of Model	Limited by skills & expertise needed to use the model Communication of results depends on ability to educate staff/senior management
Introductory Requirements	Education regarding: options theory options analogy option value calculation All levels of staff will require education

person using the model infrequently could maintain the required level of familiarity with its use to effectively use it. As a tool for a specialist, the model was relatively user friendly. It was accessible from a menu system that guided the user into the program and prompted the input of necessary information.

The form of the results of the model were also appropriate for a specialist familiar with the application. As the option/R&D analogy was not in use in business, there was no developed terminology or list of common definitions to ease the transfer of information. Generally the results of the model needed to be interpreted before presentation to the staff of the organization at large. The model provided the net risked value of the R&D program and sensitivities of that value to changes in the various input parameters. The sensitivities were presented as changes in the net risked value of the R&D program resulting from a change in each of the input parameters. The size of this change was determined by the user. This flexibility in the calculation of sensitivities was desirable to representatives of the sponsoring corporation.

The level of confidence in the results of the model was derived from two different areas: level of confidence in the input data and understanding of the workings of the model. Confidence in the results was somewhat undermined by a general concern that the input data could be manipulated by the

analyst to obtain the desired results. The model was regarded as being a 'black box' by many of the senior, middle and front line management of the corporation who attended the presentation of results. Although the option analogy was accepted, the knowledge of how an option had value and what that value represented was not sufficiently clear to allow a complete grasp of what the model was doing. The information on the sensitivity of the value of the R&D to the different input parameters was well received and understood.

The utility of the results was largely dependent on the ability of the model to provide new and useful information to the sponsoring corporation. As a result of the lack of confidence and understanding of the net risk value of the R&D, the utility of that result was reduced. In contrast to this the greater understanding of the sensitivity of the value of the R&D to the different parameters was seen as new and useful information to allow prioritizing of effort and focusing of work to improve profitability. The exercise of the evaluation of a project using the options model also had two important side effects. The examination of optional uses for technology uncovered new uses that had not previously been considered. It made the researchers and managers aware of the possibility of cascading options that could result from technology development. The process also forced an examination of the business aspects of the utilization of the technology. This broadened the focus of the researcher from

the R&D, to how the R&D can generate opportunities for the company.

The results discussed above are illustrated in Table 7. This table shows the responses to questions on the changes in perception created by the results from the model, made by the management group. Significant or moderate changes in the perception of the number of alternative uses of a technology, the sensitivity of the value of the technology to changes in different parameters, and the priority that should be assigned to different parts of the R&D program were reported by most respondents. Most respondents indicated only moderate or no change in their perception of the value of the alternative uses of the technology and of the total project.

The utility of the model was restricted by the skills and experience required to effectively use it. The skills necessary to use the model effectively and interpret the results were not available widely within the organization. Communication of the results of the model will be dependent on the education of the senior management and the staff at large. Expansion of the user base for the model will depend on the spread of that understanding and the development of the necessary skills within people in the organization.

Introductory requirements for using options theory in the evaluation of R&D opportunities demands more than just education in the use and results of the model. Senior management and staff involved in the process need to be given

Table 7

Questionnaire Responses - Changes in Perception

Did the results of the model change your perception of:	Number of Respondents Indicating:		
	Significantly Changed	Somewhat Changed	No Change
Number of alternative uses of technology	4	3	1
Value of alternative uses of technology	1	5	2
Total value of the R&D program	1	5	2
Parameters the value of the R&D program sensitive to	4	4	0
Priority that should be assigned to parts of the R&D program	3	4	1

a firm foundation in options theory and the calculation of the value of an option. Without this base of knowledge, the output of the model can not easily be understood. From this foundation, the option analogy can be developed and the model explained sufficiently to allow the results of the model to be used effectively.

7.0 Discussion of Results

7.1 The Model

The research described in this thesis has shown that it was possible to build a decision support tool for the evaluation of proposed R&D expenditures based on the framework provided by options theory. With this model the analyst was capable of determining a net risked value for the R&D program. This value was based on the option value of the alternative uses of the technology that would be developed by the R&D. It was also possible to calculate the relative sensitivity of the value of the R&D program to changes in the input parameters. The mathematical calculation of the option value performed by the model was verified by numerical testing and found to be accurate to within 1 to 1.5%, well within the accuracy needed for this application considering the uncertainty associated with the input parameters. The ability of the model to accurately calculate the value of an R&D opportunity was not rigorously tested. The evaluation of the results that was performed indicated that the model fairly represented the

value of the R&D programs, but this evaluation was largely subjective.

We can observe that it was possible to operationalize the options/R&D analogy and create a tool for evaluating R&D programs.

7.2 The Use of the Model

The evaluation of the use of the model within an R&D organization with the support and assistance of the sponsoring corporation highlighted findings in two areas. With some restrictions the model fit well with the available resources and requirements of the organization. The use of the model provided new and useful information to the sponsoring corporation but, as previously stated, confidence in the results were somewhat undermined by the perceived complexity of the option value calculation.

The model was not seen to be a tool that initially could be widely distributed for use within the organization. The skills necessary to perform an evaluation and interpret the results were not judged to be uniformly available within the R&D division of the sponsoring corporation. As well the frequency of use of the model was not expected to be high enough to allow the broader organization to maintain a competency in the use of the model. It was therefore decided to locate the model within a central group of specialists

within the R&D organization that had responsibility for the business aspects of the R&D effort.

The data that was needed to analyze the R&D programs using the option model was available or could be generated. The process of data collection provided some interesting benefits. In some cases additional uses of the technology were uncovered. A number of the managers also commented that the awareness of the commercial purpose of the technology broadened the perspectives of the researchers and was of benefit to the organization.

The sponsoring corporation's objective for cost and time of performing an evaluation was to keep these to a minimum through the use of existing resources. As the model was supported on computer equipment that was currently available within the organization, used skills available in the central specialist group and required minimal maintenance, the cost of using the model was very low. The major cost was the manpower required to collect data and perform the analysis. The time required to collect the data and perform an analysis averaged just over three man-hours per project. The model therefore met the objectives for time and cost of evaluation. It was important that the evaluation of a project with the model not be an onerous task as increased cost and time to obtain results would reduce the likelihood that analysts would choose to use the model and that the corporation would want to support its use.

Related costs in education and training will be incurred as the use of the model is expanded into the broader organization but these have not been estimated as part of this study.

The analyses of R&D projects using the options model provided information that was new and different from other evaluation tools currently used by the sponsoring corporation (discounted cash flow analysis and strategic justification). The danger of data manipulation by the analyst to obtain the desired results was a concern but it was felt that this problem could be overcome using peer group or management teams to review the input data. This is a common concern for many evaluation techniques (Gerwin 1990).

The net risked value of the R&D program calculated by the model was accepted with some reservation by the management group in the sponsoring corporation. Because they were not totally familiar with option pricing and therefore unsure of the mathematics the model used to calculate the value, the members of this group did not have faith in their understanding of the number, and were hesitant to accept it as the value of the R&D program. It was viewed rather as an indicator of value that should be used with caution. Greater familiarity with options theory and the option analogy was required within the organization if these concerns were to be overcome. The sensitivity analysis performed using the model is discussed in detail in the next section.

When the development of this model was being contemplated, it was seen as a tool that could be used to evaluate new R&D programs before they were undertaken. The evaluation of the model in the sponsoring corporation's organization, particularly the historical project analyses, uncovered another valuable use for this tool. Evaluation of projects while they are in progress allowed updated information to be included in the analysis, such as revised chance of success or implementation costs that resulted from the changes in the environment or more importantly, from the R&D effort to date. This reassessment, especially of the sensitivity analysis, could keep the project focused on the highest leverage areas. It also would allow management to discover projects that become unviable earlier in the process, reducing wasted effort and resources.

The acceptance of the options analogy by the management of the sponsoring corporation was seen as an encouraging sign that this method of evaluating contingent investment decisions may gain wider acceptance. It should be noted however that the representatives of the sponsoring corporation were from an R&D environment, accustomed to the introduction of new technology, and viewed options evaluation of R&D not just as a method of evaluating R&D projects but also as a potential method of justifying more R&D. This background may have made them more receptive than similar groups in other organizations would be.

7.3 Sensitivity Analysis Using the Model

One of the key features of the model was its ability to perform sensitivity analysis on the calculation of the value of an optional use of technology and on the net risk value of the R&D program. As stated previously, the main module of the program automatically calculated the sensitivity of the net risk value of the R&D program to changes in the input parameters. Other modules allowed the user to investigate the sensitivity of the value of individual options to use a technology and to determine minimum or maximum required values for parameters in order to meet a target value for the R&D program. The sensitivity analysis allowed the analyst to learn much more about the R&D program.

The evaluation of an R&D opportunity requires information about the program, the technology to be developed and the uses of that technology. In each evaluation, there will be varying degrees of confidence in the estimates of certain of this information. By using the sensitivity analysis feature, the sensitivity of the value of the R&D to the assumptions can be determined, particularly in the cases of information in which the analyst has a low degree of confidence. If the value of the R&D is sensitive to changes in these parameters further effort can be made to improve the estimates.

Another use of the sensitivity analysis is to determine the areas of R&D effort that can provide the greatest leverage to the corporation. By looking at the sensitivity of the

value of the R&D to changes in the parameters that could be affected by the R&D effort, the analyst can select the areas that would generate the largest potential increase in the value of the R&D. For example, if a particular R&D project was sensitive to the chance of success of the R&D, early R&D effort could be focused on investigating and improving the chance of producing the desired technology. Depending on the results of this early work, the R&D could either be continued, with a greater expectation of value or cancelled and the effort directed to other programs.

A further use of this feature of the model is to investigate the effect of changes in the cost of implementation of the technology. Although this cost is a forecast that may contain significant uncertainty, for the purposes of the model it is assumed to be known. Many of the values of the optional uses of the technology are sensitive to the cost of implementation so understanding the impact of changes in this variable is particularly important.

The final use of sensitivity analysis to be discussed is to build confidence in the value of an R&D program. Knowing that the value of a program is insensitive to changes in certain variables may allow a corporation to invest in the R&D with a greater degree of comfort. As well, the understanding of the degree of sensitivity to change allows managers to better assess the risk associated with projects.

Within the sponsoring corporation, the results of the sensitivity analysis were judged to be valuable new information. One manager stated that:

. . . sensitivity analysis provides a good analytical tool to develop and analyze additional, new options. . . .

. . . in particular, assessment of a hurdle value of certain parameters seems to be very important and attractive.

The sensitivity analysis was seen as a tool that would help evaluate the risk associated with R&D projects and allow prioritizing of R&D effort on the parts of the project that most affected the R&D project's value. This would provide the greatest leverage for the R&D effort.

7.4 Comparison of the Options Evaluation Approach

As discussed in Section 2.0 of this thesis, criticism of the option analogy is often that it adds no more information than a well performed decision tree analysis and that it is too complex for practical application. While it is true that a detailed decision tree may be able to replicate the value assigned to an R&D program by the options model, the option premium that is determined by the options model would only be recognized by a detailed decision tree if the analyst allowed for the ability of management to make decisions in the future. Two other important differences must also be recognized. Firstly the data collection and analysis process for the options model took an average of just over three hours to perform. To attempt to gather the data and perform the multiple case evaluations required for a decision tree

analysis in that amount of time would be a herculean task. Secondly, the options model was able to perform sensitivity analysis as part of the basic evaluation and further sensitivities could easily be obtained. To change the underlying assumptions in a decision tree analysis may necessitate significant rework of the analysis requiring more time and effort. So although the criticism may contain some truth, the options evaluation tool will provide more information with less effort by the analyst.

The relative complexity of the options analogy and model is a concern that should also be addressed. The options/R&D analogy was not perceived to be too complex by the managers in the sponsoring corporation. However, concern was registered as to the complexity of the model. This may be due to the newness of the concepts that were being presented, and points to the need for education and training not only in the option analogy, but in the fundamentals of option theory, when this evaluation tool is being introduced into an organization.

Although not mentioned in the literature, a third concern that should be addressed is that the same results might be obtained by Monte Carlo simulation. Monte Carlo simulation incorporates the distributions of the input parameters into the calculation of an expected value. This is done through a random sampling process. The major difference between options theory and Monte Carlo simulation is that Monte Carlo uses all outcomes to calculate the expected value, where options theory

assumes that the decision will be made to not exercise the option if the outcome is negative. Options theory therefore only considers the positive results. The use of all outcomes in the Monte Carlo simulation does not recognize the ability of management to make contingent decisions and therefore does not recognize the full option value of R&D.

Examination of the @RISK program, a Monte Carlo simulation package available for spreadsheet applications on personal computers, shows that it is possible to set conditions on the outcomes of the simulation. By specifying that only positive outcomes be considered, it would theoretically be possible to duplicate the results of the options evaluation. In effect, a hybrid of options theory and Monte Carlo simulation would be created. Evaluation of this possibility is beyond the scope of this research.

8.0 Conclusions and Recommendations

8.1 Benefits and Limitations of the Research

The research fills an important role in that it extends existing academic theory into a practical application in the business world. Authors such as Mitchell and Hamilton (1988) and Brennan and Schwartz (1986) developed the theoretical link between options pricing and investment evaluation. This research operationalizes that link with a working decision support tool. The support of the corporate sponsor in this research allowed the evaluation of the tool in a business

setting. The benefits of the options analogy and option evaluation model can be summarized as follows:

- the options analogy provides a useful framework for considering the benefits of R&D;
- new and useful information about the value of R&D can be obtained by the analysis of a program using this technique;
- evaluation of an R&D program can be done in a timely and cost effective manner;
- the process of using option theory to evaluate R&D may lead to the recognition of more uses for the technology and give a business focus to the research;
- the option evaluation model is a useful addition to the toolbox of aids for R&D investment decision making.

In order to operationalize the options analogy, it was necessary to recognize the differences between stock market options and R&D investment opportunities. These differences made it necessary to return to the first principles of options theory to build a tool to evaluate the option value of technology. It was determined that the use of an option evaluation technique such as Black and Scholes was not appropriate if the underlying assumptions in the technique were not met by the R&D opportunity to be evaluated.

The limitations of the research are generally concerned with the evaluation of the performance of the model. The nine selected R&D opportunities provided by the sponsoring corporation allowed the evaluation of the information and resources necessary to use to model but did not duplicate the day to day use of the model in a business setting. The impact of this limitation was reduced by the selection of a wide

range of types of R&D programs so that problems in use of the model would more likely be discovered.

The ultimate test of the value of a decision support tool is if it provides reasonable answers that assist in the making of decisions. As discussed in Section 5.4, it would take a number of years to determine the outcome of an R&D program so that the accuracy of the model's evaluation of that program could be tested. In this research, the evaluation of the output of the model has been done using two historical R&D projects and the best judgement of the experts who could potentially use the model in the future. This evaluation gives an indication of the confidence the experts held in the results of the model but was by no means a rigorous test of the model.

The numerical testing of the model that was performed in this research verified the calculation of the option value based on option evaluation theory but did not test the model's ability to accurately evaluate an R&D opportunity.

8.2 Limitations of the Model

The model assumes a normal or beta distribution of the forecast value of the implemented technology. This restricts the use of the model to cases where the range of expected outcomes for the stochastic variable is random, continuous and can be approximated by a beta distribution. The model would therefore not be appropriate in its present form to consider

other distributions such as step functions or multiple discrete outcomes.

For practical purposes, the model is of limited incremental value for short term projects with a high degree of certainty. For these projects where the range of possible outcomes can be narrowly defined, very little option premium will be recognized by the model. In these cases, a discounted cash flow model would be more effective in determining a value for the project.

The model is also limited to projects where reasonable estimates of the input parameters are available. If, because of the many unknowns, it is not possible to estimate a range of potential outcomes for the forecast value of the technology, the model will not be able to determine a reasonable value for the R&D. In these cases, no economic evaluation technique would be appropriate and strategic justification techniques would have to be used.

As a practical guide to the limitations of the approach, it is useful to return to the basic assumptions which underlie option pricing theory. That is, option pricing theory assumes the current existence of the asset on which the option is written. If the asset exists, a current value and the distributional properties can be estimated. Examples of this type of asset would be projects concerned with commodities such as petrochemicals, energy, agriculture or minerals. Projects concerned with products that are currently

manufactured or for which a current product could be used as a proxy would also be suitable. At the other extreme, is the realm of research that investigates 'blue sky' ideas. Research which hopes to create technology or products that do not exist, or for which reasonable proxies cannot be observed, fit into this category. In such cases the efficacy of the model is unknown.

8.3 Implications for Managers

For the manager in a company dealing with R&D decision making or with other longer range projects where contingent decisions could be made, there are two findings of interest in this study. The first is that the consideration of these projects as methods of creating options for the company can have benefits to their understanding of the value of the projects and how they fit with the future of their company. Viewing the projects from the perspective of options created may lead to the discovery of new opportunities, focus their commitment of resources and allow them to more easily communicate the value of these projects within the organization.

The second finding is that it is possible to create a usable decision support tool based on the options analogy that can be employed within an organization. Information and resources necessary to use the model can be developed or may already exist. The results or analysis performed with this type of tool gives insight into the value, the sensitivities

and the leverage areas that exist within the projects. Options analysis can provide the manager with a valuable addition to the toolbox of aids for decision making.

The research also points to the importance of the training and education of the organization when attempting to introduce a new technique such as this. Difficulties in grasping the concepts of option value calculation that became apparent in the evaluation of the model were largely a result of unfamiliarity with option theory. This foundation of understanding would have to be laid at all levels in the organization to allow the effective introduction of the new technology.

8.4 Implications for Researchers

The options analogy has been extended by this research from a conceptual link between options and R&D to a working evaluation methodology for R&D expenditures. Modifications to the method of calculating an option value were necessary in order to extend the theory to R&D evaluation. These modifications involve returning to first principles and making assumptions consistent with R&D rather than using formulae that have been developed for other purposes and that contain restricting assumptions.

The options approach to R&D evaluation has been shown to have advantages that should not be expected for other evaluation techniques, specifically net cash flow and decision tree analysis. Options evaluation should be considered as a

important addition to the tools available to support decision making for R&D investment opportunities.

8.5 Suggestions for Further Research

Several areas of further research arise from the work presented in this thesis. This thesis examines the application of options theory to the evaluation of R&D investment opportunities only. In the business world, there are many other long range opportunities that include contingent decisions. All of these opportunities are candidates for analysis using options theory. Two particularly attractive areas for investigation would be exploration for natural resources and flexible systems in manufacturing; both of which have many options created by multiple future decision points.

Examination of the process that should be used when introducing the new decision making technology into the organization needs to be performed. A lack of understanding of options theory and the option value calculation process seemed to undermine some of the confidence in the results of the model. Effective methods of providing this background and easing the integration of the technology need to be developed.

A further area to be investigated is the expansion of the flexibility of the option evaluation model as it was developed in this research. Some restrictive assumptions about the distribution of the forecast outcomes of the implemented technology were made to produce this first generation

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evaluation tool. Methods of expanding the range of types of distributions that can be considered need to be examined in order to make the tool more widely usable.

A second area of flexibility that needs to be investigated is the use of more than one stochastic variable in the option value calculation. Recognition of the uncertainty in other variables, such as the cost to implement the technology, could improve the model's ability to represent the true option value of an R&D program. The use of Monte Carlo simulation discussed in Section 7.4 may provide some insight in this area.

References

- Baldwin, Carliss Y., Scott P. Mason and Richard S. Ruback, 1984 "Evaluation of Government Subsidies to Large Scale Energy Projects: A Contingent Claims Approach", Harvard Business School Working Paper #9-783-066.
- Black, Fischer and Myron Scholes, 1973 "The Pricing of Options and Corporate Liabilities", *Journal of Political Economy*, vol. 81, pp.637-654.
- Brennan, Michael J. and Eduardo S. Schwartz, 1986 "A New Approach to Evaluating Natural Resource Investments" in *The Revolution in Corporate Finance*, Joel M. Stern and Donald H. Chew eds., Oxford UK, Basil Blackwell Ltd., pp. 78-88.
- Cox, John C. and Mark Rubinstein 1985 *Options Markets*, Prentice-Hall, Inc, Englewood Cliffs, New Jersey.
- Gerwin, Donald, 1990 "Capital Justification and the Value of Flexibility", Carleton University Working Paper #90-5.
- Hayes Robert H. and William J. Abernathy, 1980 "Managing our way to economic decline", *Harvard Business Review*, July -August 1980, pp. 67-77.
- Kester, W. Carl, 1984 "Tcday's options for tomorrow's growth", *Harvard Business Review*, March-April 1984, pp. 153-160.
- Kulatilaka, Nalin, 1988 "Valuing the Flexibility of Flexible Manufacturing Systems", *IEEE Transactions on Engineering Management*, Vol. 35, No. 4, November 1988, pp. 250-257.
- Mann, David, Gerry Goobie and Lionel MacMillan, 1991 "Options Theory and Strategic Investment Decisions", CIM Paper no. 89-40-90, Submitted for publication in *Journal of Canadian Petroleum Technology*.
- Majd, Saman and Robert S. Pindyck, 1985 "Time to Build, Option Value, and Investment Decisions", Sloan School of Management, MIT, Working Paper, June 1985.
- McDonald, Robert L. and Daniel R. Siegel, 1985 "Investment and the Valuation of Firms When there is an Option to Shut Down", *International Economic Review*, Vol. 26, No. 2, June 1985, pp. 331-349.
- Mitchell, Graham R. and William F. Hamilton, 1988 "Managing R&D as a Strategic Option", *Research Technology Management*, May-June 1988, pp. 15-22.

- Myers, Stewart, 1977 "The Determinants of Corporate Borrowing", *Journal of Financial Economics*, no. 5, November 1977, p. 147.
- Myers, Stewart C. and Saman Majd, 1983 "Calculating Abandonment Value Using Options Pricing Theory", Sloan School of Management, MIT, Working Paper #1462-83, May 1983.
- Person, Ron, 1991 *Using Excel 3 for Windows*, Que Corporation, Carmel, Indiana, 1991.
- Ross, Bradley N., 1991 "Managing R&D as an Opportunity Center", paper to be presented at the PICMET Conference, Portland, Oregon, October 27-31, 1991.
- Stoll, Hans R., 1969 "The Relationship between Put and Call Option Prices", *Journal of Finance*, Vol 24, No.5, December 1969, pp. 801-824.
- Trigeorgis, Lenos and Scott P. Mason, 1987 "Valuing Managerial Flexibility", *Midland Corporate Financial Journal*, Spring 1987.

Appendix 1

EVALUATION FRAMEWORK - COST AND EASE OF USE

Attributes of:

Characteristic	Model	Business
Input information	Requirements	Availability
Human resources	Needed skills	Available, obtainable or developable skills
Hardware	Necessary	Existing and potential
Cost of evaluation	Manpower & resources to deliver input and run model	Justifiable cost
Time of evaluation	Time to achieve output	Time available for typical evaluation

Appendix 2

EVALUATION FRAMEWORK -
FORMAT /USEFULNESS OF MODEL AND
OUTPUT

CHARACTERISTIC	EVALUATION
Usability of model	Understandable, convenient...
Form of results	Can be used and understood
Confidence in results	Credibility, potential for advocacy bias
Utility of results	new, better information
Utility of model	would sponsor use the model in conduct of business, will managers adopt results
Introduction requirements	Education and training of the organization, etc.

Appendix 3

Terminology and Definitions

- annual R&D cost: yearly expenditures that will be made by the company to conduct the R&D program; k\$
- average cost of capital: the long term average after tax cost of capital for the company (including cost of debt and equity); %
- after tax rate - revenue: the contribution to the after tax net cash flow of the company made by an additional \$ of revenue; %
- after tax rate - op costs: the reduction of the after tax net cash flow of the company made by an additional \$ of revenue; %
- after tax rate - investment: the reduction of the after tax net cash flow of the company made by an additional \$ of investment (present value effect to the year of expenditure); %
- base year of the evaluation: the year of the evaluation to which all discounted cash flows will be set; yr
- R&D chance of success: the estimated probability that the R&D program will develop the desired technology; %
- corporate hurdle rate: the target discount rate used to evaluate expenditures within the company; %
- cost of failed program: the yearly cost that would be incurred for the R&D program if it were unsuccessful and terminated at the earliest opportunity after its failure could be detected; k\$
- current outlook: the forecast present value, based on the current most likely forecasts, that would be gained by implementing the technology developed by the R&D program (does not include the investment to implement); k\$
- future investment: the annual investments necessary in the future to realize the opportunity created by the technology developed by the R&D; k\$
- high side variability: the measure of uncertainty in the distribution of the forecast present value, for the set of outcomes greater than the current outlook; k\$

low side variability: the measure of uncertainty in the distribution of the forecast present value, for the set of outcomes less than the current outlook; k\$

minimum required value of the R&D program: the target net risked value of the R&D program that can be set for running sensitivities; k\$

net risked value of the R&D program: the risked present value of the R&D program that recognizes the values of the various optional uses of the technology that is to be developed and the chance of success of developing that technology; k\$

option value - implementation: the net present value calculated for the opportunity to implement the technology at some point in the future; k\$

option value - enhance tech.: the net present value calculated for the opportunity to enhance the technology and then implement it at some point in the future; k\$

option value - other products: the net present value calculated for the opportunity to use the technology to improve other products at some point in the future; k\$

option value - sell technology: the net present value calculated for the opportunity to sell the technology at some point in the future; k\$

PV cost to exercise option: the present value, after tax of the future investments needed to take advantage of the opportunity created by the technology (this will be the PV of the 'future investment' described above); k\$

PV cost of failed program: the present value, after tax of the 'cost of failed program' described above; k\$

PV cost of R&D program: the present value, after tax of the 'annual R&D cost' described above; k\$

PV high case: the forecast after tax present value of the most optimistic result of investing in the technology developed by the R&D; k\$

PV low case: the forecast after tax present value of the least optimistic result of investing in the technology developed by the R&D; k\$

R&D investment tax credit: the tax credit rate granted by the government for eligible R&D expenditures; %

total failed R&D cost: the arithmetic sum (undiscounted) of the 'cost of failed program' costs described above; k\$

total cost of R&D: the arithmetic sum (undiscounted) of the 'annual R&D cost' costs described above; k\$

total value of all options: the sum of all of the option values (described above) that exist for the technology that is to be developed by the R&D program; k\$

year spent: the calendar year in which the referenced investment or cost is made; yr

years until technology available: the elapsed time from the 'base year of evaluation' until the technology developed by the R&D program will be available to be invested in; yrs

Appendix 4
Option Evaluation Model

OPTIONS - R&D EVALUATION TOOL

MAIN MODULE (1) - EVALUATION OF R&D PROGRAM:

Enter name of R&D program here

DATA INPUT SECTION

Input basic data about the proposed R&D program:

**ANNUAL R&D COST (K\$ AS SPENT) -
YEAR SPENT -**

R&D CHANCE OF SUCCESS -
COST OF FAILED PROGRAM (K\$) -
YEAR SPENT -

BASE YEAR OF EVALUATION -
YEARS UNTIL TECHNOLOGY AVAILABLE -

Verify the following corporate default values:

AVERAGE COST OF CAPITAL =	10%
AFTER TAX RATE - REVENUE =	55%
AFTER TAX RATE - OPCODES =	55%
AFTER TAX RATE - INVESTMENT =	60%
R&D INVESTMENT TAX CREDIT =	20%
CORPORATE HURDLE RATE =	15%

0

YEAR SPENT -

What improvement in the profitability of the implemented technology could be expected from the additional invest made above? Enter the current outlook of the improvement or select a button to obtain a worksheet for calculations.

Calculate Factors

Calculate Option Value

What additional investments could be made to improve the profitability of other related products? Enter estimates below:

FUTURE INVESTMENT (K\$) =
YEAR SPENT =
PV COST TO EXERCISE OPTION (after tax K\$) =

CURRENT OUTLOOK (K\$) =
HIGH SIDE VARIABILITY (K\$) =
LOW SIDE VARIABILITY (K\$) =

Calculate H/M/L

OPTION VALUE - OTHER PRODUCTS (K\$) =

Calculate Option Value

SALE OF TECHNOLOGY OPTION VALUE:

Could the technology developed by this R&D be sold to other companies in the future? Enter estimates of the costs to sell the technology:

FUTURE INVESTMENT (K\$) =
 YEAR SPENT =
 PV COST TO EXERCISE OPTION (after tax K\$) = 0

What profit could be expected from the sale of the technology? Enter the current outlook of the sales option or select a button to obtain a worksheet for doing calculations.

CURRENT OUTLOOK (K\$) =
 HIGH SIDE VARIABILITY (K\$) =
 LOW SIDE VARIABILITY (K\$) =

Calculate H/M/L

Calculate Factors

Select 'Calculate Option Value' button to calculate value of selling technology to other companies. Hit 'ENTER' at the Solver Menu to confirm solution.

OPTION VALUE - SELL TECHNOLOGY (K\$) =

Calculate Option Value

Select the option values you wish to calculate with the buttons below. When all required option values have been obtained, continue to results section below.

Implement
Technology

Enhance
Technology

Improve Other
Products

Sell Technology

SUMMARY OF RESULTS:

TOTAL COST OF R&D (before tax K\$) =	0
PV COST OF R&D PROGRAM (after tax K\$) =	0
R&D CHANCE OF SUCCESS =	0%
TOTAL FAILED R&D COST (before tax K\$) =	0
PV COST OF FAILED PROGRAM (after tax K\$) =	0
YEARS UNTIL TECHNOLOGY AVAILABLE =	0
OPTION VALUE - IMPLEMENTATION (K\$) =	0
OPTION VALUE - ENHANCE TECH (K\$) =	0
OPTION VALUE - OTHER PRODUCTS (K\$) =	0
OPTION VALUE - SELL TECHNOLOGY (K\$) =	0
TOTAL VALUE OF ALL OPTIONS (after tax K\$) =	0
NET RISKED VALUE OF THE R&D PROGRAM (K\$) =	0
(INCLUDING COST OF R&D)	
BASE YEAR OF EVALUATION =	0

SENSITIVITY OF RESULTS

A change of 5% in the value of the input parameters is the default assumed in the program. You may select any % change you wish by typing over the 5% with the number of your choice.

An increase
of:

5%

in the value
of the:

TOTAL COST OF R&D

#DIV/0!

R&D CHANCE OF SUCCESS

#DIV/0!

TOTAL FAILED R&D COST

#DIV/0!

TOTAL VALUE OF OPTIONS

#DIV/0!

Results in a
change of:

In the net
risked
value of
the R&D
program.

Appendix 5

Current Outlook Spreadsheet - H/M/L

MOD4 XLT

OPTION 4 - THE R&D EVALUATION TOOL
 MODULE 4 - CURRENT OUTLOOK OF UTILIZED TECHNOLOGY
 MID-LEVEL CASE EVALUATION

OPTION 4 - THE R&D EVALUATION TOOL
 MODULE 4 - CURRENT OUTLOOK OF UTILIZED TECHNOLOGY
 MID-LEVEL CASE EVALUATION

DATA INPUT SECTION

Update default information below (if necessary) and enter high, current estimate and low estimate in the appropriate worksheets. Enter production and test data on the input or a net cash flow profile can be entered for each technology.

CORPORATE DISCOUNT RATE - 15%
 AVERAGE COST OF CAPITAL - 10%
 AFTER TAX RATE REVENUE - 90%
 AFTER TAX RATE OP COSTS - 90%
 AFTER TAX RATE INVESTMENT - 80%
 YEARS UNTIL TECH AVAILABLE -
 BASE YEAR OF EVALUATION -

HIGH CASE

YEARS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLUME (ANNUAL UNITS IN '000)																
PRICE (\$/UNIT)																
OTHER REVENUE (ANNUAL \$)																
OPERATING COSTS (ANNUAL \$)																
SUSTAINING CAPITAL (ANNUAL \$)																
ANNUAL NET CASH FLOW (\$)																
ANNUAL DISCOUNTED NCF (\$)																

MOD4.XLT

CURRENT OUTLOOK

YEARS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLUME (ANNUAL UNITS IN 000)																
PRICE (\$/UNIT)																
OTHER REVENUE (ANNUAL \$)																
OPERATING COSTS (ANNUAL \$)																
SUSTAINING CAPITAL (ANNUAL \$)																
ANNUAL NET CASH FLOW (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL DISCOUNTED NCF (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LOW CASE

YEARS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLUME (ANNUAL UNITS IN 000)																
PRICE (\$/UNIT)																
OTHER REVENUE (ANNUAL \$)																
OPERATING COSTS (ANNUAL \$)																
SUSTAINING CAPITAL (ANNUAL \$)																
ANNUAL NET CASH FLOW (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL DISCOUNTED NCF (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PV HIGH CASE (\$)

CURRENT OUTLOOK (\$)

PV LOW CASE (\$)

RESULTS SECTION

- CURRENT OUTLOOK (\$)
- HIGH SIDE VARIABILITY (\$)
- LOW SIDE VARIABILITY (\$)

Please read results from this module, and add your module under the name appropriate to the project

Appendix 6

Current Outlook Spreadsheet - Variability

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OPTIONAL - R&D EVALUATION TOOL
MODULE 5 - CURRENT OUTLOOK OF UTILIZED TECHNOLOGY
VARIABILITY OF INPUT FACTORS METHOD

OPTION 1 - LOW R&D EXPENDITURE AND OPTIMISTIC R&D RESULTS

Update default information below (if necessary) and enter appropriate values in the worksheet. Either production and cost data can be entered in yearly cash flow numbers can be entered at the bottom of the worksheet

CORPORATE HURDLE RATE = 15%
AVERAGE COST OF CAPITAL = 10%
AFTER TAX RATE REVENUE = 90%
AFTER TAX RATE OF COSTS = 90%
AFTER TAX RATE INVESTMENT = 90%
YEARS UNTIL TECH AVAILABLE =
BASE YEAR OF EVALUATION =

CURRENT OUTLOOK

YEARS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
VOLUME (ANNUAL UNITS IN Q200)																
PRICE (\$/UNIT)																
OTHER REVENUE (ANNUAL \$)																
OPERATING COSTS (ANNUAL \$)																
SUSTAINING CAPITAL (ANNUAL \$)																
ANNUAL NET CASH FLOW (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANNUAL DISCOUNTED NCF (\$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRESENT VALUE (\$)	0															

Enter the average values for price and volume in the table below and either the expected variance for the input factors (standard deviation) or input the distribution minimum and maximum range of the factor and variance will be calculated

INPUT FACTOR	Average Value	High Side Variance	Low Side Variance	High Side Possible	Low Side Possible
VOLUME (KBO UNITS)					
PRICE (\$/B)					
OTHER REVENUE (K\$)					
OPERATING COSTS (K\$)					
SUSTAINING CAPITAL (K\$)					
TOTAL					

RESULTS SECTION

CURRENT OUTLOOK (K\$) =
HIGH SIDE VARIANCE (K\$) =
LOW SIDE VARIANCE (K\$) =

Record the results from this module, and add across the module under a name appropriate for the project

Appendix 7

Sensitivity Model - Option Value

MOD3.XLT

OPTIONS - R&D EVALUATION TOOL
MODULE 3 - OPTION VALUE SENSITIVITY ANALYSIS TOOL

PROGRAM:

Enter the highest, current outlook and lowest case forecast present values and the expected cost of exercising the option (implementation cost, marketing cost, etc.) below and hit 'Calculate Option Value'

PV HIGH CASE (K\$) =
CURRENT OUTLOOK (K\$) =
PV LOW CASE (K\$) =

CURRENT OUTLOOK (K\$) = 0
HIGH SIDE VARIABILITY (K\$) = 0
LOW SIDE VARIABILITY (K\$) = 0

PV COST TO EXERCISE OPTION (after tax K\$) =

Calculate Option Value

OPTION VALUE (K\$) =

Select the appropriate button(s) to calculate the sensitivity of the Option Value to the different input variables.

A change of 5% in the value of the input parameters is the default assumed by the model. You may select any % change you wish by typing over the 5% with the number of your choice. NOTE: the sensitivity results MUST be recalculated by reselecting the buttons after any change to the amount of variance for the sensitivity.

An increase
of:

5%

in the value
of the:

High Value of Exercise

Medium Value of Exercise

Low Value of Exercise

Cost of Exercise

Results in a
change of:

In the
option
value

Appendix 8

Sensitivity Model - R&D Value

MOD6.XLT

OPTIONS - R&D EVALUATION TOOL
MODULE 6 - SENSITIVITIES USING MINIMUM REQUIRED
VALUE OF THE R&D PROGRAM

Program:

Enter the values for the 'Parameters of the R&D program' and enter a target value that you want to achieve for the Net Risked Value of the R&D Program. This module will then calculate a required value to achieve this target for each parameter assuming the other parameters remain as entered.

PARAMETERS OF THE R&D PROGRAM

PV COST OF R&D PROGRAM (after tax K\$) =
R&D CHANCE OF SUCCESS =
PV COST OF FAILED PROGRAM (after tax K\$) =
TOTAL VALUE OF ALL OPTIONS (after tax K\$) =

NET RISKED VALUE OF THE R&D PROGRAM (K\$) = 0

MINIMUM REQUIRED VALUE OF THE R&D PROGRAM (K\$) =

SUMMARY OF RESULTS:

To achieve the target net risked value for the R&D program with all other parameters as you have entered, the parameter:

PV COST OF R&D PROGRAM	<	#DIV/0!
R&D CHANCE OF SUCCESS	>	#DIV/0!
PV COST OF FAILED PROGRAM	<	0
TOTAL VALUE OF ALL OPTIONS	>	#DIV/0!

must
be:

Appendix 9

Detailed Manual Option Value Calculation

TEST # 4

EXPECTED VALUE = 100
HIGH & LOW VARIABILITY = 30
PV COST TO IMPLEMENT = 120

μ	σ	X	$\bar{X}$	$\bar{X} - 120$
.1524	.667	120	-	-
.2398	.707	121.2	120.6	0.6
.2272	.748	122.4	121.8	1.8
.2145	.791	123.7	123.1	3.1
.2019	.835	125.1	124.4	4.4
.1893	.880	126.4	125.8	5.8
.1767	.928	127.8	127.1	7.1
.1641	.977	129.3	128.6	8.6
.1514	1.030	130.7	130.1	10.1
.1388	1.086	132.6	131.8	11.8
.1262	1.145	134.4	133.5	13.5
.1136	1.208	136.2	135.3	15.3
.1010	1.273	138.2	137.2	17.2
.0883	1.351	140.5	139.4	19.4
.0757	1.435	143.1	141.8	21.8
.0631	1.530	145.9	144.5	24.5
.0505	1.640	149.2	147.6	27.6
.0379	1.776	153.3	151.3	31.3
.0252	1.957	158.7	156.0	36.0
.0126	2.238	167.1	162.9	42.9
0	3	193	178.6	58.6

361.4 x probability that value will be in any one area

$$\text{OPTION VALUE} = 361.4 \times 0.0126$$

$$= 4.54$$

model value = 3.63, corrected model value = 4.56

- where X = the maximum value of implemented technology in any of the areas to be calculated
 ρ = the probability that the value will be above X
 μ = the number of standard deviations X is above 100
 $\bar{X}$ = average X in any area
 $\bar{X} - 120$ = average difference between value and cost in any area

Appendix 10
Summary Sheets for Projects

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OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project A - New plastics product development

R&D COST: \$150,000 in 1992, \$11,350,000 total

CHANCE OF SUCCESS: 35%

NET RISKED VALUE OF THE R&D PROGRAM: \$2,000,000

DISCUSSION

The options analysis of this project indicates that is profitable but the level of profit is low compared to the large R&D investment that would ultimately required to deliver the desired technology. Sensitivity analysis (Mod 1) shows that the project is sensitive to the total value of the options created by the technology, the chance of success and the cost of the R&D. Further analysis (Mods 6&3) confirm the sensitivity to chance of success and show that the option value is sensitive to the high side outlook for implementing the technology and the cost of implementation.

If the decision to go forward with R&D is made, maximum benefit could be gained by attempting to discover ways of reducing the cost of the R&D and the cost of implementation, improving the chance of success, and improving or developing new options for the technology.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project B - Environmental cleanup

R&D COST: \$305,000 in 1992, \$830,000 total

CHANCE OF SUCCESS: 40%

NET RISKED VALUE OF THE R&D PROGRAM: \$8,800,000

DISCUSSION

Options analysis shows that this is a very valuable project, but it may be prudent to exercise some caution regarding the potential value of implementing the technology as the numbers in this area may be soft. To examine the effect on value of changes in those input parameters, sensitivity analysis (Mod 6) was run. This shows that the R&D program is still very valuable, even at a much lower value for the implementation and at much lower chance of success. We can therefore be comfortable that the project is profitable over a wide range of potential outcomes.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project C - Petrochemical process analysis

R&D COST: \$180,000 in 1992, \$570,000 total

CHANCE OF SUCCESS: 90%

NET RISKED VALUE OF THE R&D PROGRAM: \$5,780,000

DISCUSSION

Options analysis shows this to be an excellent project, with a high value returned for the R&D expenditure. The sensitivity analysis (Mod 1) shows that the program is relatively insensitive to changes in the cost of the R&D and although it is sensitive to chance of success and option value of implementation, the analysis in Mod 6 indicates that the program is still valuable when these variables are reduced to a fraction of their forecast values.

This R&D program shows very high value relative to cost and is still valuable even at chance of success as low as 10%.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project D - Plastics catalyst development

R&D COST: \$200,000 in 1992, \$800,000 total

CHANCE OF SUCCESS: 20%

NET RISKED VALUE OF THE R&D PROGRAM: \$1,360,000

DISCUSSION

Analysis of this R&D program shows good value although not as high as some of the others analyzed. Sensitivity analysis shows that the value is particularly sensitive to the chance of success and the value of the implemented technology. In order to improve the value of this program, improvements would be needed in the chance of success, cost to implement and particularly in the expected outlook for the value of implementation of the technology.

If R&D were to proceed, it would best be aimed at improving the chance of success of the program and the value of implementing the technology. (other new optional uses of the technology could also significantly affect the value)

OPTICNS - R&D EVALUATION TOOL

RETROSPECTIVE ANALYSIS

PROJECT: Project E - MHEALTH system

R&D COST: forecast \$200,000; actual \$500,000

CHANCE OF SUCCESS: forecast 75%

NET RISKED VALUE OF THE R&D PROGRAM: forecast \$35,000; actual \$144,000

DISCUSSION

Evaluation of this project from the perspective in 1986 showed a profitable project that should have had a value that exceeded its cost by about 20%. The analysis of actual performance showed higher cost for the R&D and a value that exceeds the cost by about 30%. In this project, it seems as though the model would have fairly represented the project for decision making purposes, although the estimates of costs and returns were smaller than the actual result.

OPTIONS - R&D EVALUATION TOOL

RETROSPECTIVE ANALYSIS

PROJECT: Project F - Cloudpoint

R&D COST: forecast \$50,000 in 1989

CHANCE OF SUCCESS: forecast 90%

NET RISKED VALUE OF THE R&D PROGRAM: forecast \$77,000

DISCUSSION

Data insufficiencies made it impossible to recreate the situation when the R&D for this project were first undertaken. The decision was therefore made to model the 1989 decision point for further development and marketing of the technology. The analysis shows that the marketing option has a positive value, well in excess of the cost of development and a high chance of success. (owing no doubt to the 'D' nature of the work rather than 'R') Further information will be required to assess the effectiveness of the model in establishing value. The analysis performed does however show the usefulness of the model in evaluating a program after it has started but prior to completion.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project G - Build catalyst test facility

R&D COST: \$100,000 total, all in 1992

CHANCE OF SUCCESS: 90%

NET RISKED VALUE OF THE R&D PROGRAM: \$245,000

DISCUSSION

This is a good solid program with option value arising from three different areas. Although the value of the program is not high, it is significantly in excess of the investment required to develop the technology. Each of the optional uses of the technology could justify the R&D providing a very sound basis for proceeding.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project H - Plastics Application

R&D COST: \$75,000 in 1992, \$150,000 total

CHANCE OF SUCCESS: 70%

NET RISKED VALUE OF THE R&D PROGRAM: \$3,200,000

DISCUSSION

The options analysis of this project indicates that is extremely valuable although only one optional use of the derived technology has been explored. The low R&D costs, low implementation cost, high chance of success and high expected value of implementation combine to give a very robust project that could withstand considerable unfavourable movement in any of the input parameters.

Further effort could likely be profitably spent developing further alternative uses for the developed technology.

OPTIONS - R&D EVALUATION TOOL

SUMMARY OF ANALYSIS

PROJECT: Project I - New catalyst for new and existing products

R&D COST: \$200,000 in 1992, \$800,000 total

CHANCE OF SUCCESS: 35%

NET RISKED VALUE OF THE R&D PROGRAM: \$5,100,000

DISCUSSION

This is an excellent project with two solid options, each of which could easily justify the program on its own. The program has a very high value relative to the required investment, even at a moderate to low chance of success. As outlined in the input data supplied by the project sponsor, the program also has several other optional uses that could not be evaluated at this time but that have significant intangible benefit.

Appendix 11
1st Questionnaire

FEEDBACK ON USE OF OPTION ANALOGY

● EFFECTIVENESS OF COMMUNICATION:

- **Rate your understanding of the concept of options theory for R&D evaluation.**

UNDERSTAND

- **Areas requiring clarification (if any):**

o APPROPRIATENESS OF ANALOGY:

How appropriate is it to view R&D as a method of creating options?

VERY

What is the strongest/weakest link in the R&D - options analogy?

• **INFORMATION REQUIREMENTS:**

From your experience, is the information necessary to evaluate R&D in this manner available?

AVAILABLE

What information would be the most difficult to obtain?

o **APPROPRIATENESS OF OPTIONS EVALUATION TOOL FOR R&D:**

How appropriate is it to use the options evaluation tool to examine R&D projects?

NOT AT ALL

VERY

| | | | | | | | | |

What uses do you see for the results of evaluating an R&D project in this manner?

Do you feel that the development of the options model is worth pursuing?

WASTE OF TIME

WORTHWHILE

| | | | | | | | | |

What aspects of the model/analogy need to be highlighted on in communication and education of the options evaluation technique?

o **GENERAL COMMENTS:**

NAME: (Optional) _____

Appendix 12

2nd Questionnaire - Managers

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Do you think that discussing R&D projects in terms of options will improve your ability to communicate the features and benefits of a project to senior management? (please explain)

Do you think that discussing R&D projects in terms of options will improve your ability to communicate the features and benefits of a project within the research organization? (please explain)

EVALUATION OF OUTPUT FROM THE MODEL

Rate your understanding of the results obtained from the options analysis model.

DON'T UNDERSTAND SOMEWHAT COMPLETELY UNDERSTAND
| | | | | | | | | | | | | | | | | |

What areas are particularly clear or unclear?

What improvements in the presentation of results would be useful (if any)?

Rate your perception of the credibility of the results of the model.

NOT CREDIBLE MODERATELY VERY CREDIBLE
| | | | | | | | | | | | | | | | | |

What aspects of the model or analysis contribute most to your perception of credibility?

Did the results of the model provide any new or different information about the R&D project compared to other analyses currently being used? (Please describe)

Rate your willingness to use the options model as an additional method of evaluation of R&D projects in the normal conduct of business.

UNWILLING MODERATELY VERY WILLING

| | | | | | | |

What factors contribute the most to your (un)willingness to use the model?

What training would you require if the use of the options evaluation model were to be adopted by the company for regular use?

What associated changes to existing procedures and systems within your department would be necessary if the options evaluation model were to be adopted by the company for regular use? (eg. capital appropriation procedure, roles and responsibilities...)

Did the options analysis process change your perception of the number of alternative uses of the technology to be developed by the R&D?

Describe any changes in your perception.

Describe any changes in your perception.

Describe any changes in your perception.

NO CHANGE **SOMEWHAT** **SIGNIFICANT CHANGE**

Describe any changes in your perception.

Did the options analysis process change your perception of the priority that should be assigned to the different parts of the proposed R&D project? (eg. higher priority on defining implementation cost)

NO CHANGE SOMEWHAT SIGNIFICANT CHANGE

| | | | | | | | | | | | | | | | |

Describe any changes in your perception.

Did the options analysis process have any other benefits or drawbacks? (please describe)

Do you have any other comments?

Appendix 13

2nd Questionnaire - Project Sponsors

Questionnaire 2a - Project Sponsors

EVALUATION OF OPTIONS ANALYSIS OF R&D PROGRAM

PROJECT:

EVALUATOR'S POSITION:

The following questionnaire is divided into four sections. These sections gather information on the data collection process, the evaluator's opinion of using options analysis, the evaluator's rating of the data output from the options evaluation model and the perception of the benefits and drawbacks of the options evaluation process from data gathering through to presentation of results. Please provide as complete answers as you can as this will allow us to not only to evaluate the process but also to make improvements to increase its effectiveness.

DATA GATHERING AND PREPARATION

How much time was spent on data collection and preparation for the options evaluation of this project? _____

Was the information required for the evaluation generally available?

NOT AVAILABLE MODERATELY EASILY AVAILABLE
| | | | | | | | |

What type of data (if any) was difficult to obtain or estimate?

Generally how reliable is the data that was collected?

NOT RELIABLE AVERAGE VERY RELIABLE
| | | | | | | | |

What type of data (if any) is particularly unreliable?

Is any of the data particularly prone to manipulation or bias by the person collecting or supplying the data?

Do you have any recommendations as to ways to reduce the potential bias in the data used for options evaluations?

Did the data collection and preparation process provide any other benefits or drawbacks?

CONCEPT OF OPTIONS ANALYSIS

Rate your understanding of the concept of options analysis of R&D projects.

NO UNDERSTANDING SOMEWHAT COMPLETELY UNDERSTAND
| | | | | | |

What areas (if any) require clarification?

How appropriate is it to view R&D as a method of creating options?

NOT AT ALL SOMEWHAT VERY APPROPRIATE
| | | | | | |

Rate your understanding of the results obtained from the options analysis model.

UNSUITABLE **MODERATELY** **VERY SUITABLE**

What improvements in the presentation of results would be useful (if any)?

Rate your perception of the credibility of the results of the model.

NOT CREDIBLE MODERATELY VERY CREDIBLE

| | | | | | | | |

What aspects of the model or analysis contribute most to your perception of credibility?

Did the results of the model provide any new or different information about the R&D project compared to other analyses currently being used? (Please describe)

Rate your willingness to use the options model as an additional method of evaluation of R&D projects in the normal conduct of business.

UNWILLING MODERATELY VERY WILLING

| | | | | | | | |

What factors contribute the most to your (un)willingness to use the model?

What training would you require if the use of the options evaluation model were to be adopted by the company for regular use?

What associated changes to existing procedures and systems within your department would be necessary if the options evaluation model were to be adopted by the company for regular use? (eg. capital appropriation procedure, roles and responsibilities...)

BENEFITS AND DRAWBACKS OF THE OPTIONS ANALYSIS PROCESS
(from data collection to analysis of the results)

Did the options analysis process change your perception of the number of alternative uses of the technology to be developed by the R&D?

NO CHANGE SOMEWHAT SIGNIFICANT CHANGE
| | | | | | | | |

Describe any changes in your perception.

Did the options analysis process change your perception of the values of the alternative uses of the technology to be developed by the R&D?

NO CHANGE SOMEWHAT SIGNIFICANT CHANGE
| | | | | | | | | | | | | | | |

Describe any changes in your perception.

Did the options analysis process change your perception of the total value of the proposed R&D project?

NO CHANGE SOMEWHAT SIGNIFICANT CHANGE
| | | | | | | | | | | | | | | |

Describe any changes in your perception.

Did the options analysis process change your perception of the parameters that the value of the proposed R&D project was most sensitive to?

NO CHANGE SOMEWHAT SIGNIFICANT CHANGE
| | | | | | | | | | | | | | | |

Describe any changes in your perception.

Did the options analysis process change your perception of the priority that should be assigned to the different parts of the proposed R&D project? (eg. higher priority on defining implementation cost)

NO CHANGE

SOMEWHAT

SIGNIFICANT CHANGE

| | | | | | | |

Describe any changes in your perception.

Did the options analysis process have any other benefits or drawbacks? (please describe)

Do you have any other comments?

END

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FIN