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USING INFORMATION GENERATED BY A DISCRETE EVENT SIMULATION TO EVALUATE REAL OPTIONS IN A RESEARCH AND DEVELOPMENT ENVIRONMENT

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ABSTRACT

This article examines how a discrete event simulation can be developed to evaluate the impact of real options on a research and development project. Previous work with real options has been primarily mathematically based and the approach was not transferable to actual projects. The results shown in this article indicate that simulation is a valid method to evaluate real options and that the real options do impact the net present value of a process.

1 INTRODUCTION

The pharmaceutical and agricultural chemical industries must regularly introduce new products as disease causing agents and pests become resistant to their current products and as new diseases and pests arise. The introduction and competitive pricing of new products depends on an effective research and development (R&D) process. Moreover, the speed with which new products can be introduced can give a company the significant competitive advantage of being the first to market a new product. For many companies, effective allocation of R&D resources (e.g., money, equipment, personnel, time, labs, agricultural research stations, clinical facilities) to a wide variety of projects and control of resource costs are crucial to delivering new products to market in a timely and profitable manner.

Maintaining sufficient resources to complete all possible R&D projects in the shortest possible time is neither cost effective or practical for most pharmaceutical and agricultural chemical companies. For this reason, R&D projects must compete for resources. Resources allocated to one project are eliminated from the total available pool of resources that can be allocated to all projects, at least for a period of time. Expending resources on one project typically means that another potential project is delayed or not funded. Resource allocation and scheduling is further complicated by the fact that many projects are abandoned during development due to failure of regulatory tests or test results indicating that the product may be less effective or may have undesireable side effects that indicate an increased risk of putting the product on the market. Resources allocated to abandoned projects may then be reallocated to other projects, potentially allowing them to be completed sooner. Unfortunately, the inherent randomness of project abandonment produces runs of successful and unsuccessful projects which, in turn, cause periods of resource competition and resource underutilization.

In order to determine where an organization should spend its resources, typically some type of formal process is used. Most firms use some sort of quantitative analysis technique such as net present value or return on investment. However, these techniques tend to underestimate the potential value of a project because they ignore the flexibility associated with a potential project.

In order to overcome the concern with underestimating the value of a project, the approach of "real options" was developed. In theory, real options provide a method to quantify the value of the flexibility associated with a project. However, in practice, the value of the real options is not easily incorporated into a quantitative analysis. Revenue streams are often modeled as Brownian motion. The internal consequences of decisions are frequently treated as deterministic, or at best dealt with in terms of expected values only. This paper attempts to provide a simulation-based method for assessing the impact of the randomness in project abandonment and the impact of resource competition for purposes of evaluating the real option of abandoning projects in a research and development environment. Although this paper focuses on R&D in terms of chemicals and pharmaceuticals, it has implications in other environments such as software development.

2 EVALUATING COMPETING PROJECTS

The majority of organizations use some form of quantitative analysis technique to evaluate potential projects (Bacon 1992; Gillin 1994). These analyses are straightforward to perform along with being universally recognized and accepted methods to evaluate capital asset acquisitions. They allow direct comparison to other projects and allow management to determine if projects meet or exceed the hurdle rate.

The three most common techniques used are internal rate of return, net present value, and payback (Baksh 1986; Cooper and Petry 1994; Cooper, Cornick, and Redman 1992; Freeman and Hobbes 1991; Pike 1989). Of these three techniques, net present value provides the "best" answer. However, net present value analysis as described in the textbooks (i.e., traditional net present value) has some associated limitations that can result in the value of an investment being underestimated.

A traditional net present value analysis makes implicit assumptions concerning an expected scenario of cash flows. It presumes management's passive commitment to a certain "operating strategy" (e.g., to initiate the project immediately, and operate it continuously at a set scale until the end of its pre-specified expected useful life). However, these techniques typically assume clear, measurable and reliable returns and are oriented to cost saving, productivity-oriented projects. They ignore intangible benefits and ripple effects and do not deal well with projects that have a high degree of uncertainty or have very different time horizons. The techniques ignore the synergistic effects that an investment project can create. Traditional net present value analysis usually underestimates investment opportunities because it ignores management's flexibility to alter decisions as new information becomes available (Bacon 1992; Brealey and Myers 1991; Brennan 1995; Brookfield 1995; Busby and Pitts 1995; Hayes and Abernathy 1980; Hayes and Garvin 1982; Kogut and Kulatilaka 1994; Ross 1995; Sercu and Uppal 1994; Smith and Nau 1995; Trigeorgis 1993b; Weaver et al. 1989).

Some skeptics wonder whether traditional measurement techniques associated with a project underestimate the benefits sufficiently to cause problems with determining whether a project's continuation is warranted or unwarranted. Studies have found that 76 percent of firms accept projects that fail quantitative analysis (Flatto 1996; Freeman and Hobbes 1991). In 94 percent of these cases, strategic concerns overrode the quantitative analysis (Flatto 1996; Freeman and Hobbes 1991). Based on this information, it appears that one reason organizations may continue projects even in light of negative information is the intuitive understanding that the existing measurement techniques may not be fully capturing all the benefits associated with certain projects.

2.1 Concept of Real Options

To address the limitations associated with traditional net present value analysis, Myers (1974) proposed the use of an analysis technique he called "adjusted present value". The concept of adjusted present value includes the impact of dynamic decision-making. One approach to including the value of dynamic decision-making in the adjusted present value model is through the use of real options. Real options are based upon Myers' (1977) initial discussion of discretionary investment opportunities as growth options.

The concept of real options is based upon the fact that management does have the flexibility to alter decisions as further information becomes available. If future conditions are favorable, a project may be expanded to take advantage of these conditions. On the other hand, if the future is unfavorable, a project may be curtailed or even canceled as the conditions warrant. A traditional net present value analysis does not take these factors into account management's flexibility to improve a project's upside potential while limiting the impact of the project's downside losses.

Previous work in real options (Trigeorgis 1988; Trigeorgis 1993b) has generated a taxonomy that has broken down real options into six categories based upon the type of flexibility provided. The six categories are (1) the option to defer, (2) the option for staged investments, (3) the option to change the existing scale, (4) the option to abandon, (5) the option to switch use, and (6) the option to grow. It is also possible for more than one category of real options to be applicable in a given project that leads to multiple interacting real options.

Many projects do not have only a single real option that is applicable to them. Depending on the type of project, more than one real option must be considered when computing the adjusted present value (Rose 1998; Trigeorgis 1993a). These options can interact in various ways. The value of interacting multiple options may not be equivalent to the value of the individual options added together.

Real options may be valued similarly to financial options even though they can not be directly traded (Dixit and Pindyck 1994; Kasanen and Trigeorgis 1993; Mason and Merton 1985). The value of a stock (i.e., financial) option is determined by five variables: current value of stock; exercise price; time to expiration; stock value uncertainty; and riskless interest rate. An analogy can be made between the variables that determine the value of a stock call option and a real option as shown in Table 1 (Dasgutpa and Stiglitz 1980; Dixit and Pindyck 1994; Gehr Jr. 1981; Kester 1984; Luehrman 1998; Trigeorgis 1988). Changes in the individual variables will affect the value of the real option.

Unfortunately, the process of modeling and including the value of real options into a situation is nowhere as easy as evaluating financial options. In practice, determining the values of the variables are extremely difficult (Davis 1998; Lander and Pinches 1998; Majd and Pindyck 1987; Rose

Table 1: Comparison of Variables on Stock and Real Options

Stock Call Option	Real Option
Current value of stock	Gross present value of expected cash flows
Exercise price	Investment cost
Time to expiration	Time until opportunity disappears
Stock value uncertainty	Project uncertainty
Riskless interest rate	Riskless interest rate

1998). Additionally, the level of the mathematics is too sophisticated for most organizations (Bhappu 1995; Davis 1998).

3 A SIMULATION APPROACH

Quantifying the value of a real option to abandon a project is difficult because of delays caused by resource competition amplified by the randomness of which projects are abandoned. Specifically, this article uses a simulation approach to determine the real option value when the option to abandon has been included in the simulation. The model described in this paper is a test model of a simplified and abbreviated R&D process typical of pharmaceuticals and agricultural chemicals. It is simplified from the industrial models with which the authors have experience in order to keep the details from obscuring the principles to be tested. It is designed to be complex enough to be realistic.

3.1 The Simulation Model

The simulation model is an R&D process consisting of fifteen tasks and four decision points illustrated in Figure 1. The nodes represent tasks and the arrows represent precedence relationships. Decision points at which projects may be abandoned are marked with hexagons and up-arrows are labeled with the probability that the project will be abandoned. The decision to continue or abandon any specific project is made at the end of the task. Using the decision point probabilities, only 28.35% ($0.5\times0.7\times0.9\times0.9$) of the projects successfully complete the process and generate revenue for the company.

The model assumes that projects begin the R&D process at intervals of 8 weeks for the deterministic versions of the model and at intervals that are normally distributed with a mean of 8 weeks and a standard deviation of 1 week for stochastic versions of the model. Table 2 provides the details for each of the 15 tasks. Task times (in weeks) are equal to the mean task time in Table 2 in the deterministic model.

Times for each task are normally distributed as specified in Table 2 for the stochastic model. Costs are assumed to be proportional to the task time. Sufficient resources have been allocated for certain tasks to allow more than one project to be worked on at the same time. For example, sufficient resources have been allocated to task 1 to allow two projects to be worked on simultaneously. This might correspond to having two separate labs where work can be done. The model assumes that there are no costs while a project sits in a queue waiting to be processed. The model is a "push" model rather than a "pull" model. The simulation models are created in Extend, a simulation package available for Windows and Macintosh.

The model deals with four scenarios:

1. Deterministic task times assuming all projects that are initiated are also completed although some

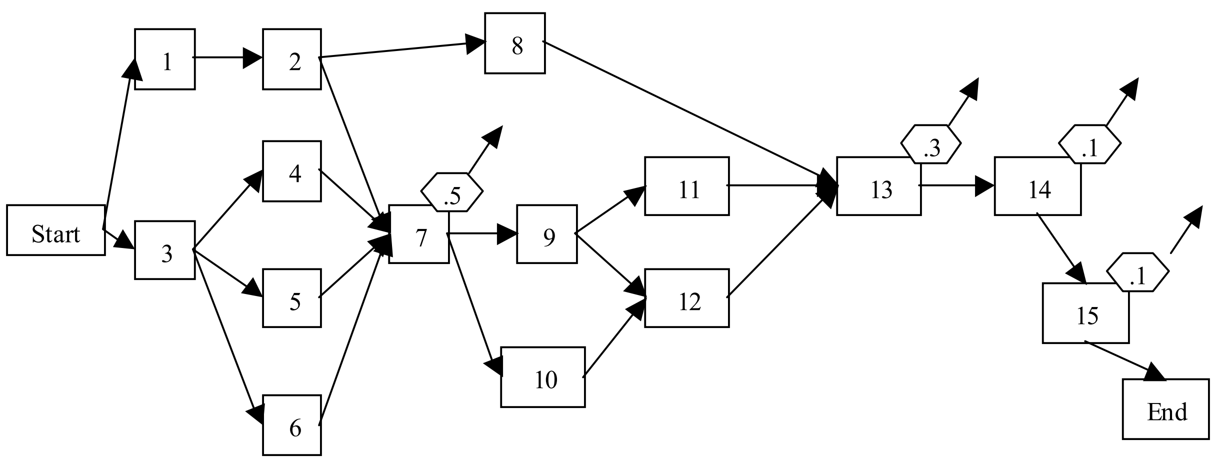

Figure 1: The R&D Model

Table 2: R&D Tasks

Task Number	Mean Task Time (Weeks)	Std. Dev. (Weeks)	Cost per Week ($1,000's)	Number of Resources	Total Cost per Task ($1,000's)
1	7	1.0	1	2	7
2	3	0.5	2	1	6
3	6	1.0	3	2	18
4	3	0.5	1	1	3
5	4	0.6	2	1	8
6	2	0.2	1	1	2
7	1	0.1	1	1	1
8	20	2.0	1	2	20
9	10	1.0	4	1	40
10	12	1.0	1	1	12
11	10	1.0	3	1	30
12	8	1.0	2	1	16
13	1	0.1	1	1	1
14	25	3.0	5	3*	125
15	25	3.0	5	3*	125

* Tasks 14 and 15 share the same 3 resources.

will generate no revenue – deterministic, no-abandon model.

2. Deterministic task times assuming that certain projects unlikely to generate sufficient revenue are abandoned at the decision points shown in Figure 1 – deterministic, abandon model.
3. Stochastic task times assuming all projects that are initiated are also completed although some will generate no revenue – stochastic, no-abandon model.
4. Stochastic task times assuming that certain projects unlikely to generate sufficient revenue are abandoned at the decision points shown in Figure 1 – stochastic, abandon model.

The model collects project cost based on discounted future cash flows for each project as a function of task times and time in system for each project for use in post-process revenue generation. Post-process revenue generation is done in a spreadsheet using the formulas given in Section 3.2. Projects in runs of the no-abandon versions corresponding in start order to projects abandoned in the abandon versions are assumed to generate no revenue. Resources, task times and input rate are set so that candidate products flow relatively freely through the process when projects are randomly abandoned at the decision points in the model given the specified probabilities and so that intense competition for resources occurs when no projects are abandoned.

3.2 Expected Costs and Revenues

The expected profit derived from an R&D project is the revenue obtained from the project less manufacturing costs and the R&D costs. R&D costs are often a function of the task times. For simplicity, the test model assumes R&D costs are a multiple of the task time. The cost of a task is computed by multiplying the mean task time by the cost per time unit as shown in Table 2. It is assumed that there are no waiting costs for the projects while they sit in a queue waiting to be processed.

The probability that a task is done depends on whether or not it falls later in time than decision points at which projects may be abandoned as shown in Figure 1.

Tasks 1 through 7 are always done because they fall before the decision point at task 7. In the deterministic model, task 8 begins after the decision at task 7 is made so it occurs with a probability of 0.5. This is not necessarily the case for the stochastic model. Tasks 9 through 13 occur after the decision at task 7 and before the decision at task 13. Therefore, they have a probability of 0.5. Task 14 falls after the first two decision points so it has a probability of 0.35 which is the probability that a project continues after both decision points obtained by multiplying the probabilities at the decision points. Similarly, Task 15 falls after three decision points so its probability of being done is a product of the probabilities of continuing at the three decision points. Expected costs are the product of costs and the probabilities that the task is done. The total cost and total expected costs are obtained by summing the costs and expected costs respectively. Results are shown in Table 3.

Table 3: Expected Costs

Task Number	Total Cost per Task ($1,000's)	Probability Task Done	Expected Cost
1	7	1.000	7.000
2	6	1.000	6.000
3	18	1.000	18.000
4	3	1.000	3.000
5	8	1.000	8.000
6	2	1.000	2.000
7	1	1.000	7.000
8	20	0.500	10.000
9	40	0.500	20.000
10	12	0.500	6.000
11	30	0.500	15.000
12	16	0.500	8.000
13	1	0.500	0.500
14	125	0.350	43.750
15	125	0.315	39.375
Total	414	Total exp.	187.625

For purposes of revenue generation, each project is assumed to have a fifteen-year lifespan from start of R&D to end of revenue generation. No revenue is generated during R&D, so the amount of revenue generated is a function of time left in the lifespan after completion of R&D. The amount of revenue generated is assumed to decrease over the lifespan of the product as competing products enter the market and the product becomes less effective against the pest or disease it treats. For this reason and the fact that continuously compounded interest is modeled by an exponential function, the function:

$$2000(e^{-0.2(releasetime)} - e^{-0.2(15)})$$

is used to model revenue less manufacturing costs. The number 2000 is the amount of revenue less manufacturing costs in thousands of dollars that a candidate product would generate during its fifteen year lifespan if it could be released instantaneously. The discounting of future cash flows and the rate of deterioration of the market over the life of the product is combined into the value of 20% (i.e., 0.2) seen in the exponent. The release time less 15 is the remaining lifetime of the product over which it generates revenue. The values of 2000, 20% and 15 years are based on the authors' experiences.

In portfolios of real projects, different projects might have different values for the revenue less manufacturing costs. Similarly, different projects might have different lifetimes. For simplicity of exposition, all projects are assumed to have equal value and equal lifetimes in this paper. Agricultural chemicals typically use a step function to represent revenue rather than an exponential because of the seasonality of their products. Again, the exponential function was used for simplicity.

A critical path analysis of the R&D process gives an expected completion time of 82 weeks or 1.577 years for projects. The revenue (less manufacturing costs) is computed from the formula:

$$2000(e^{-0.2(1.577)} - e^{-0.2(15)}) = 1359.442.$$

The expected revenue is obtained by multiplying the revenue by the probability that a project will not be abandoned which is 0.2835. Thus,

$$1359.442 \times 0.2835 = 385.402.$$

The NPVs without and with abandonment are obtained by subtracting the total cost and total expected cost respectively from the expected revenue.

NPV without abandonment:
385.402 – 414.000= –28.598.
NPV with abandonment of projects:
385.402 – 187.625 = 197.777.

The results are summarized in Table 4. The theoretical expected value does not account for delays to the project due to resource competition that reduce revenue nor does it account for variation in task times and time between project starts in the stochastic models.

Table 4: Expected Revenue

Lifetime of product in years	15
Maximum revenue less manufacturing costs	2000
Development time in weeks	82
Development time in years	1.577
Rate to allow for discounting of cash flows and decrease in revenues	0.200
Revenue if released in 82 weeks	1359.442
Expected revenue (1359.442×0.2835)	385.402
Expected cost of R&D without abandonment (from Table 3)	414.000
Expected cost of R&D with abandonment (from Table 3)	187.625
NPV without abandonment (385.402–414.000)	–28.598
NPV with abandonment of projects (385.402–187.625)	197.777

For purposes of valuing the real option of project abandonment, the revenues generated are only a function of the lifetime of the project and not of the time since the beginning of the simulation run. Likewise, the cost of the tasks are not discounted over time. The reason for this is so that delays caused by resource competition will not be discounted more for later projects in the portfolio.

4 ANALYTICAL RESULTS

One thousand repetitions of a portfolio of 25 projects each were run for each scenario. The simulation package automatically collects the cost and time to complete each project. In the no-abandonment scenarios, all 25 projects complete the R&D process and thus, each project has the full cost associated with it. However, not all of these projects generate revenue. In order to accommodate this assumption, projects are matched between the abandonment and no-abandonment models and only those projects that match generate revenue. For example, assume in one run of the deterministic, abandonment model that projects 2, 4, 7, 8, 11, 15, and 19 complete successfully while the other projects are abandoned prior to completion. In the matching deterministic, non-abandonment run; only projects 2, 4, 7, 8, 11, 15, and 19 will generate revenues. The other projects will have revenue of $0. All projects, regardless of completion, will still accumulate costs. Table 5 shows a summary of the simulation results while Table 6 compares the simulation results to the theoretical calculations.

Several observations can be made from the data of Table 6.

- The NPVs of the abandon scenarios are positive while the NPVs of the non-abandon scenarios are negative, regardless of whether the NPV comes from the deterministic version of the simulation model, the stochastic version of the simulation model, or theoretical calculations.
- The NPVs for both the simulation pairs are less than the theoretical values. This is due to delays in project completion caused by the competition for resources. The expected values assumes that there is no waiting at all for any activity and thus each project completes in 82 weeks. As can be seen Table 5, the average time in weeks for a project to complete in the abandon model is roughly twice the expected value and the average time in weeks for a project to complete in the no-abandon model is roughly three and one half times the expected value.
- The values for the stochastic scenarios are slightly worse than the corresponding deterministic scenarios. This is caused by the increased random nature of the task durations. However, the effect of stochastic task durations is much less than the impact of the fact that the projects are abandoned in random order.

Table 5: Simulation Results

	Deterministic		**Stochastic**	
	No Abandon	**Abandon**	**No Abandon**	**Abandon**
Successful Projects	7,166	7,166	7,109	7,109
Unsuccessful Projects	17,834	17,834	17,891	17,891
% Successful	28.66%	28.66%	28.44%	28.44%
Average Weeks*	286.00	156.95	288.17	158.20
Average Years	5.50	3.01	5.53	3.04
Total revenues**	$6,585,823.87	$7,236,956.10	$6,037,365.65	$7,143,426.24
Total Costs***	$10,350,000.00	$4,644,062.00	$10,349,999.47	$4,610,976.18
Revenue per project****	$263.43	$289.48	$241.49	$285.74
Cost per project****	$414.00	$185.76	$414.00	$184.44
NPV per project****	-$150.57	$103.72	-$172.51	$101.30

* Average weeks for projects that complete successfully.

** Revenues are for the 7,166 or 7,109 projects that match -- abandon versus no abandon.

*** Costs are for all 25,000 projects that start.

**** Revenue per project and costs per project are allocated over the 25,000 projects total, not just the successful projects.

Table 6: Comparison of Revenues, Costs and Profits

Scenario	Theoretical, No Abandon	Theoretical, Abandon	Deterministic. No Abandon	Deterministic, Abandon	Stochastic, No Abandon	Stochastic, Abandon
Revenue	$385.40	$385.40	$263.43	$289.48	$241.49	$285.74
Cost	$414.00	$187.63	$414.00	$185.76	$414.00	$184.44
Profit	–$ 28.60	$197.77	-$150.57	$103.72	-$172.51	$101.30

The reader should note that the literature examines the impact of real options from a theoretical mathematical perspective. Moreover, the literature typically examines a single project. As such, the literature does not take into account portfolios of multiple projects (e.g., 25) nor does it consider the impact of a random abandonment order.

5 CONCLUSION

Two obvious conclusions can be drawn from the results shown in Table 6. The first is that simulation does appear to be an appropriate method to evaluate the value of real options. This method will provide another avenue of research into the valuation of real options in addition to the direct mathematical approaches currently being used. The other conclusion is that the real option to abandon does have a positive impact on the net present value of a portfolio of projects. As such, including the real option to abandon concerts a portfolio of projects from having a negative net present value to a positive net present value.

Theoretical calculation of the value of the real option of abandoning R&D projects does not capture impact of the delays in project completion caused by the competition for resources resulting from the fact that the projects abandoned in random order. Discrete event simulation does assess the impact of these factors for the real option of project abandonment and shows promise to assist in the calculation of the value of other real options such as changing scale. Future plans are to develop an approach to simulating other real options, to study the interaction of real options and to determine if the value of the individual options is additive.

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