REAL OPTIONS: DEALING WITH UNCERTAINTY IN SYSTEMS PLANNING AND DESIGN

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ABSTRACT

The integration of "real options" analysis will radically change the design of public and private systems. It will change the processes of system design, the way planners deal with uncertainly and risk. It will also change the outcomes, the kinds of elements designers build into the system as they develop it. This paper explains this coming evolution, and presents cases documenting the changes in attitude and the results already occurring.

To think in terms of options alters the way one deals with uncertainty. Conventionally, good design minimizes risk. It focuses on increasing reliability and making the best decisions in risky situations. In short, it is reactive to risk. The framework of options thinking, however, recognizes that uncertainty adds value to options. In this context, uncertainty is a driver of value and can be viewed as a positive element. Correspondingly, systems design from this perspective is proactive towards risk. It seeks out opportunities to add value and commits to ongoing processes of information gathering to ensure that options can be exploited at the correct time

Thinking in terms of real options leads designers to build much more flexibility into a system than is common in current practice. For example, they may build duplicate combustion facilities that allow a plant to burn both natural gas and oil, or deliberately develop products that they may never launch. These investments that may be unused are "options"; they give the system managers the capability to change the design or product mix, without requiring them to do so.

The analysis of real options involves a set of procedures that adapt and extend the options analysis that won a Nobel in economics for its developers. Options analysis is now widely used for contracts on all kinds of widely traded financial instruments (stocks and bonds), commodities (oil, grain, and foreign exchange) and services (electric power, communications bandwidth). The analysis of real options applies the same basic principles, but adapts them to the particular circumstances of systems design, which generally deals with unique projects that lack historical statistics on risk.

The analysis of real options enables managers and designers to estimate the value of system flexibility. As this has not been practical before, designers have previously not considered the value of flexibility. Incorporating this capability into systems analyses adds two significant dimensions to design. Public and private operators of major systems will come to recognize:

- Large classes of projects as much more valuable than they now seem to be -- these include all those that enable further development without committing to it prematurely, such as research, product development, system modularity, exploratory mining, etc.; and
- New classes of design alternatives, specifically those enabling managers to adjust the system as needed when relevant information becomes available, that is design alternatives that involve deferral, acceleration and closure of facilities.

The paper illustrates the wide range of applications of for the analysis of real options, using documented cases in many fields of engineering. It also refers to the extent possible to companies changing their procedures for system design and management to capitalize on the promise of real options.

Key Words: Real Options, Systems Design, Flexibility, Technology Policy, Innovation

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Richard de Neufville

1. INTRODUCTION

Many thoughtful practitioners who have considered the matter conclude that the way public and private operators design and manage technological systems is about to undergo a fundamental evolution. Specifically, they believe that the introduction and analysis of “real options” into practice will have a profound effect on how we think about dealing with risk, how we develop technological systems, and how we manage these enterprises over time. They believe that although this approach may simply look like another way to assign value to projects being considered for development, the “real options” perspective

- leads analysts to adopt a substantially different perspective on how to design systems for uncertainty;
- systematically recognizes that broad classes of projects are much more valuable than they have appeared to be, and thus will tilt investments toward these activities; and
- underlines the desirability of an extensive proactive approach to gathering information about the ways uncertainties resolve, so that the system managers can exploit the value in the options.

The eventual impact of real options on systems design is not obvious, however. Practitioners come to recognize its fundamental importance as they analyze real options and see how it leads them to re-frame the way they approach systems design, and to build in much more flexibility into their designs. This paper attempts to develop and present the nature of the effect that real options will have on engineering systems design.

The immediate justification for the use of real options is that it provides a far better and much needed substitute for the current methods of project evaluation. Indeed, current practice uses discounted cash flow or, equivalently, net present value, to assign value to projects and, thus, to determine which should be funded and incorporated into design. Yet, these approaches are fundamentally flawed and inadequate whenever a project will exist in an uncertain environment. The difficulties, the fatal flaws of the discounted cash flow methods as practiced are both conceptual and mechanical.

The conceptual flaw is crucial from the perspective of options analysis. It is that discounted cash flow procedures assume a single line of development for a project. The working assumption is that a project is carried through to the end, even it fails. The analysis simply incorporates the probability of failure into the overall expected value for the project. The premise that the project continues unchanged constitutes the basis for estimating the cash flow that will be discounted and analyzed. This reasoning completely disregards the fact that public and private managers routinely abort projects mid-way through their anticipated development. For example, managers often cancel research and development projects well before these reach the point of launching products. Public authorities likewise cancel the development of major bits of infrastructure such as highways or urban rail lines. The fact that system managers abort projects that perform badly means that they truncate the distributions of risk on the downside. The expected values of these projects are therefore systematically higher than they would seem to be from the perspective of a discounted cash flow.

Simply put, the traditional approaches to evaluation do not recognize that system operators do manage their systems. Most obviously, as indicated above, they abort projects that are going bad. As many commentators have observed, the recognition of this process raises the expected value of a project significantly (see for example Trigeorgis, 1996, Neely, 1998; Amran and Kulatilaka, 1999; and Perdue et al, 1999; Neely and de Neufville, 2001). Equivalently, system managers can also manage their risks by augmenting their projects when they are performing well. This is simply the complementary action to aborting them when they do poorly. They can also manipulate the speed of the development, either accelerating or deferring projects. They can thus not only truncate the distribution of the downside risk of failure, but also augment the upside distribution of the chances for success.

In short, the discounted cash flow procedures fail – when applied to systems operating in an uncertain environment – to recognize that effective management of the risks enhances the value of the system. These methods are still adequate for calculating present values of unchanging projects, for example the return on a fixed annuity, or of investments that once made are not managed, such the insulation of a building. Put another way, the discounted cash flow methods are adequate over a limited range that does not include major technological investments operating in the midst of considerable technological and market uncertainties.

Additionally, standard discounted cash flow methods have at least two mechanical flaws. As applied in practice, they:

- assume that the expected value of the average conditions used to generate the cash flow is equal to the average of the expected values of the range of cash flows that may actually occur. This is false because the returns from projects are routinely asymmetric. (This fallacy is commonly referred to as the "flaw of the averages".) For example, the results arising from a 10% increase in sales can be expected to differ markedly in size from the losses resulting from a 10% decrease in sales.

- have no way to adjust the discount rate according to the level of risk, contrary to the precepts that higher discount rates should apply for riskier situations. (For a textbook presentation of this, see for example the discussion of the capital asset pricing model in Brealey and Myers, 1991.)

The mechanical flaws in the use of discounted cash flows are not fatal, as is the conceptual flaw. They can either be circumvented or ignored. Decision analysis, for example, can deal with the range of outcomes and the asymmetry in the returns. For system planning and design, analysts can probably disregard adjustments to the discount rate, in the context of the large uncertainties in the performance of the system and in other parameters. As the case examples in Section 6 indicate, analysts evaluating a major system should recognize that any calculation they carry out depends on assumptions about future markets and technological developments. As these may not be correct, the analysts need to validate their results through extensive sensitivity analyses. In this context, the nicety of adjusting the discount rate to account for the varying levels of risk can probably be ignored.

The “real options” approach overcomes the flaws of discounted cash flow analysis. Most importantly, it explicitly recognizes the value of flexibility and the additional value associated with options in the context of uncertainty, especially when system operators can manage these uncertainties. This fundamental conceptual advantage is the primary reason why the approach should be adopted.

Adoption of the “real options” approach to the evaluation of projects, and thus of the design of systems, brings with it additional advantages that may be most important in the long run. The integration of "real options" analysis is likely to change radically the design of public and private systems. It will change the processes of system design, the way planners deal with uncertainly and risk. It will also change the outcomes, the kinds of elements designers build into the system as they develop it. This paper explains this coming evolution, and presents cases documenting the changes in attitude and the results already occurring.

2. WHAT IS AN OPTION? A REAL OPTION? OPTIONS ANALYSIS?

To appreciate how and why the "real options" approach is likely to effect fundamental changes in the way practitioners do systems planning and design, it is necessary to understand the basic concepts of options. This section provides this, placing the emphasis on the characteristics that are likely to lead to the anticipated evolution in practice. For detailed explanations, readers should go to the range of texts that treat the subject in whole or in part, at various levels of intensity (for example: Dixit and Pindyck, 1994; Trigeorgis, 1996; Luenberger, 1998; Amran and Kulatilaka, 1999; and Brennan and Trigeorgis, 2000, Copeland and Antikarov, 2001, Mun, 2002).

Option: The definition of an option in this context is significantly different from the connotation the word implies in ordinary conversational English. Although people new to the topic of "options analysis" might reasonably assume that the meaning of the word "option" is equivalent to that of "choice" or "alternative", since native speakers of English use these words interchangeably, they would be quite wrong to do so. This point is fundamental. It needs emphasis because the topic of options and real options is new to the field of technology policy and many people get confused on this point.

An option has a precise meaning in this discussion. An "option" represents a "right, but not an obligation", "to do something at under predefined arrangements". The key feature of an option is that cost of exercising the option, of using one's right to do an action, is somehow defined in advance. It is in this respect that an option has value. This is the feature that distinguishes an "option" from a "choice or an alternative".

In the financial markets, options are contracts. In their basic form, they specify the price at which the holder of the option can buy or sell some asset, such as a stock, some commodity, or foreign exchange. For example, a company might have a contract specifying the right, that is the option, to buy 1 million Euros at the price of US$ 1 per Euro. (The company might want such a contract because it receives dollars for its exports to the United States, but must pay for the production in Europe.)

It is worth examining the financial implications of the option, because they show why an option (as formally defined) can provide so much value. Consider the implications of the option on Euros defined in the previous paragraph. If at some future date the value of the Euro is in fact US$ 1.01, this option is worth at least $10,000 – the difference between the cost to buy the Euros under the contract and their value at that time. If the value of the Euro goes up a further penny, that is about 1%, the value of the option goes to US$ 20,000 and doubles. The first observation is thus that options can increase in value much faster than the asset to which they refer. In this example, 1-percent increase in the value of the Euro led to a 100% increase in the value of the option.

A crucial point to remember is that the option is a “right, but not an obligation”. This means that the returns from an option (as formally defined) are asymmetric. Thus, if the value of the Euro drops below US$ 1.00, to 0.98 say, the holder of the option does not have to buy the Euros at a higher price of US$ 1.00. The value of the option is zero, no matter how low the Euro might go. A simple option can thus offer “all gain and no pain”. Something so attractive obviously has value, and equally obviously must be paid for. Thus, the outcome of a simple option can be a net loss of the limited cost of acquiring the option.

Most remarkably, options become more valuable when uncertainty and risks are higher. To persons trained in the notion that risks are bad and should be avoided, this can be a startling and counter-intuitive statement. It does not fit comfortably with the notion embedded in discounted cash flows, that people need to be paid a premium to take on risk. Yet, the fact remains that options are more valuable when the risks are greater.

The Euro example illustrates how uncertainty increases the value of the option. If the exchange rate between the Euro and the dollar were fixed, the value of the option would be fixed; any buyer of the option would have to pay that price, and would have no opportunity to make a profit. The option only acquires value when the exchange rate fluctuates. Moreover, the size of the potential profit varies directly with the size of the fluctuations. The more the exchange rate varies from 1:1, the greater the upside potential while the downside remains unchanged, due to the asymmetry in the rewards (the option is a “right, but not an obligation”). The more risk there is, the more valuable options become.

In short, options are attractive because they offer the prospect of high gains with limited losses. They thus constitute very attractive additions to the design of a system. It should be carefully noted however, that investing in options is definitely not a sure way to fortune. If a group places all its assets on options, it can lose all it owns. If a group overpays for these options, it may not obtain good returns. The commitments to options thus have to be carefully considered, which is the purpose of options analysis, as discussed below.

It is important to stress that options are a routine feature of the daily lives of reasonable people. Even though options may sound exotic, are often used by speculators and other gamblers, and are associated with some remarkable economic bubbles and bankruptcies, the fact is that most people routinely use options as part of our individual and collective ways to manage risk.

Insurance is a form of option. In paying the fee to a company providing fire insurance for example, the buyer acquires the right the sell the damaged property at a fixed price, no matter how badly a fire damages the building. (Technically speaking, the buyer of the insurance places a form of "put" option on the building.) In practice, the person of course does not usually sell the property, but instead simply receives the value of the losses. The point is that properly considered options are and should be an integral part of the way we manage risks.

The proper use of options requires an effective information gathering process. In order to get the most benefit from an option, for example to buy Euros in the example suggested above, it is important to spend effort to collect information about how events are developing. In that simple example, all one has to do is to follow the price as quoted in the financial markets. In general, however, the operators of a system may have to engage substantial effort to obtain the information they need. In this respect, the insurance example misses an important feature of most options: when one has insurance, one does not need to look for information – if you have an accident, you will know it! Insurance is thus an exception to the general rule that the effective use of options necessitates suitable effort to collect and analyze information.

Real options: "Real" options deal with physical things rather than financial contracts. Specifically, they refer to elements of a system that provide "rights, not obligations" to achieve some goal or activity. Generally speaking, all elements of a system that provide flexibility can be considered as "real options".

Some examples give this definition concrete meaning:

- The Portuguese built the first bridge across the Tagus at Lisbon with the access and strength to carry trains eventually, although they were not needed at the time. They thus built a "real option" into this system: the public authorities then had the "right, but not the obligation" to create a metropolitan rail line across the river whenever they chose to do so. They in fact did so many years later.
- Building a production system so that it can change easily from one input to another or from one product to another is equivalent to creating "real options". Thus dual-fuel burners that can use either oil or gas give the operators of power plants the right to switch between fuels whenever it is economical to do so (Kulatilaka, 1993). Likewise, production lines designed to switch equipment so that they can produce different products give managers the right to do so when they wish.

- A modular design of a system that permits elements such as computers to be replaced with newer models, gives the makers or operators of the system the right to do so, which they otherwise would not have if the system were completely integrated.
- A research and development process that enables a country or a company to launch an industry or a product gives the sponsors the “right, but not the obligation” to do so. Even if the R & D process is successful, the market may not be ready for the launch of the new activity. Thus success in genetically modified research gives the sponsors the opportunity to produce and market GM products, but whether they do so depends on the market conditions. (See Paxson 2002 for cases studies of R&D options.)

Options Analysis: Options analysis consists of a set of procedures for calculating the value of options, and specifically of “real options”, the elements of a system that provide flexibility. Essentially, they estimate the expected value of the asymmetrical distribution of possible outcomes associated with options. The result of an options analysis is a value for a particular option or element of a system.

It is important to note carefully that the value of an option is largely determined by market conditions, not by technical performance. The value of a dual-fuel burner for a power plant, for example, depends on the possibility of change in the relative prices of oil and gas. The value of R & D that permits the launch of a new product similarly rests on the both the desires of the consumers and the success of competitive products. The technical performance of the product itself is of course essential, but this factor is only part of the equation.

The fact that the value of flexibility in a system largely depends on market conditions is crucial for understanding how the use of options analysis will change the process and practice of systems planning and design. This fact introduces into systems design elements that are outside of most engineering analyses and perspectives. The design of the architecture and components of a system, its modularity and its burners for example, is clearly within the province of engineering design. Yet, once systems designers recognize that these elements are “real options”, whose value and desirability can only be assessed through an understanding of the fluctuations of the market, they must introduce a whole new way of thinking into systems design. The logical consequence of recognizing the value of options is to make systems designers re-frame their thinking from a purely engineering analysis to one that explicitly incorporates market considerations.

The analysis of “real options” is a blend of technical and market considerations. This observation has important implications for the way options analysis, as presented in financial textbooks, which focuses on financial contracts, is translated into systems planning and design. Two implications flow from the fact that real options deal with physical projects:

- the data available for the analysis of "real options" is normally far less accurate than that used in the analysis of financial options, and
- managers make decisions about whether to acquire a real option, for example to build a flexible manufacturing facility, only a few times, perhaps only once.

Whereas the analysis of options on commodities and stocks can be based on years of data on the volatility of these assets, it is probable that no such data exist for options on engineering systems, for example on the technical and market performance of new products (Faulkner, 1996). Analysts of financial options can expect to use detailed as sophisticated descriptions of the risks associated with these options, and can thus aspire to great precision and accuracy. Analysts of "real options", however, may have little historical data to draw upon and may thus have to use speculative assumptions. In these circumstances, they know their estimates of value are approximate within bands described by sensitivity analyses, and recognize that analytic niceties that might lead to greater precision may be a waste of effort. In short, the analysis of "real options" leads to approximate rather than precise values.

Fortunately, managers of technological systems do not require great accuracy because they typically only need to make choices, not precise judgements. In making a choice, one only needs to know the relative value of alternatives, not their precise value. To decide whether to do the R & D that will lead to a real option on the launch of a new product, for example, managers only need to know if the value of the option is greater than the cost to acquire it. If yes, then they should invest in the R & D. In this respect, the object of doing an options analysis is quite different for systems managers than for financial analysts who have to decide on a precise price to pay for options, as they trade them day after day. Table 1 summarizes these differences between the analysis of "real options" and conventional financial options.

Table 1: Options Analysis used in Systems Design differs from that of Financial Trading both in terms of its Objective and the Accuracy of the Data.

		Accuracy of Data	
		Low	High
Object of Analysis	Choice	Systems Design	
	Judgement		Financial Trading

3. A NEW WAY TO DEAL WITH UNCERTAINTY

To think in terms of options alters the way one deals with uncertainty. Conventionally, good design minimizes risk. It focuses on enhancing reliability and making the best decisions in risky situations. Moreover, it is reactive to risk; it deals with the uncertainties as they are rather than tries to manage them. The framework of options thinking, however, recognizes that uncertainty adds value to options, and can be viewed as a positive element. The real options approach to systems design seeks out opportunities to add value. Correspondingly, systems design based on options thinking is proactive towards uncertainties and prepares plans to manage the risks. Table 2 summarizes these differences.

Seen from the perspective of normal engineering practice, the new, options-based approach is fundamentally – perhaps even cataclysmically -- different. Engineers are trained to reduce risk, to prevent failures. Engineering education and practice places great emphasis on building in adequate margins of safety into design. The bridge must not fail; the airplane must not crash; the catalytic cracking plant must not blow up; the automobile must not catch fire in an accident. Furthermore, public opinion and legal actions sanction these professional mandates. When the chemical plant releases toxic gasses (Bhopal), the power plant melts down (Chernobyl), the space shuttle fails (Columbia) or the car explodes when hit from the rear (Pinto), public inquiries look for culprits, for the engineers that failed to do their job properly. The standard culture of engineering does not encourage risky ventures.

Although real options should not compromise safety, the act of seeking out risks can be difficult for designers to accept. Although the construction of a flexible manufacturing plant should in no way increase the safety risks, it may be culturally difficult to persuade designers to look at risky situations as opportunities to develop real options that will add value to the overall performance of the system. Engineering education promotes the ideal of reliability, of minimizing if not avoiding risk (see for example Petroski, 1994).

Table 2: Real Options Approach to Systems Planning and Design differs from Conventional Approach in how it faces Risk and in the Object of Design.

		Stance toward Risk	
		Reactive	Proactive
Object of Design	Minimize Risk	Conventional	
	Maximize Reward		Real Options

The real options approach seeks out risky situations. The greater the uncertainty, the greater the potential for gain through appropriately placed options, as the discussion in Section 3 illustrates. The approach therefore looks to identify the parts of the system that may have the most uncertainty, and tries to see how these situations can be exploited.

Procedurally, the difference between the conventional analysis of risk in system design, and the "real options" approach is also substantial. Conventional analysis reacts to uncertainties; the "real options" approach is proactive. For example, decision analysis is a standard approach to systems planning and design in the face of uncertainty (see standard texts such as de Neufville (1990) for detailed discussions of this approach). This method presents the problem as one in which the designer, faced with an array of risks over time, must define the best reaction to these uncertainties, the best strategy to adopt so as to maximize performance over time. Although analysts can modify the process in many ways, the canonical procedure is reactive. It provides an answer to the question "what is the best choice under the given circumstances?"

The options approach seeks to manage risks, rather than react to them. Most obviously, for those who have not studied options, insurance is a form of option (see Section 2) that provides the holders of insurance policies with some control over uncertainties. More generally, financial managers routinely use options to insure their supplies of commodities, to protect their organizations from fluctuations in foreign exchange and to manage all sorts of other monetary risks.

The real options approach to systems design similarly attempts to manage the major risks confronting the design. In practice, it seeks out opportunities to build real options into design, evaluates these possibilities and implements the best ones. In contrast to the conventional decision analysis that works with a predetermined set of possible decisions, the options approach seeks to identify new possible paths, to change the decision tree by adding in flexibility. For example, conventional analysis of R & D projects uses an expected value or decision analysis approach to evaluate projects. By contrast, a "real options" approach to the same problem inserts additional decision nodes into the tree to reflect the options (Neely, 1998; Perdue et al, 1999). Thinking in terms of real options leads designers to build much more flexibility into a system than is common in current practice.

Applying real options to the evaluation of systems projects is thus much more than using a different way of calculating value of possible projects. The approach implies re-framing of the ways engineers approach design. Instead of avoiding risk, they need to exploit it; instead of reacting to it, they need to manage it.

4. ANALYSIS OF REAL OPTIONS

Experience in major organizations applying and analyzing real options to technology management indicates that the effective use of this approach requires a substantial process. It is much more than the application of the analysis itself. In this respect, it is different from the use of options analysis in the financial world. Although financial options can be highly complex, a large number of them involve standard contracts, using readily available data that can be analyzed relatively easily. (For example, hand-held calculators typically have the Black-Scholes formula for pricing options programmed into them.) In that context, the focus is on the accuracy of the formulas and means of calculation. When it comes to systems planning and design however, there is no menu of available options, let alone a standard option, and the relevant data may be hard to discover. In technology management, much of the work in applying real options lies in the processes for determining when and how to implement the options.

Interviews with major organizations using real options in their planning and development of major systems indicates that the process seems to involve at least three distinct phases:

- Discovery, during which the group attempts to identify the most interesting areas of uncertainty, which may potentially offer the greatest rewards from options;
- Selection, which evaluates the possible means of providing flexibility to the system, and determines which of these options should be implemented; and
- Monitoring, the process of monitoring the evolution of the uncertainties so that the organization will know when to implement or abandon the options that it has built into the system.

The discovery process is likely to be a multidisciplinary activity involving major sectors of an organization. The development of a major system involves certainly involves technical, marketing and macroeconomic risks. It may easily also involve regulatory and political risks. Consider the development of the Hibernia oil field off of Newfoundland, far off shore in the path of major icebergs (see Smets, 1998). This project certainly had significant technical uncertainties concerning both the construction of the wells and the size of the field. It also involved huge investments whose profitability depended on the fluctuations of the market for oil. It was also vulnerable to the changing structure of the major oil companies that were merging and reorganizing their lines of supply and distribution. In such a situation, it is hard for any one group to specify the major uncertainties in the system. Experience indicates that is useful at this stage to assemble representatives familiar with the many aspects of concern. They can then jointly explore how different real options could be inserted into the project, and how these might have value across the company.

The selection process involves calculating the value of the options and picking the best ones. Experience so far indicates that some form of decision analysis most practically forms the basis for these calculations, either by itself (Faulkner, 1996; Perdue et al, 1999) or in combination with a more traditional options analysis (Neely and de Neufville, 2001). From a theoretical point of view, this approach is deficient. This is because a decision analysis provides no way to adjust the discount rate consistently, and these procedures are at the heart of the development of options theory (Black and Scholes, 1973) that led to their Nobel Prize. From a practical perspective however, the value added from this refinement may be overwhelmed by the uncertainty of the data, as Section 2 indicates. It may be most important to focus on the great value of "options thinking", compared to the conventional discounted cash flow analyses. Furthermore, since many of the real options may interact with each other, and may have value in resolving several uncertainties, it may be difficult to set out a theoretically correct framework for a conventional options analysis (Oueslati, 1999). In short, the selection process necessarily involves many approximations. However it is done, it provides an analytic justification of a list of projects that introduce flexibility into the design.

The monitoring process is an essential part of the application of real options. This element insures that the system managers obtain full value from the system. Indeed, the value of the real option lies in exploiting it when conditions are right. For example, the value of the dual-fuel burner as a real option lies in switching from one fuel to the other when their relative prices reach a critical point. When one is dealing with commodities whose prices are publicly available, as frequently happens for financial options, there is no need to invest much effort in the monitoring process. In many cases, it may even be possible to have one's computer automatically query prices and then sound an alarm when prices are right. In dealing with real options however, the owner will almost certainly need to mount an important effort to monitor the situation to identify when the option should be exercised. For example, when R & D has provided the basis for launching a new product, the managers will need to find out when to exercise this real option. They will need to monitor the readiness of customers to accept the product, the prices of substitute products and the strategic intents of their competitors. Little of this information will be publicly available, and the holder of the real option should spend considerable time on discovering the ongoing market conditions. In short, it is necessary to commit to ongoing processes of information gathering to ensure that real options can be exploited at the correct time.

5. VALUE-ADDED THROUGH REAL OPTIONS

Thinking in terms of real options brings out two large classes of projects that add value to systems, opportunities that designers have previously underused or ignored. The analysis of real options enables managers and designers to estimate the value of system flexibility. As this has not been practical before, designers have previously not considered the value of flexibility. Incorporating this capability into systems analyses significantly improves to design. Public and private operators of major systems will come to recognize much greater value in:

- Development activities, and
- Flexibility in timing.

Development Activities: A large class of activities and projects are developmental in that they enable the system managers to proceed to a further stage, without requiring them to commit prematurely to the further development. The value of all these projects will appear much greater, when appropriately estimated as options, than they have been when valued using conventional discounted cash flow techniques.

Most obviously, this class includes R & D and product development activities. By definition, these processes prepare results and prototypes that enable the further development of products and prospective benefits. Several studies have already demonstrated that these activities, when viewed as options on the future, are far more valuable than they would seem to be when viewed through the lens of discounted cash flow as integral parts of a total product launch (Nichols, 1994; Faulkner, 1996; Neely, 1998; Perdue et al, 1999; Paxson, 2002).

All other activities that normally proceed through a linear developmental process can be included in this category. For example, each of the steps in the discovery and exploitation of natural resources can each be thought of as option on the next phase. Thus, a lease of mineral rights to an area is an option on subsequent exploration, which is in turn an option on eventual exploitation. Case studies for the oil industry (Siegel et al, 1987; Paddock et al, 1988) and for mining (McDonald, 2000) demonstrate this approach.

Flexibility in Timing: The timing of an investment may be considered as an option (Dixit and Pindyck, 1994; Luenberger, 1998). For example, not doing an investment now provides the opportunity to do it later, perhaps when market opportunities are more favorable. More generally, this class includes all the design alternatives enabling managers to adjust the system as relevant information becomes available, that is those that involve deferral, acceleration and closure of facilities (see the examples in Brennan and Trigeorgis, 2000).

Managers of technological enterprises can thus view many features of the design of a system as real options involving flexibility about the timing of an investment. Under this heading one can for example include:

- Modular design, which permits the system operators to perform upgrades as and when they are most desirable (Baldwin and Clark, 2000);
- Platform designs, which enable designers to launch new models of products easily and rapidly; and
- Land-banking, for example of extra width along a highway as an option on the addition of more lanes later on (de Neufville, 1991).

By analyzing their real options, designers of engineering systems can now calculate the value of such actions, compare them to their cost and prepare a firm rationale for justifying or rejecting them. This will represent a significant advance over current practice, in which arguments for and against design features such as modularity, platform design and land-banking have generally been conceptual and intuitive.

6. EXAMPLE APPLICATIONS

Several leading global technological companies are beginning to use real options to re-frame the way they think about technology management, innovation and system development. This activity is recent, dating only from the mid 1990s, and often later. Among these are certainly BP/Amoco, Ford, General Motors, Kodak, Merck and Westinghouse and surely many more. These companies are generally secretive about their activities in real options, since they see that these give them a competitive advantage over competitors that do not exploit the advantages of real options.

Kodak, Merck and Westinghouse have each explicitly considered and justified their research and development processes in terms of its option value for future development (Nichols, 1994; Faulkner, 1996; Perdue et all, 1999). Similarly, Ford Motor Company invested approximately C$ 330 million in Ballard, developers of prototype fuel cells. Although the prospects for a fleet of automobiles powered by fuel cells have been so poor that this investment made little sense from the perspective of a discounted cash flow, the investment can be justified as an option on this eventuality. The investment can be seen as insurance against the possibility that the United States might at some time mandate the production of fuel cell cars (Oueslati, 1999).

Other companies are working on connecting their engineering and marketing departments, which have historically been disconnected. They are doing this because much of the value of real options lies in the probability that a technology or a product will be needed in the marketplace. When the engineering departments learn about the opportunities available in potential markets, they can design the facilities or equipment that can effectively serve as real options. Thus, suppliers of gas turbines have recognized the value of these machines as options for supplying peak load power. Although small gas turbines may not be competitive with other generators at normal prices, they may be very profitable when peak prices soar. The engineering departments can only appreciate this value, and thus be motivated to design and deliver the equipment, when they understand the nature of the price fluctuations in the newly deregulated markets for electric power. This is another instance in which the planning and designers of technological systems have to reframe their thinking when they use real options. In this case, they move shift from thinking about "capital efficiency" to "trading activity".

Readers interested in additional cases of the application of real options should consult the web sites devoted to links to web sites discussing real options. This landscape changes. However the following URL has been useful in the past: http://www.puc-rio.br/marco.ind/ro-links.html (Pontifical Universidade Catolica de Rio de Janeiro, 2001).

7. CONCLUSIONS

A fundamental evolution is occurring in the field of management of technology and innovation, in the field of systems planning and design. It is due to the introduction of the concepts and use of "real options" that represent the flexibility of the system to adjust to new circumstances, avoiding the downsides and exploiting the upsides. The value of this flexibility has not been recognized by the traditional methods of project evaluation, the procedures associated with discounted cash flows.

This new methodology entails a deep, almost revolutionary change in the way technical professionals think about technology management and design. It brings them to:

- Recognize that the value of the projects is integrally associated with the fluctuations of the market, and thus that they need to be in closely in touch with these matters in order to design appropriate products;
- Understand that uncertainly is not always a risk to be avoided, but also presents valuable opportunities that can be exploited;
- Adopt a proactive stance toward risk, looking not just to respond to it passively, but to manage it proactively through the use of real options; and
- Introduce far more flexibility, justified in terms of its option value, into the design of systems than has been the norm.

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This paper reflects the experience and many of the ideas of practitioners in several global companies that are actively using real options as an integral part of their technology management and systems design. Because these companies believe that these approaches can give them a substantial competitive advantage, the details of their experience has had to be kept confidential for the moment. Although it is thus impossible to list these persons, they know who they are. Many thanks for their valuable suggestions and insights!

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