Options Analysis: An Innovative Tool for Manufacturing Decision-Making

by

Craig Spencer Belnap

B.S. Manufacturing Engineering Technology, Brigham Young University, 1987
B.A. Asian Studies (Chinese), Brigham Young University, 1987

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Signature of Author

Department of Materials Science & Engineering
Sloan School of Management
May 12, 1995

Certified by

Thomas W. Eagar, POSCO Professor of Materials Engineering
Department Head
Thesis Supervisor

Certified by

James M. Utterback, Leaders for Manufacturing Professor of Management and Engineering
Thesis Supervisor

Accepted by

Carl V. Thompson II, Professor of Electronic Materials
Chair, Departmental Committee on Graduate Students
Materials Science & Engineering

Accepted by

Jeffrey A. Barks, Associate Dean
Master's and Bachelor's Programs

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ABSTRACT

As manufacturers become more cross-functionally integrated and globally competitive, manufacturing decisions are becoming increasingly complex. One such industry undergoing dramatic change in response to new market dynamics is the business of product packaging. As manufacturers weigh the evolving demands on packaging, they have turned to new materials, new designs, and new operations to satisfy their many customers. This thesis discusses the dynamics of the packaging industry and reviews some of the material and operational solutions being pursued to address these dynamics. With packaging as a product domain, this work seeks to illustrate a new approach for assessing the strategic elements within a manufacturing decision.

Among the tools available to manufacturing decision-makers, net present value (NPV) and other financial tools have traditionally been the backbone for operational decision analysis. However, because these financial tools capture only financial value and not strategic value, decision-makers are often misguided in their decisions and/or the management of those decisions. This oversight combined with the burgeoning growth of lower level decision-makers mandates the need for a simple, effective tool for assessing the strategic value for manufacturing decisions in combination with their financial (NPV) value. Options analysis is a tool which satisfies this need.

In introducing options analysis, this thesis has essentially two purposes: First, to provide a framework that helps develop strategic decision-making skills. Second, to help decision makers to analyze and develop strategic projects and to manage accordingly. These purposes are accomplished by three means: By demonstrating a unique method (real options) for quantifying the strategic value of a manufacturing decision as a complement to operational value (NPV); by introducing a practical framework and methodology based on real options for broadly analyzing, developing and managing the strategic elements of a decision; and, by providing substantial annotated sources for further investigation, applications, refinement, etc.

Thesis Supervisors:

Dr. Thomas W. Eagar
Professor of Materials Engineering

Dr. James M. Utterback
Professor of Management

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Andrew, Christine and Julianne,
who have sacrificed much on my behalf.
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1.0 Introduction

From an economics perspective, the goal of a firm is to create value. Accordingly, it follows that, theoretically, every decision within a company should be made with regard to its added value to the company. Unfortunately, with the complexities of today's industrial environment, it is often unclear as to what does and what does not constitute "added value." It is even more unclear as to how "value" should be measured.

1.1 Operational Value vs. Strategic Value

Net Present Value (NPV), the standard tool for investment analysis has enhanced significantly the ability for decision makers to assess a project's value. Unfortunately, this tool can only address operational value; that is, by implementing a given decision (the purchase of a new machine tool, for example), following a prescribed plan, and given an expected performance, what is the anticipated value of the reduced costs and/or increased sales due to the investment? While this information is essential, every manager or "high-level" strategist well knows that, in some cases, a large portion of a decision's value is strategic not operational; that is, how does the new machine tool help us in circumstances that are less certain? What new choices does a decision offer? What new avenues are available to the company? These strategic decision makers have long sensed that total project value is more than just operational value (as measured by NPV) but includes strategic value as well, as the following equation illustrates:

Total Value = Operational Value + Strategic Value

Unfortunately, while operational value has been reasonably well understood and quantified (via NPV), strategic value has not. This makes decision making within companies today—particularly at the operations level—highly uncertain. At worst, decisions are made by individuals who are oblivious to strategic value; at best, experienced or inherent "strategists" (including most managers) armed with analytical tools such as risk analysis mentally assess a decision's strategic value as an addendum to its operational value. In fact, neither approach is very satisfying. Consider the situation diagrammed in Figure 1: "What happens today when a strategically "good" project does not look operationally good?"

Managing Investment Decisions

When a Strategically Good Project Does Not Look Good

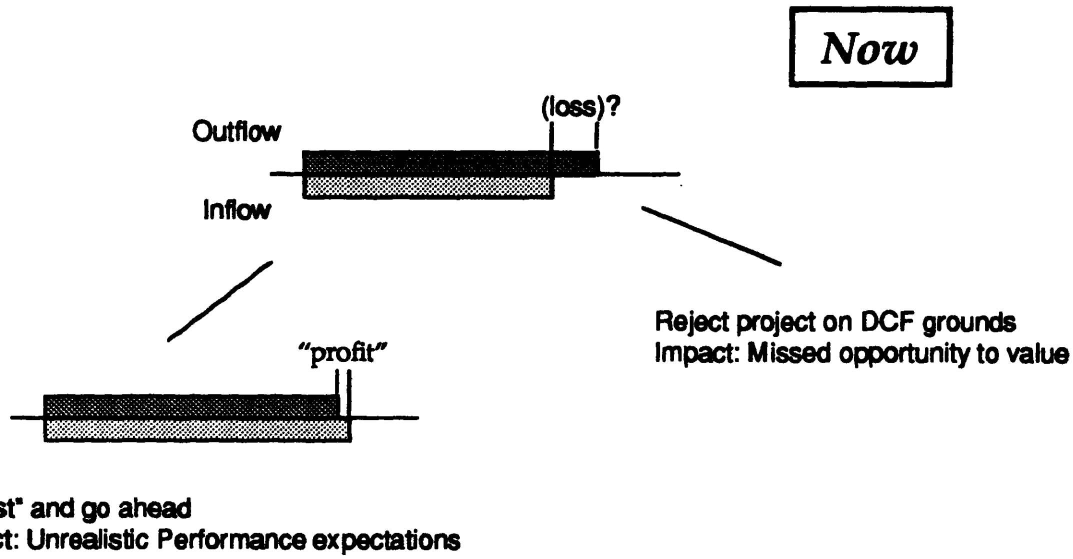


Figure 1: NPV Alone Leads to Inadequate Investment Decisions

Today, when a strategically "good" project does not look good, there are two common scenarios: In the first case, either out of ignorance or because of the inability to circumvent rigid NPV-based decision criteria, strategic value is neglected and the project is rejected. The result? An opportunity to add economic value to the company is missed. In the second (and very common) case, a strategically savvy decision maker "adjusts" the operational value of the decision—using optimistic estimates and questionable sources of added margin—to indicate a financially justifiable project. The result? On the one hand, the correct decision—to go ahead with a project that adds economic value—is made; unfortunately, the downside is that project managers become accountable to reach the inflated financial paybacks that made the project "acceptable." Project managers know that they have virtually no chance of meeting expectations and morale suffers. There is a resource management mismatch.

Numerous replays of the preceding scenarios beg for a method of understanding, identifying and quantifying strategic value. This need becomes all the more urgent as industries seek to flatten organizational structures thereby pushing decision making farther down into the organization. Accordingly, as more decisions (virtually all with some strategic implications) are made at lower levels of the organization, the need for knowledgeable, capable strategists throughout the organization becomes essential.

1.2 Problem Statement

> As manufacturers become more cross-functionally integrated and globally competitive, manufacturing decisions are becoming increasingly complex. Among the tools available to manufacturing decision-makers, NPV and similar financial tools have traditionally been the backbone for operational decision analysis. However, because these financial tools capture only operational value and not strategic value, decision-makers are often misguided in their decisions and/or the management of those decisions. This oversight combined with the burgeoning growth of lower level decision-makers mandates the need for a simple, effective method of assessing the strategic value for manufacturing decisions in combination with their financial (NPV) value.

This thesis has essentially two purposes: First, to provide a framework that will help develop strategic decision-making skills. Second, to help decision makers to analyze and develop strategic projects and to manage accordingly. These purposes will by accomplished by three means:

1. By demonstrating a unique method (real options) for quantifying the strategic value of a manufacturing decision as a complement to operational value (NPV).
2. By introducing a practical framework and methodology based on real options for broadly analyzing, developing and managing the strategic elements of a decision.
3. And, by providing substantial annotated sources for further investigation, applications, refinement, etc.

These three initiatives will be accomplished via the format and audience of this thesis. Directed at the typical Operations decision maker, this thesis is designed to serve as a basic, practical guide for applying options and options analysis to manufacturing decisions. Because of the greater emphasis on response time vis-à-vis exactness common to manufacturing operations, this approach outlines a method for quickly identifying the sources and relative magnitude of strategic options as opposed to precise modeling. (This work subscribes to the 80/20 rule that suggests that 20% of the effort typically yields 80% of the value).

1.3 Thesis Structure

This work describes, as a problem domain, the manufacturing complexities of product packaging as a product component facing tremendous demands to improve performance for a diversity of internal and external customers. Compounding the demands for improvement in packaging is an additional set of characteristics that must, at minimum, be maintained at their current level of performance. As these demands come into conflict, investment decisions must be made to maximize the long-term value of the packaging "system" (the materials, design, process, product delivery and sale, and disposal) as it affects the corporation as a whole. In Chapter 2, considerable attention is focused on the packaging industry dynamics as a whole and on Polaroid and their packaging of instant film in particular to help illustrate an options-based assessment method for industrial decisions (which will hereafter be referred to generally as options analysis).

With this backdrop, Chapter 3 introduces the theory of financial options (stock options) and develops the analogy of stock options to options on real assets (real options). In Chapter 4, a valuation method for real options is demonstrated. Building on this method, a framework for applying options analysis generally to a manufacturing decision is presented in Chapter 5. This details specifically what information is necessary and how it might be obtained. In Chapter 6, this thesis demonstrates how the understanding of options can be used to "craft" option value into decisions and how to then manage those decisions. Chapter 7, Conclusions, presents a discussion of key learnings, contributions and cautions stemming from the presented framework and suggests areas for future research. More importantly, Chapter 7 draws on the thesis's demonstration of options analysis as a framework for plant-level decision-making and expands it to consider the broader decisions facing Polaroid packaging given the dynamics of the industry. Appendices outlining packaging material choices and various option valuation tools are attached as is an annotated bibliography providing extensive sources for further information.

2.0 Problem Domain

In the product cycle, perhaps no other single product component is being asked to perform as many functions while satisfying as many constraints as is the product package. As a result, the complexities surrounding a packaging operation serve as an ideal environment for illustrating how options and options analysis can be used to assess strategic value.

Packaging is one facet of nearly all products that is facing tremendous pressures to change. The world community, the customer base, the distribution system, and the supplier community are all undergoing revolutionary transformations. Such change is necessitating like changes in the packaging world. Fundamentally, there are eight major packaging characteristics that are being affected by today's dramatic market dynamics:

- Environmental Impact
- Cost Effectiveness
- Product Configuration
- Customer Convenience

- Physical Performance
- Display
- Supplier Availability
- Packaging Process

The particular product line which served as the genesis of the ideas detailed in this thesis is Polaroid instant film, a high volume, global consumer product that is highly sensitive to air and moisture. Currently, this product is packaged primarily in a physical package with a design that is three decades old; its standard appearance (graphics) was redesigned three years ago. The package comprises a paperboard / aluminum foil laminate formed into a carton which is then sealed on each end with a polymer / foil film as diagrammed in Figure 2.

Polaroid's Current Filmpack

A Laminate Carton with Laminate Endseals

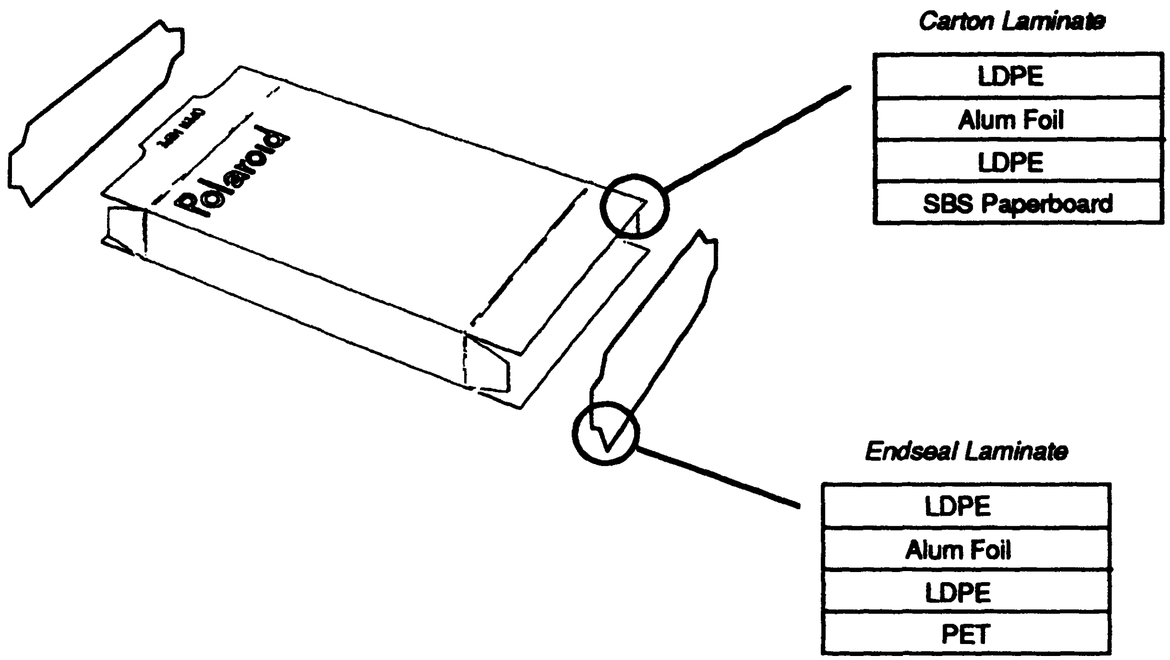


Figure 2: Polaroid's Current Filmpack Design is Three Decades Old

This package, like that of most products, is facing particular pressure to improve its performance in the first group of four packaging characteristics: Environmental Impact, Cost Effectiveness, Product Configuration, and Customer Convenience. The second group of four characteristics (Physical Performance, Display, Supplier Availability, and Packaging Process) serve as constraints; that is, the current package's performance in these areas is acceptable but improvement is desirable.

To provide background into the dynamics of the industry as a whole and to introduce the opportunities for applying options analysis, each product characteristic will be discussed from both a global and specific perspective:

2.1 Primary Characteristics: Characteristics Demanding Change

Environmental Impact

Without a doubt, the environmental impact of packaging is the most emotional and debatable issue facing product packaging. While manufacturers readily acknowledge the value and necessity of packaging, the concerns (both real and perceived) of consumers for environmental responsibility has fallen even harder on product packaging than on the products themselves.

Today, the environmental watchcry is "Reduce, Reuse, Recycle"—in that order. In this regard, the packaging emphasis has essentially shifted from recycling to minimization. This emphasis on minimization is reflected in a phrase of growing usage within the environmental packaging discussion: "The best package is no package." After packaging has been minimized to the greatest extent possible, the emphasis then falls on developing packaging which is reusable—either within the manufacturing and distribution system or by the end customers themselves. Only after focusing on packaging reduction and reuse does the emphasis then shift to recyclability.

Life cycle analysis (also called eco-balance) comprises a holistic study of the environmental resource impact of a product from cradle to grave. In theory, "reduce, reuse, recycle" is a simplified interpretation of life cycle analysis. In practice, life cycle analysis has so many different interpretations that the three R's (reduce, reuse, recycle) are more a practical environmental strategy for dealing with the muddled world of environmental impact. Despite a lack of unanimity on international life cycle analysis standards, the scientific community recognizes at least three basic parameters ([65]):

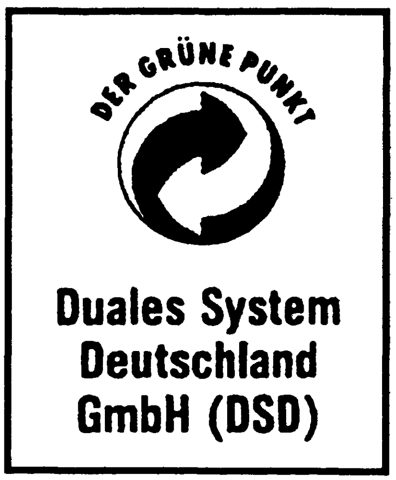
1. total energy consumed during the manufacturing process from basic raw materials (crude oil, natural gas, wood, grain, etc.)
2. amount of pollutants released into the atmosphere during all manufacturing steps
3. amount of pollutants discharged into waste waters

Despite this agreement, the lack of standards obscures the current usefulness of life cycle analysis for comparison of product environmental impact. Disposable diapers and fruit juice boxes are examples of recent products which have (rightly or wrongly) used life cycle analysis to clear their names as environmental offenders.

Legislation and the Green Dot

Because of the emotion surrounding environmental issues, legislators throughout the world have actively sought to address product environmental impact. The most ambitious legislative effort regarding packaging and the environment is the German Topfer Decree on packaging (1991). The motto of the Decree is "Packaging manufacturers shall design packaging as to make the smallest possible contribution in terms of volume, weight, material and energy use to the impact on the environment during its life cycle consistent, however, with its functional needs."

Also intent on the focus of the three R's, the Topfer Decree essentially requires manufacturers to pay for packaging waste levels and to ensure waste recycling. The means of implementation is known as the "Green Dot" system because voluntary participants who pay a fee based on projected packaging volume are allowed to place the Green Dot symbol on their packaging (Figure 3).



This symbol, the "Green Dot," can be found on the packaging for all participants in Germany's packaging reclamation system

Figure 3: The "Green Dot" Distinguishes the Packages for Duale System Participants

The fees from the Green Dot system (and penalties for non-participants) support a privately developed national packaging collection system called the Duale system which is to create the infrastructure for the collection of all consumer packaging.

Recently, the juice box industry came under attack for its "environmentally unfriendly" plastic-aluminum foil laminate, a material very similar to Polaroid's film packaging material. Though this attack has subsided somewhat recently in light of favorable life cycle studies of juice boxes, the continuous environmental scrutiny of packaging is prompting Polaroid to consider new materials with still lower life cycle impact, which enable greater use of post-consumer recycled materials, and which will more readily accommodate existing recycling streams. Under particular consideration is packaging composed of a singular material such as metals and uniform polymers. (See Appendix A.)

Cost Effectiveness

The preceding discussion regarding the environment provides the perfect backdrop for the consumer's emphasis on cost. While a 1994 survey found that most consumers participate in recycling programs and the vast majority of consumers state that they will buy environmentally positive products even if it costs more, the surveyors concluded that "Overall, nutrition [in the case of food products] and price are still more important than environmentally responsible packaging when it comes to consumers' buying decisions today." (Packaging Digest, May 1994, p.20)

This consumer price sensitivity has been sustained by the explosive growth of national, customer focused discount chains which have been able to leverage their volumes to extract extensive cost reductions from suppliers. This fact has greatly intensified the cost pressures on consumer product manufacturers. Since packaging generally has less impact on product performance than the elements of the product itself and because packaging is of little apparent utility to end users, it typically faces an inordinate level of cost attention. This is particularly true in commodity items where the ratio of packaging cost to product cost is high. Packaging cost attention generally centers on three areas: Package material, packaging processes and product configuration.

Often the quickest and simplest means for reducing packaging cost is the substitution of less costly material. However, many of today's more complex (and costly) materials address a range of packaging requirements simultaneously such that these materials are less costly to the packaging function overall. Consider the snack package diagrammed in Figure 4 ([83]).

Given that the manufacturer is satisfied with a given package material configuration's ability to meet numerous package requirements, they have two options for reducing cost. First, through improving operational efficiencies such as labor costs, scrap, overhead costs, etc. in the packaging process, the product manufacturer effectively reduces the cost per package. Second, by increasing the product size (for liquids and powders) or by increasing the number of components per package (for discrete products), the product manufacturer also reduces the effective cost per package.

Single Serve Snack Bags

An Efficient Material Solution

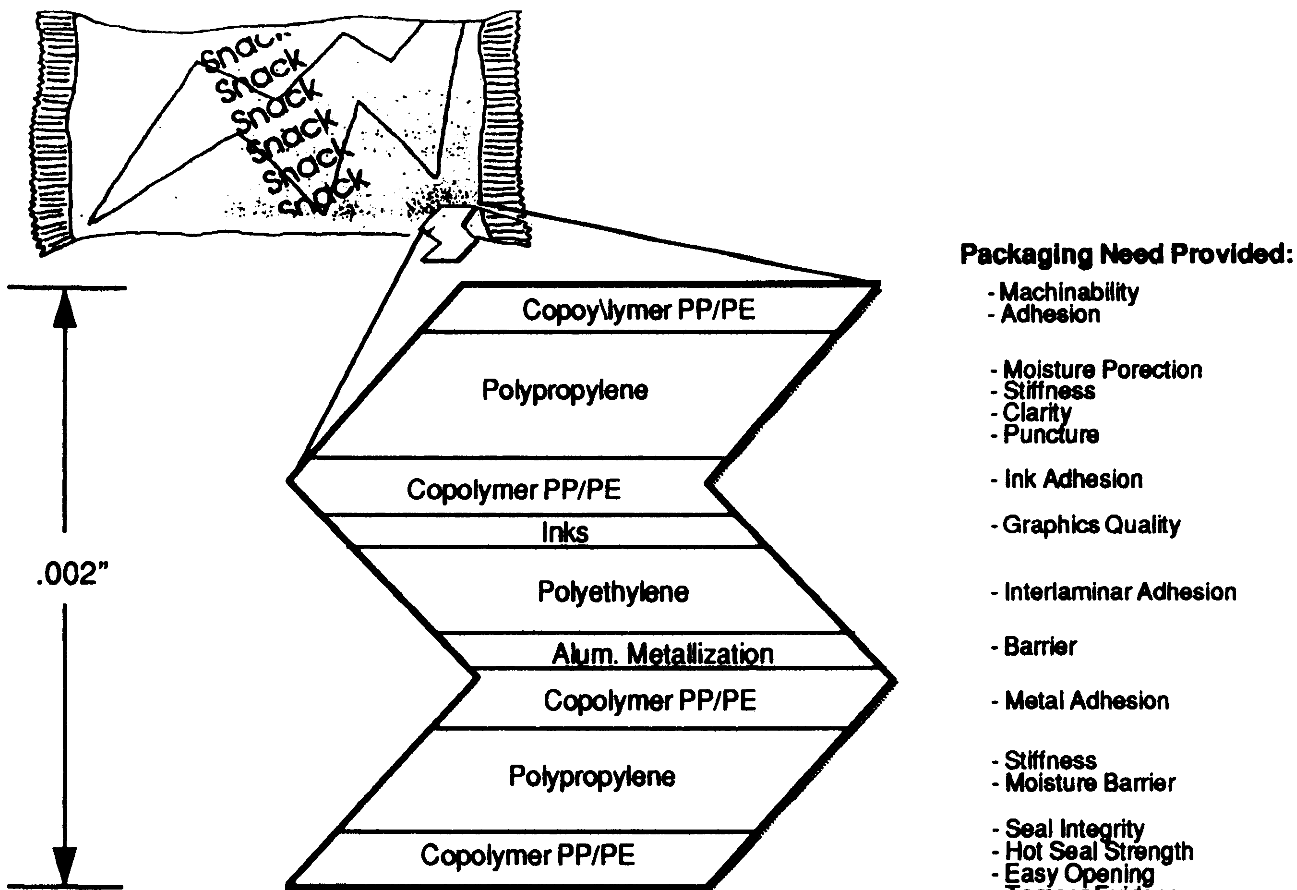


Figure 4: Materials Technology Has Dramatically Improved the Effectiveness of Packaging

In one regard, Polaroid's instant film is different from commodity products in that the product costs far exceed the packaging costs. However, because of the film product's numerous interdependencies with the camera systems, instant film product changes are much more difficult and costly to implement. Accordingly, at rates of tens of millions per year, Polaroid considers every opportunity to reduce costs via packaging initiatives either in the material costs or in the product packaging operation.

Product Configuration

The recent emphasis on customers (particularly the demands of retailers as customers) has given rise to an unprecedented growth in product and, therefore, packaging configurations. Such complexity compounds the difficulties already facing packaging operations. In a period of just eight years, the flagship line for Polaroid film, has grown from three configurations to more than eighty and the pace of growth is increasing. In fact, the number and variety of secondary operations that have been incorporated into the product system (marketing promotions, retailer customization demands, safety and security devices, etc.) translates to a potential combinatorial variety well into the billions.

To handle such complexity in the product development world, manufacturers have pursued strategies of lean manufacturing and mass customization. Similar strategies are being applied to the packaging world. However, while products are primarily differentiated based on end-user needs, packaging variety is being driven by a trio of "customers": End-users, retailers (presently the most demanding customer), and the distribution system. Currently, Polaroid is addressing packaging proliferation primarily through the consideration of more modular package designs and processes.

Customer Convenience

The rising market focus on customers has also translated to a greater demand for and attention to customer needs in packaging. In a recent survey, seventy percent of Americans indicated that package ease of opening or resealing was "extremely" or "very" important. Accordingly, packaging is facing a growing market demand for improvements in not only opening features but other customer interfaces such as handling and disposal.

Compounding the general population's desire for improved product interfaces is the growing recognition of large groups of disaffected consumers who, due to diminished dexterity or other physical skills, are disinclined to purchase a given product. The design response to this need holds that products expressly designed for the impaired, the elderly, children and others of diminished skills in a functional area are better for and will draw greater sales appeal from all markets. Such principles have focused considerable attention on improving the comprehension and ease of package opening features. In fact, a major challenge to the development of new opening methods is the ubiquitous comprehension of existing features. The challenge, then, to package designers and manufacturers is either to dramatically improve the effectiveness of currently available opening methods or develop new improved methods that are readily understandable.

As an extension of the environmental discussion earlier, consumers are increasingly attentive to the disposal of products and packaging. Accordingly, product manufacturers are having to consider (for both packaging and products) waste minimization, component separability, compatibility with existing recycle streams, etc. In sum, consumers simply are becoming less comfortable with the arbitrary disposal of large quantities of packaging materials and are responding, via the marketplace, to improvements in packaging (and product) disposability.

For some time, opening difficulty has been a major concern with the Polaroid instant film package. Accordingly, Polaroid continues to investigate easier opening features which can be incorporated into the current package design. With regard to disposability, improvement for the current film package will likely be obtained only through substantial changes in materials, package design or both.

2.2 Secondary Characteristics: Characteristics Constraining Change

The preceding section highlights those characteristics that have been most profoundly affected by the recent transformations in the consumer market place. This second group of characteristics discusses those packaging system elements which have always been recognized as essential. In fact, the suggestion that these are "secondary" is in reference only to their level of relative attention vis-à-vis their attention in prior years. In fact, the importance of these characteristics is anything but secondary; the first of these, physical performance, is principally the essential function of a package.

Physical Performance

Physical protection comprises protection from mechanical, electrical, and chemical damage. As a primary objective of packaging, physical protection cannot be compromised. In general, once acceptable levels of protection have been established, little effort is invested in improvements. As such, a minimum package performance serves more as a constraint when making other changes. A leading source of these "other changes" today is the attempt to lower the package's environmental impact and cost.

For Polaroid film, the greatest need for improved package performance concerns barrier consistency. As film products are very sensitive to moisture and other contaminants, film packaging demands extremely high barrier protection. While older high barrier materials such as aluminum foils and polyvinylidene chloride (PVdC) have slowly been yielding to metallized oriented polypropylene (OPP) and ethylene vinyl alcohol copolymers (EVOH), the demand for barriers which are transparent, non-polluting, high-yield and recyclable continues to push the materials world. One promising group of materials is the so-called flex glasses.

As a group, the flex glasses represent the group of polymer coatings that have as their barrier material, thin coatings of silica, alumina and other oxides. The appeal of these materials is their potential contribution to a number of key packaging attribute areas (ref. Appendix A):

- Very high gas and moisture barrier potential
- Insensitivity to water, temperature, acids, etc. due to their inorganic nature
- Visual and microwave transparency
- Acceptability for recycling. Minuscule coating thickness (<2000 Å) is widely regarded as inconsequential for recycling purposes.

Currently applied by sputtering, electron beam, or plasma deposition, the primary obstacles to the flex glasses are cost and consistency. Accordingly, they have been slow to display the promise they are believed to hold as the "perfect" packaging material. Nonetheless, should they eventually fulfill that promise, flex glasses will revolutionize both the flexible and rigid packaging worlds.

Display

Package display comprises the graphics, aesthetic design and means of product display (stacked, hung, dispensed, crated, etc.) inherent in a package. From a marketing perspective, display is one of the key contributions of a product's package because of its utility as a sales and information tool. Fundamentally, as market dynamics are always changing so are the demands on package display; yet, a minimum standard of quality is essential. In fact, product packaging is primarily complicated by the fact that the least valuable product element—the package—generally has the largest burden of conveying product value.

Changing demands on package display are largely being driven by product differentiation, product globalization and marketing initiatives. Since altering the display is a common means of communicating configurational differences, the proliferation and globalization of products has tremendously complicated the management of packaging display. In fact, a key consideration when altering a display either for configurational or promotional reasons is the method of alteration: Should the graphics themselves be changed or should attachments be applied which necessitate an additional process? Until technology enables near instantaneous package display modifications, the question as to how to accommodate demands for display alterations is largely dependent on strategic intentions.

Polaroid currently supports two primary package designs for display: one with a tab for hanging racks and one simple box design for stacking. Initially, Polaroid handled graphics variations primarily by altering the printed graphics; more recently, they have included the ability to modify graphics with stickers, "outserts," wraps, etc. Because product proliferation is a growing concern for its impact on packaging at Polaroid, a wide range of alternatives are being considered for customizing the package at various stages in the packaging/distribution process.

<u>Supplier Availability</u>

As defined here, supplier availability refers to those processes external to the company that result in the acceptable delivery of packaging materials. It comprises, therefore, the availability of raw materials, equipment and operations necessary for delivery of all package materials in finished form to the packaging operation. Some would consider this a cost question. However, in many cases, package materials of acceptable cost are obtainable but other uncertainties in the system (especially single sources of raw materials or processors) strain a manufacturer far more than would a slight increment in cost.

As packaging raw material availability is an essential characteristic of any OEM product, the rise of globalized manufacturing and lean manufacturing initiatives are placing greater pressure on manufacturers and their interface with packaging material suppliers. Accordingly, manufacturers are increasingly wrestling with the issues of specialized packaging designs or contracts that rely on proprietary materials, isolated material sources or single source suppliers. This concern is one of the major obstacles to adopting new material technologies regardless of the benefits technically or environmentally.

A major drawback to the current Polaroid package is the uniqueness of its materials. While the raw materials are common, the particular laminate used in the package has only a handful of suppliers in the world. One of the reasons sustaining Polaroid's consideration of new, singular material packaging is the reduced complexity and general availability of materials. Similarly, this stands as a near-term drawback to the use of advanced material (such as the flex glasses).

Packaging Process

In contrast to supplier availability (as defined above), packaging process refers to the internal processes such as package forming, loading, closing, conveying, packing, etc. As such, attention to the packaging process addresses the needs of the packaging operation itself. Can standard equipment be used? Is the process robust? Is the process simple and inexpensive to run and maintain?

As with supplier availability, established package designs with proven, multiple providers of equipment greatly lessens the risks to manufacturers. One key driver for Polaroid's current consideration of new packaging designs is the uniqueness of the current design (especially the membrane seal) combined with the aging of its unique packaging equipment.

2.3 Polaroid's Manufacturing Response

With regard to its instant film packaging, Polaroid is struggling to deal with the market changes affecting the eight packaging characteristics outlined above. In response to these dynamics, Polaroid is considering new package designs, new processes and new distribution systems. One underriding element of both package designs and processes is the packaging material. As Polaroid's current material / manufacturing system could come under fire from environmentalists; is unique in its design, materials and equipment; is considered "unfriendly" by customers and is seeing demands for increased physical performance, Polaroid is assessing various packages based on alternative materials. A review of packaging material alternatives and a comparative outline of some of these choices vis-à-vis the packaging characteristics discussed in this chapter can be found in Appendix A.

2.4 Summary

The consumer product market has been undergoing profound restructuring recently; this restructuring is prompting responses from all manufacturers who want to continue to play in the consumer market. One facet of consumer products that readily reflects the influence of today's market dynamics is product packaging. For years packaging has been valued primarily for its physical performance, its display, the ready availability of suppliers and its manufacturability. Recent market shifts have demanded attention to other characteristics as well, namely: environmental impact, cost effectiveness, product configuration and customer convenience. Polaroid is looking to new initiatives based on alternative materials to address many of the demands emerging from the new consumer product market dynamics.

3.0 Financial Options and Real Options

With the preceding outline of the problem domain, product packaging, this work can now introduce the theory behind options and relate that theory to the prescribed problem domain.

3.1 Financial Options

In its simplest form, a financial option is a right that a person pays for today to buy a stock at a set future date for a price agreed upon now. The value to the person who pays for this option is that if, when that future date arrives, the actual price of the stock is higher than the agreed upon price, he can "exercise" his option: buy the stock for the agreed upon (lower) price and then resell it at the (higher) going market rate, pocketing the difference. On the other hand, in the unfortunate event that at that future date the actual stock price were lower than the agreed upon price, the owner of the option has no obligation to buy the stock so he simply chooses not to exercise the option and his only loss is the money he put up front to buy the right to make this future choice.

Consider one-year options on the two stocks diagrammed in Figure 5: At the end of one year, an investor would exercise her option to buy stock 1 because its price is above the exercise price. (She would pocket the difference less the amount she paid to have this option). The investor would not exercise her option to buy stock 2 since it is lower than the agreed upon exercise price. (She would simply lose whatever she paid to have this option.)

What makes a stock option valuable is that, over time, a stock's price fluctuates and drifts from today's price. In fact, even if the agreed upon future price is substantially higher than today's stock price, it still may be worth it for an investor to pay for the option because the variability in the stock's price over time offers some hope that the future price will still exceed the agreed upon price.

Option Value for Two Sample Stocks

Option Owners Do Not Have to Take the Loss for Stocks That Underperform; Only the Gain for Those That Overperform

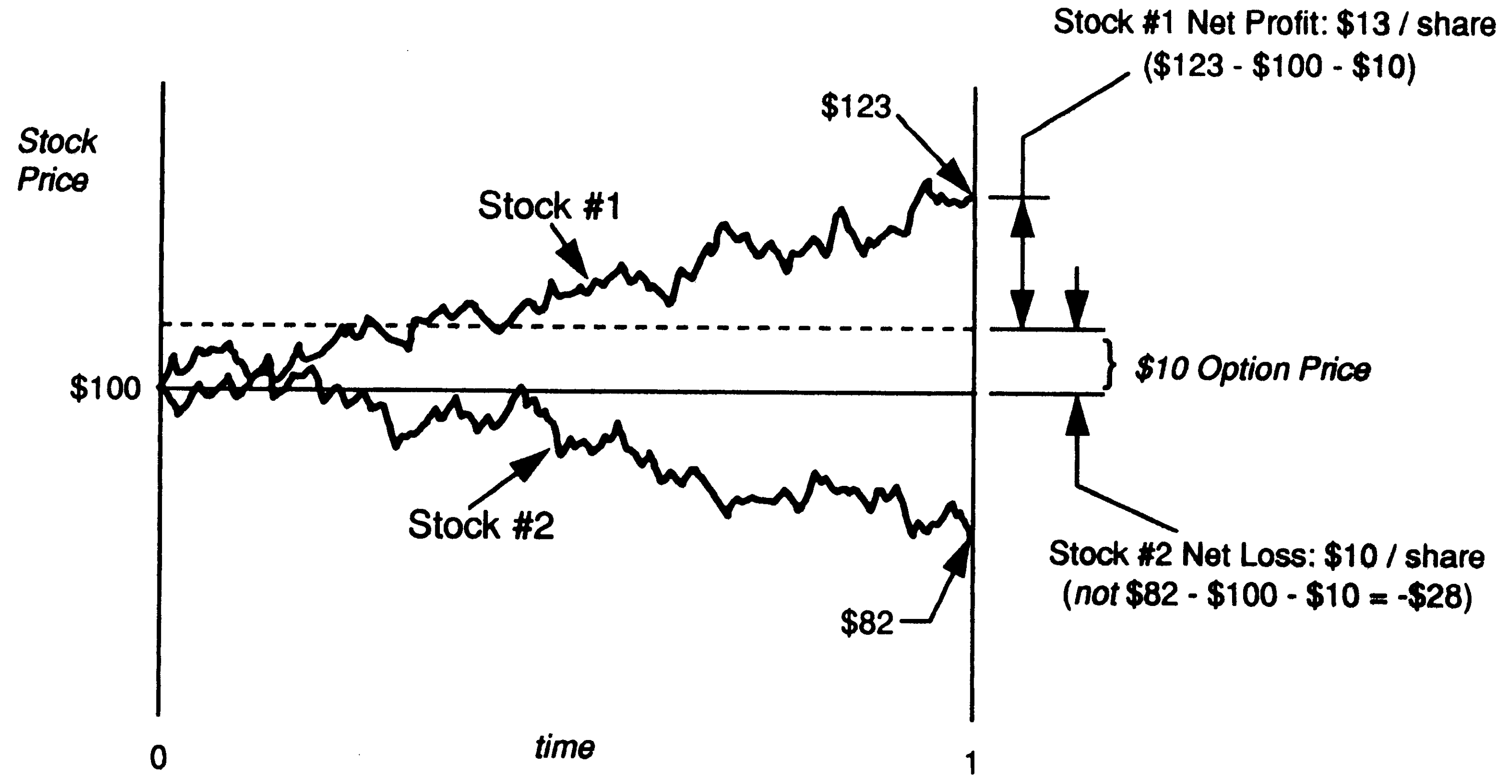


Figure 5: Stock Options Capitalize on the Upside and are Immune from the Downside

3.1.1 Dependent Variables

The amount an investor would pay for a stock option is heavily dependent on at least four factors: the price of the stock today and the agreed upon future price (called the "exercise price" or the "strike price"), the length of time between now and the agreed upon future date, the expected variability (volatility) of the stock's price over that time, the risk free interest rate. Table 1 outlines how the price of an option to purchase a stock is affected by these variables:

Variable	Effect on Option to Purchase Stock
Increase in Stock Price	Increases
Increase in Exercise Price	Decreases
Increase in Variability of Underlying Asset	Increases
Increase in Time to Expiration	Increases
Increase in Interest Rates	Increases

Table 1: Option Values are Influenced by Five Factors

3.1.2 Payback Profile

Since options allow an investor to choose to exercise her right and buy a stock only when its price is favorable, the payback to the investor is not like a typical (statistically normal) stock purchase where "you win some and you lose some;" rather, the payback "profile" is truncated since the buyer reaps all upside potential and suffers no downside loss. (See Figure 6.)

Because of this truncated payback inherent in options, for years it had been difficult to determine how much an investor should actually pay for the option (the right to purchase) in the first place. In 1973, three finance academics working on two fronts (Fischer Black and Myron Scholes [7]; Robert Merton [58]) used common market principles to demonstrate how options could be reliably valued. [1]

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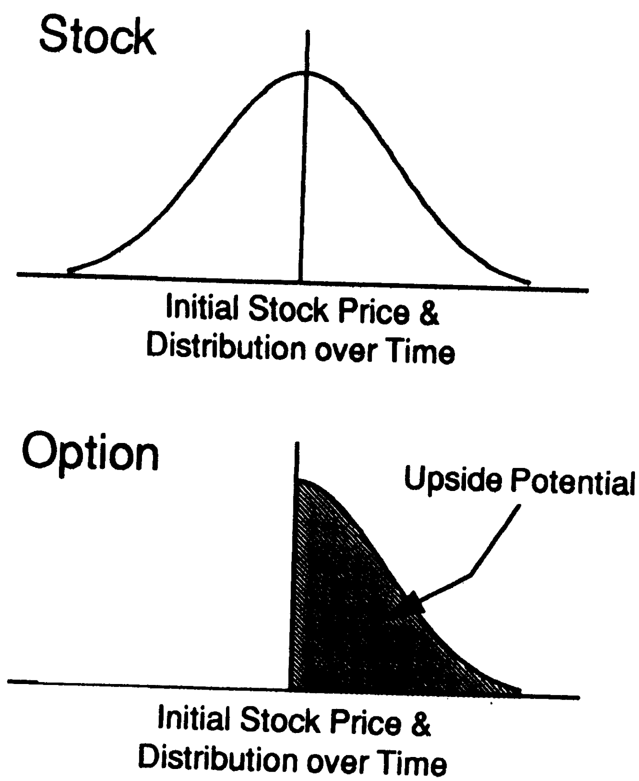
[1] Briefly, their contribution was that options can be duplicated by a mixture of other market investments; this conclusion allowed them to develop option valuation formulas based on the risk-free interest rate over all periods of the life of the option.

Stock vs. Option Payout



An investment in a stock is subject to the entire range of potential stock values over time.

An investment in an option on a stock is immune to downside risk over the life of the option. (Of course the investor pays for this immunity in the form of an option price.)

Figure 6: Options on Stocks Have a Different Payout then the Stocks Themselves

3.1.3 Valuation Methods

Based on the principles of their work, today there are at least five methods for valuing financial options: Black-Scholes, Binomial, Monte-Carlo simulation, Dynamic Programming and Heuristic-based algorithms. As the Black-Scholes method is the primary basis for this work, it will be illustrated in detail; substantial information on other methods can be found in the annotated bibliography. (See Bibliography Cross Reference Chart, p. 100)

Black-Scholes

The Black-Scholes formulation is the simplest of all methods for determining option value in that it can be captured in a single equation (an equation that is still widely employed in the options market today). The beauty of Black-Scholes is in both its simplicity and its dependence almost completely on agreeable, measurable factors. The equation follows:

$$C = S*N(d1) - Xe^{-rt}*N(d2)$$

where:

$$d1 = \frac{\ln\left(\frac{S}{X}\right)+\left(r+\frac{1}{2}\sigma^2\right)t}{\sigma\sqrt{t}}$$

$$d2 = d1 - \sigma\sqrt{t}$$

C = Call value
S = Current stock price
N(dx) = the cumulative normal distribution for d1 and d2
X = Exercise price
e = 2.71828, the base of a natural log
r = Annual risk-free interest rate (continuously compounded)
t = Time to maturity of the option in years
σ = Annual standard deviation for the stock (continuously compounded)

There are several fundamental assumptions inherent in the Black-Scholes formulation. These assumptions are outlined in Table 2:[2]

[2] For a fascinating review of the collective assumptions in Black-Scholes, see "How to Use the Holes in Black-Scholes" by Fischer Black [6].

Assumption
The risk-free interest rate is constant over the life of the option
The stock price volatility is constant over the life of the option
The stock price changes smoothly without substantial jumps either up or down over short periods
The stock does not pay dividends
The option cannot be exercised before its expiration

Table 2: Black-Scholes is Based on a Specific Set of Assumptions

In the finance literature, many adjustments have been suggested to the standard Black-Scholes equation to account for either general or specific exceptions to these assumptions. While there have and will continue to be many variations on the Black-Schole formulation to address individual circumstances, the basic equation itself continues to stand as a powerful, useable method for evaluating options.

Using Black-Scholes to value an option

To illustrate the application of the Black-Scholes method for valuing options, consider the following example:

> A stock currently selling for $100 has a historical standard deviation of 25% per year. (By definition, using a lognormal distribution, that means that one standard deviation from either side of nominal is +/- 25% of the preceding year's price. In even simpler (and less precise) terms, that means that each year there's a 66% likelihood that the price will be within +/- 25% of the preceding year's price.) If the life of the option is 5 years and the agreed upon exercise price is $125 (and assuming an annual risk-free interest rate of 10%), the value of the option is calculated as follows:

Current Price	P = $100
Exercise Price	X = $125
Life of option	t = 5 years
Standard Deviation	σ = 25%
Risk-free interest	r = 10%

Option value = $C = S^{*}N(d1) - Xe^{-rt}*N(d2)$

d1 = .775, N(d1) = .7823

d2 = .216, N(d2) = .5793

$$C = (\$100 * .7823) - (\$125e^{(-.1)(5)} * .5793) = \$34$$

Therefore, if an investor were offered the option scenario described above, he would be willing to pay $34 per share for the right to buy a share for $125 in 5 years.

3.1.4 Puts

Up to this point, the discussion has talked about options in general and has used the Black-Scholes equation to value an option to buy a stock at some future date. This kind of option is termed a "call." The counterpart to a call, the option to sell a stock at some future date is termed a "put." Puts are not calculated directly but are calculated from their corresponding calls using a relationship known as put-call parity. Therefore, for the example worked above, the amount an investor would pay to have the option to sell a share of stock for $125 in 5 years would be calculated as follows:

$$\text{Put} = \text{Call} + Xe^{-rt} - S$$

Call = $34 (from Black-Scholes example, above)
$X = \$125$; $PV(X) = 125e^{-rt} = 125e^{(-.1)(5)} = \$76$
$S = \$100$

$$\text{Put} = \$34 + \$76 - \$100 = \$10$$

Therefore, an investor would pay $10 per share to have the right to sell a share of the stock described above for $125 five years from now. The fact that value of the right to sell ($10) is lower than the value of the right to buy ($34) reflects the belief that the stock price in 5 years is more likely to be greater than $125 than less than $125.

With the distinction made between calls and puts, it is instructive to return to the effect of the dependent variables on the value of each type of option. (The earlier representation of the influence of these variables referred only to calls.) The following chart (Table 3) outlines how the price of call and put options are affected by the underlying variables:[3]

[3] The actual computational sensitivities to each variable are outlined in Jarrow and Rudd [39]; for reference, these sensitivities are reproduced in Appendix C.

Variable	Effect on Call Option	Effect on Put Option
Increase in Stock Price	Increases	Decreases
Increase in Exercise Price	Decreases	Increases
Increase in Variability of Underlying Asset	Increases	Increases
Increase in Time to Expiration	Increases	Increases
Increase in Interest Rates	Increases	Decreases

Table 3: Calls and Puts Do Not Behave as Opposites with Respect to the Variables[4]

Of particular note is the counter-intuitive dependency of calls and puts on stock price variability (volatility) and time to expiration. Regardless of the type of option, the value of the option is increased by greater volatility and longer time horizons.

3.1.5 American vs. European Options

With the distinction made between calls and puts, there is one more distinction to be made with respect to financial options. There are two kinds of options distinguished by the way in which they may be exercised. European options can only be exercised at their maturity data; that is, when they expire, the owner chooses either to buy the underlying stock for the agreed upon price or they let the option expire unexercised. American options, on the other hand can be exercised at any time during their life. Table 4 outlines the various option types which have now been discussed:

	European	**American**
Call	An option to buy a stock when the option matures at a price set today	An option to buy a stock up until the option expires at a price set today
Put	An option to sell a stock when the option matures at a price set today	An option to sell a stock up until the option expires at a price set today

Table 4: Investors Can Buy and Sell Four Types of Options

Since both calls and puts increase in value with time to maturity, it would appear that investors would wait until the option matures regardless of the stock performance. In fact, this would be true as long as the underlying stock does not pay dividends. The payment of dividends is the primary differentiator between the investors preference for American or European options. Since dividends do not go to the owner of an option but rather to the owner of the stock, large dividend payouts may entice an option owner to exercise prior to the option's maturity.

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[4] The mathematical sensitivities of each variable in the Black-Scholes equation are quite complex. They can be found in Appendix B.

3.2 Real Options

In 1977, Stewart Myers of MIT suggested that the principle of options could apply not just to financial products like stocks but to investments in real assets such as land, buildings, equipment, people, etc. These "real options," he proposed, could capture the opportunities for follow-on growth inherent in an investment that are not captured by NPV. The striking element of this concept is that options on real assets can be interpreted analogously to stock options and, therefore, the well-developed techniques for stock options valuation can be applied to real options.

In keeping with the analogy of stock options, real call options are characterized by a situation where an investment in a real asset gives the investor the right but does not obligate them to make follow-on investments that may have value. The simplest example is land. Many buyers of land buy it not for its near-term financial payback (NPV) but rather as an "investment." The value of this investment is simply the value of the options to develop the land at some future time as a business park, residential development, shopping area, parking garage, etc. Though none of these "improvements" may be financially wise today, they may prove lucrative in the future and, by owning the land, the buyer owns the option to make these developments should they become lucrative in the future. Of course, they also have no obligation to make these developments. Eureka! an option.

3.2.1 Real Option Classifications

The extent and variety of real options imbedded within an operation are virtually limitless. Nonetheless, real options take on some standard forms that systematically arise in the literature of real options. These forms include: Growth options, the option to expand, the option to wait, the option to switch (inputs, outputs or processes), the option to contract, and the option to abandon. Each type of option offers specific value under varying circumstances as outlined in Table 5.

In a simpler graphical representation, these options and the types of "news" that might prompt the exercise of each option are outlined on the following spectrum (Figure 7) prepared by Edleson [22].

Option to:	Description
Grow	An early investment (R&D, land, strategic acquisition, infrastructure) is a prerequisite or link an a chain of interrelated projects, opening up future growth opportunities (new generation product or process, oil reserves, access to new market, strengthening of core capabilities).
Expand	If market conditions are more favorable than expected, the company can expand the scale of production or accelerate resource utilization.
Wait	Inherent in all investment decisions, management can delay an investment expense to see if the revenues and costs resulting from an investment become more favorable over time, thereby justifying the investment.
Switch	If prices or demand change, management can change the output mix of a facility ("product flexibility); Alternatively, the same outputs can be produced using different types of inputs ("process flexibility).
Contract	If market conditions are less favorable than expected, the company can contract the scale of production or decelerate resource utilization.
Abandon	The extreme of contracting, if market conditions drop severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets in second hand markets.

Adapted from Trigeorgis [87], p.202

Table 5: Real Options Research Typically Identifies Six Option Types

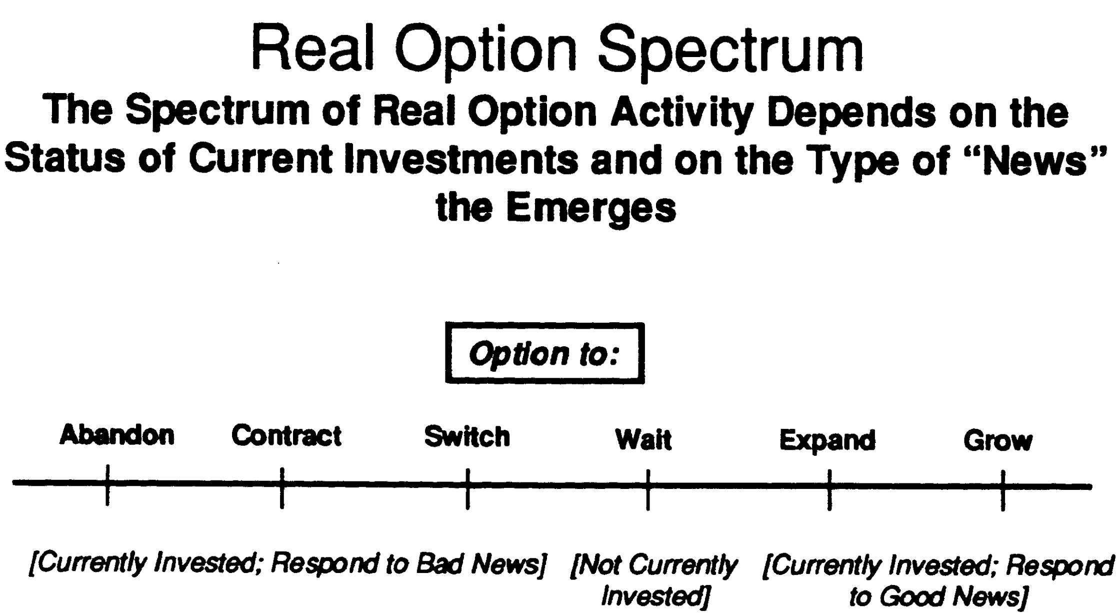


Figure 7: The Six Typical Option Types Fall on a Spectrum of Behavior

3.2.2 Real Options valuation using Black-Scholes

To complete the analogy of real options to stock options, this section will illustrate the use of the Black-Scholes method for valuing real options—one real call and one real put.

Real Call Option

One common real option often imbedded in the purchase of a new machine is additional capacity. By paying more for greater capacity, a manufacturer is buying an option to satisfy increased demand. Accordingly, real options can be used to determine the value of the added capacity. Consider the following example:

> A plant can purchase a $200,000 machine which can produce 1500 components a week; they determine that a machine rate of 1000 components per week will satisfy their reasonable expectations. Based on their NPV calculations, the machine's value is marginal. Yet, they wonder, what value does the greater capacity add to the operation? They recognize, that if demand were 1500 components / wk, the present value of the cash flows for the additional 500 components/ wk would equal $450,000 over the estimated life of the product (5 years); while they believe that the likelihood of needing the extra capacity is low (10%), marketing admits that it could be three times that much...it could also be that much lower. To be able to run at 1500 / wk, however, the company would have to commit to additional tooling and storage capacity—a one-time cost of $50,000.

Consider the financial option to real option analogy:

Financial Options	Real Options	Example Values:
Stock Price	Expected Present Value of the upside opportunity	$450,000 * 10% = $45,000
Time	Time (window of opportunity)	5 years
Exercise Price	Irreversible Monetary commitment to enable upside opportunity	$50,000
Volatility	Uncertainty in PV of upside opportunity	estimated @ 50% / yr (explained in Ch. 4/ App. B)
Risk-free Interest Rate	Risk-free Interest Rate	6% per year

Table 6: Capacity is a Real Option that is Analogous to a Stock Option

Calculation:

$$\text{Call value} = C = S^{*}N(d1) - Xe^{-rt}{*}N(d2)$$

$d1 = .733$, $N(d1) = .768$

$d2 = -.385$, $N(d2) = .350$

$$C = (\$45{,}000 * .768) - (\$50{,}000e^{-(.06)(5)}{*}(.350) \cong \$21{,}600$$

Drawing on the preceding values, the value of the call option (i.e.: of the extra capacity) as computed using Black-Scholes is about $21,600. Therefore, the additional (option-determined) NPV for the machine due to its additional capacity is about $21,600. Or put another way, if they could purchase a machine with sufficient capacity for 1000/wk for less than $200,000 - $21,600 = $179,400, they would better off. It is important to note that this $21,600 does not represent the potential value of the additional capacity—the upside could be $450,000!—instead, it represents the likely break-even point.

Real Put Option

As a counterpart to the preceding real call option, consider the application of Black-Scholes for the valuation of a real put. Anytime a company purchases resources for which a ready resale exists, they simultaneously purchase the option to resell the resource. For example:

> A company is trying to boost a mature product's sales by launching an innovative but risky new package that they hope will attract more buyers. For roughly the same projected cash flows, they can choose a special paperboard laminate or a standard PET material as the base. In the event that the product (and package) does not take hold, what advantage does the resellable PET offer over the laminate if they must commit to substantial raw materials inventory up front?

As noted earlier, the put value is not directly calculable but must be calculated from the corresponding call option. The analogy of the corresponding call option to a financial call option is outlined below (Table 7):

Financial Options	Real Options	Example Values:
Stock Price	Expected Present Added Value due to package	.5*$200,000 + .5*$5,000 = $102,500
Time	Time (window of opportunity)	2 year
Exercise Price	Cost of Resale Market PET (Resale value of package mtl)	$30,000 (2 year's worth of PET)

Volatility	Uncertainty in PV of upside opportunity	estimated @ 210% / yr (explained in Ch. 4 & App. B)
Risk-free Interest Rate	Risk-free Interest Rate	6% per year

Table 7: Material Choice is a Real Option that is Analogous to a Stock Option

Calculation:

$$\textbf{Call value} = C = S^{*}N(d1) - Xe^{-rt}{*}N(d2)$$
$$\textbf{Put} = C + Xe^{-rt} - S$$

Therefore, $$\textbf{Put} = (S^{*}(N(d1)-1)) - (Xe^{-rt}{*}(N(d2)-1))$$

$d1 = 1.95,\ N(d1) = .975$

$d2 = -1.06,\ N(d2) = .145$

$$\textbf{Put} = (\$102{,}500 * (.975 - 1)) - (\$30{,}000e^{-(.06)(2)}{*}(.145 - 1)) \cong \$20{,}200$$

Given the preceding data, the estimated value for the real put option to sell off the unused PET vs. discarding the unused laminate is approximately $20,200. The magnitude of this put is due to the high possibility that the hoped-for sales increase not to occur. It must be recognized that the $20,200 is a rough approximation. Nonetheless, directionally the value of the put option is clear—it's not a trivial amount. Hence, while there is no resale put option for the laminate (or the put = $0) there may be a sizable resale put option for the PET. Even if the laminate material NPV were slightly better, the PET resale put suggests it may be the higher value choice.

3.2.3 Black-Scholes Intuition

Drawing on the preceding real option examples, the Black-Scholes formula can now be understood intuitively. Consider again the equation but with the analogous real option variables substituted:

Option value = PV(Cash Flows)*N(d1) - PV(Irreversible Investment)*N(d2)

or more simply:

Option Value = Net Variable Revenues * N(d1) - Fixed Investment*N(d2)

The N(d) terms, in effect, account for uncertainty. If there were no uncertainty in a given investment and its payback, N(d1) and N(d2) would approach 1.0 and the option value would become just today's expected net present value of the follow-on project. In effect, the Black-Scholes equation is an NPV calculation that accounts for uncertainty via the N(d) terms.

Such intuition is helpful (particularly for the Operations finance personnel) in recognizing the consistency of options valuations with NPV. As the Black-Scholes formulation (and other formulations) for valuing options becomes more widely understood and applied, the range of applications will continue to grow. The introduction of options valuation to the world of real options offers an entirely new analytical tool for decision making that will have widespread effects.

3.2.4 Caution: What Real Options Do NOT Do

Unfortunately, options are not a placebo for valuing all intangible benefits; they do not assign value to capabilities that are currently unassignable. For example, options cannot value the benefit of reduced variability any more than traditional discounted cash flow (NPV) techniques. In fact, the real value of options is that they use the same data and assumptions as NPV and, therefore, the two methods are compatible.

Though real options are not the answer to all unknowns, they do provide real insight into the value of many decision elements once thought of as intangible. By considering the options inherent in any decision, many of the strategic sources of value imbedded in the decision becomes apparent and quantifiable. This is the real value of options and this is the intent of the next chapter: to introduce an approach for identifying and assessing options.

4.0 Options Analysis: Assessing Options

As the preceding chapter demonstrates, financial option theory can be a powerful tool for evaluating strategic value in real asset decisions. Unfortunately, the breadth of option-like scenarios, valuation techniques and interactions within a single manufacturing decision cloud the effective use of real options. To navigate this complexity, this chapter introduces a broad framework for identifying and approximating real options.

Options analysis draws on the decision maker's ability to step back and take a broader view of the decision: Who are the stakeholders? What are the likely (and unlikely) future actions of these stakeholders? And what are all the options these actions bring to the decision? Using real options (in this case, Black-Scholes) as a basis for approximation, options analysis provides an approach for estimating the value of the options. In doing so, options analysis makes two major contributions to decision making: it illuminates strategic value and it develops in its practitioner strategic thinking. This chapter will primarily focus on the illumination of strategic value; Chapter 5 will more fully address strategic thinking.

4.1 Strategic Value

Because NPV is measured in today's dollars, value as measured in NPV is additive. This means that if a project generates two different streams of profit or if the NPV is calculated separately for each year in the expected life of the project, the total NPV is equal to the sum of the individual NPV's:

$$NPV_{tot} = NPV_1 + NPV_2 + NPV_3 + \ldots$$

Option values reflect the amount of money a project manager would pay today to have a specific option. (Options also are measured in terms of today's value.) The value of options are generally additive to each other as well and, the strategic value of a project (as measured by options) is additive to a project's NPV.[5] Going back to this paper's original equation:

[5] Trigeorgis [88] notes that a series of options may become interdependent in which case their interactions change the total value of the set of all the options (they are not fully additive). In general, though, real options of different kinds are additive; hence the 80/20 rule emphasis of this approach (regarding payback vs. effort) implies that if a few significant calls and puts can be identified, their combined value can reasonably be approximated by adding the totals.

$$\textbf{Total Value} = \textbf{Operational Value} + \textbf{Strategic Value}$$

$$NPV_{tot} \qquad\qquad Option_{tot}$$

$$NPV_1+NPV_2+\ldots \qquad\qquad Opt_1+Opt_2+\ldots$$

Trained manufacturing decision makers are versed in aggregating NPV; however, their exists no means for aggregating strategic value. Conceptually, options analysis fills this role. However, in keeping with the 80/20 rule, to be of operational value to manufacturers, options analysis as presented in this work offers a summation of option approximations and, therefore, sacrifices precision for expediency. Clearly a key value of options analysis is its contribution to the discovery of striking sources of large strategic value. The "Aha" experience of options analysis permits a thorough analysis of those individual options deemed to be of greatest value.

4.2 The Options Assessment Approach

There are four main elements for the successful application of options analysis: 1) Involve a cross functional team, 2) Identify the options using a "DoCan/DoCan't" chart, 3) Estimate the option values, and 4) Analyze the results.

The following scenario will be used to illustrate these steps for the application of options analysis in this chapter:

> A packaging plant has 10 aging packaging machines all of the same specialized design each attached to a specialized product assembly machine. Though all the product in this plant is essentially the same, it is differentiated by 15 different packages (differentiated only by graphics, not fundamental design). The company is considering buying one high speed HCX packaging machine to replace all 10 of the current machines. The 10 assembly machines will remain in tact but will now feed a single packaging line. The cost justification is based on direct labor savings, maintenance savings and material & scrap reduction. On this basis, the NPV is marginal. Does the project have additional strategic value? Does is have additional strategic costs?

4.2.1 Involve a Cross-Functional Team

When a company considers any new initiative, they recognize that that initiative enables them to do things which can add value to the firm. Inherent in all such decisions are numerous options which are also now available to the firm. These options may include new ways to respond to customers, new means of drawing on the strengths of suppliers, new modes of internal operations, etc. They may also include an increased ability to reclaim the investment should its operating value deteriorate. Because of the numerous options imbedded in a given decision and because of the limitless sources of uncertainty affecting these options, the use of a highly skilled, experienced cross-functional team is essential for quickly identifying and approximating option values.

To gather a team with broad core skills, talent needs to be tapped which covers both internal operations and external conditions. In addition, a global strategic view of the company needs to be reflected in the team. For the scenario outlined above, an effective team might comprise the following functional resources:

Internal Operations	External Conditions	Global Strategy
Equipment Engineering Production Control Shop-floor Labor	Marketing Sales Distribution	Sr. Management Strategic Planning

Table 8: A Good Options Analysis Team Includes Internal and External Experts

Because champions for a given initiative have an inherent bias, it is imperative that the team include an alternative perspective to identify the downsides of a given approach. If alternative views are not inherent in the make-up of the team, at least one individual needs to be assigned the "devil's advocate" role to provide a counter perspective.

4.2.2 Identify the Options

While all initiatives include the potential "acquisition" of many new options, it also must be recognized that new initiatives exclude some options which would formerly have been available. Accordingly, options analysis frames the investigation of options in a "DoCan/DoCan't" relationship. That is, given that we "do" a certain action, what "can" we now potentially do that we previously could not do and what "can't" we now potentially do that we previously could do? The recognition of the newly available and newly unavailable options can be understood via the "DoCan/DoCan't" chart shown in Table 9.

	Addt'l Value ("With") Created Option	*Opportunity Cost ("Without")* Exercised Option
If you do this:	You will be able to do this:	You won't be able to do this:
Do	**Can**	**Can't**

Table 9: A "DoCan/DoCan't" Chart Helps Identify Options

The preceding chart provides a framework for assessing the real options that are (and are no longer) available when the "Do" initiative is enacted. Fundamentally, this "DoCan/DoCan't" thinking is what is done when an NPV analysis is prepared (though the "Can't's" are often downplayed or neglected). With NPV, those "Can's" which are immediately available and are expected to yield a positive cash flow (such as labor and scrap reduction) are included as positive cash flows in the NPV calculation for the given project. These "Can's" are offset by a set of negative cash flow "Can't's." However, those "Can's" which require additional investment and particularly those for which the cash flow is uncertain are options and should be evaluated as such. These option "Can's" are also offset by option "Can't's" that should also be evaluated as options.

The "Do"

To fully consider the options within a decision, the decision must completely specify the primary initiative. To do so, the "Do" must state what will be done, when it will be done and how it will be done. (If these elements have not all been specified, then there are some options which are still undetermined since these questions—what, when and how—describe the types of options available for any initiative.) Consider the "Do" for the given scenario:

> "Replace the 10 old machines with a high speed HCX packaging machine by mid next year."

The "Can's" and "Can't's"

To identify the options imbedded in a "Do" decision, there are at least two workable approaches:

1. Start from a clean sheet and group-brainstorm potential "DoCan's" and "DoCan't's"
2. List the standard option types (abandon, contract, defer, etc.) and consider how each may be applied to the decision

For groups which need to jumpstart the process, the second approach may prove to be more effective in quickly identifying the potential options. A combination approach will enable the most thorough extraction of imbedded options. Consider the following combined approach.

For the HCX centralized packaging machine purchase decision, a clean sheet brainstorm session might yield the abbreviated "DoCan's" and "DoCan't's" listed in Table 10.

DoCan	DoCan't
• N Reduces operating and maintenance labor cost	• N Use current packing tray
• N Reduces energy consumption	• Take assembly machines off-line one at a time
• Upward packaging capacity	• Service very small batch sizes that may be common in the future
• Shorter cycle, less capital for bar coding	• N Keep equipment as currently laid out
• N Improved yield	
• Purchase additional assembly machine without additional packaging machine	
• N Reduce noise at the machine	

Table 10: The HCX Creates and Negates Capabilities—Some Options, Some NPV's

Those "DoCan's" and "DoCan't's" that will change the cash flows from the moment the project is implemented or for which the uncertainty is very low (and, therefore, as options they will be exercised) should be captured in the standard NPV evaluation. These items in Table 10 are marked with an "N" for NPV.

The remaining items represent potential options that may add (or subtract) value from the project. Each remaining item (and new ones) can be analyzed with respect to the standard options discussed in Chapter 3:

- Options to Grow
- Options to Expand
- Options to Wait
- Options to Switch
- Options to Contract
- Options to Abandon

By reconsidering the non-NPV "DoCan's" and "DoCan't's" with regard to the preceding standard option types, a master list of potentially valuable options can be created. Using both the non-"N" denoted "DoCan's" and "DoCan't's" and additional options that were brainstormed for each type of option, a list of newly available and newly unavailable options can be compiled for a given project. Consider, as an example, the brainstormed and refined outline for "DoCan's" and "DoCan't's" shown in Table 11.

	DoCan	DoCan't
Options to Grow	• Shorter cycle, less capital for bar coding • Purchase additional assembly machine without additional packaging machine • Apply elsewhere within the corporate structure	• Service very small batch sizes that may be common in the future
Options to Expand	• Upward packaging capacity	
Options to Wait		• Invest later
Options to Switch	• Run multiple package sizes (different products / new packages)	
Options to Contract		• Take assembly machines off-line one at a time
Options to Abandon	• Resell machine to recoup investment is market deteriorates	

Table 11: Some of the HCX's New Capabilities are Reflected in Options

4.2.3 Estimate the Options

With the options identified, they can now be estimated to determine their effect, if any, on the total value of the decision. Using a spreadsheet based on the Black-Scholes formulation, the "DoCan/DoCan't" chart can be expanded to serve as a tool for evaluating and analyzing the options. The expanded chart with spreadsheet formulas is shown in Appendix C.

As noted earlier, while methods other than Black-Scholes are available, Black-Scholes will be used here because of its simplicity and its ease of manipulation making sensitivity analysis particularly easy.

To demonstrate the use of the spreadsheet based analysis for valuing the imbedded options, several of the preceding "DoCan's" and "DoCan't's" are illustrated below. At the end of the chapter, these are aggregated and conclusions are drawn regarding those that require additional consideration. The specific option types will be illustrated in the following structure:

- Upside Call Options: Options to Grow and Expand
- Downside Put Options: Options to Abandon and Contract
- Combination Calls and Puts: Option to Switch
- Option to Wait

Upside Call Options: Options to Grow and Expand

Options to Grow and Expand are considered together here since they both offer increased value by investing in the future should circumstances develop favorably. Typically, growth options represent the group of options that enable dramatic new market alternatives. Expansion options, on the other hand, comprise those options available by increasing the scale of a current operation.

Growth options represent the greatest area for potential value in most investment decisions. Most shop-level decisions will not have the growth option impact of an R&D investment; nonetheless, growth options are still pertinent to operations and may still be quite valuable. Every time a company invests in a capability which enhances its infrastructure, its technical capability or its people, it is buying a growth option to be able to make future choices which are not currently available to it. For the HCX machine scenario, growth options suggested above might be more thoroughly considered as noted in Table 12.

Do	Can	Can't
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	The single HCX now makes it much more financially reasonable to consider bar-coders and other ancillary activities that would previously have required 10 devices, one for each packaging machine. This is a real call option.	The current system would be more capable of running very small lot sizes. To the extent that this capability satisfies more customers, it is a real call option.
	The specific technologies of the HCX centralized machine may be applied elsewhere within the corporate structure depending on the success of this experience. This is a real call option	
	The HCX enables the purchase of a new product assembly machine without an accompanying packaging machine. This is a real call option.	

Table 12: The HCX Purchase Includes the Acquisition and Relinquishing of Growth Options

Because growth options and expansion options are simply different points on a continuum of call options, the distinction between the two can be blurred; typically the upside potential of expansion options are more inherent in the typical operational use of the original asset than growth options. (Nonetheless, it could be argued that the option to buy an additional machine is an expansion option as opposed to a growth option).The easiest way to identify an option to expand is to consider the NPV factors for an investment and imagine a scenario where an investment in response to some emerging information makes them worth more. The cleanest example: demand for the product increases, can the machine run a third shift? Consider this option for the HCX:

Do	Can	Can't
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	If the machine can satisfy expected demand at less than full capacity, then we can increase output (until output is constrained elsewhere in the system). This is a real call option.	The current machines are running near capacity. They do not offer much upside opportunity and, therefore, minimal value as a real call option.

Table 13: The HCX Purchase Includes the Acquisition of Extra Capacity

Using the Black-Scholes spreadsheet format, the approximate value of each of these options could be assessed as shown in Table 14.

To provide the reader with a methodical understanding of how these values can be obtained, the approximation for three of these options will be illustrated step by step: The growth option to enable bar coding, the (lost) growth option to manufacture in small lot sizes, and the expansion option to increase capacity. Consider first the option to on-line bar-code the packages via the addition of a single high-speed bar-coder.

<u>Bar Coding</u>

> The shop management has been interested in bar coding for some time in that they feel it will help them to more easily identify and reduce quality and distribution problems. Currently, though, the payback on 10 bar coders is so low that it really is not thinkable. However, with a centralized system where they only need to purchase one machine (albeit a more expensive machine), they believe the idea has merit. As the industry is still settling on standards, they feel no urgency to rush into an implementation but believe that within three years they will need to decide. Over the course of the next three years, they believe they will have a better understanding of the industry and of the applications for bar-coding. They recently estimated the value of bar coding at $70,000 and figured that the fixed costs for a high speed machine installation would also be about $70,000. It appears to be marginal, does it have value?

To determine the option value, the variables (exercise price, time, asset price, volatility and risk-free interest rate) must be estimated. These estimates could be developed as outlined in Table 15. The estimation of these values is a primary contribution of the cross-functional team. Collectively, they will have a feel for the cost of implementing follow-on investments, the time frame over which these decisions must be made, and hopefully some feeling for the predicted cash flows potentially generated by the investment. To be used in the Black-Scholes-based spreadsheet, these cash flows need to be discounted.[6] Volatility, one of the more influential

[6] In keeping with the assumptions of Black-Scholes, cash flows should be discounted at the risk-free interest rate. (Sachdeva [74])

		Addtl Value: Created Option	*"Opportunity Cost:"* Exercised Option						
If you do this:	Option Type	You will be able to do this:	You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	Call
Do		**Can**	**Can't**	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Interest Rate]	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Grow	Add bar-coder		$70,000	3	$70,000	60%	6.00%	$31,482
	Grow	Apply HCX elsewhere within the corporate structure		$1,000,000	2	$700,000	20%	6.00%	$24,447
	Grow	Purchase of a new product assembly machine without an accompanying packaging machine		$1,500,000	2	$1,250,000	20%	6.00%	$106,747
	Grow		Run very small lot sizes	$400,000	5	$250,000	40%	6.00%	$72,067
	Expand	The HCX can satisfy expected demand in 2 shifts, increasing output until constrained by the system max is a real call		$85,000	3	$60,000	20%	6.00%	$4,444

Table 14: Options to Grow and Expand Add Value (or Increase Opportunity Costs) for the HCX Purchase

variables in options valuation, tends to be a harder number to estimate. Accordingly, two workable approaches are suggested in Appendix D.

Exercise Price	Irreversible follow-on investment costs	Estimated by the group based on previous quotes at about $70,000 including purchase, training, installation, etc.
Time	Window to decide to invest	Estimated by the group as 3 years; uncertainty in the industry accounts for much of the window.
Asset Price	Expected present value of cash flows from follow-on investment	The shop's previous discounted cash flow estimate was $70,000 over the foreseeable life of the equipment.
Volatility	Uncertainty in Asset Price estimate over the time window	Because the industry's bar-coding position itself is very uncertain and due to the company's uncertainty of bar-coding's capabilities, they believe that between now and three years from now when they have to decide whether to invest, the estimate of cash flows over the life of the investment could vary tremendously; anywhere from $25K to $200K.
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6% (all numbers are in nominal terms)

Table 15: For the HCX, Bar Coding is Analogous to a Stock Option

Using the first approach in Appendix D, an estimate of $70,000, a 3-year upside estimate of $200,000 and downside estimate of $25,000, yields an approximate annual standard deviation of 60%. These numbers in combination with the risk-free interest rate indicate an option value for Bar-coding of about $30,000. That means that, in addition to the NPV associated with the HCX, it offers an option on Bar-coding worth approximately $30,000 today. Consider now the potentially lost option offered by small lot sizes:

Small Lot Sizes

One of the major concerns expressed by some in the group was the inability to run very small lot sizes on the HCX. They note a growing trend toward customization and suggest that the ultimate package customization would be to make a different package for each customer. The rate and scheduling complexity for the HCX favor larger, not smaller batches. The HCX proponents note that while the small lot idea has merit it is probably much more expensive than it is worth. The marketing representative notes that customization is receiving a lot of attention and could boost sales significantly. Just a 10% increase would be worth $250,000 she notes. The Operations folks quickly prepare a list of things that would have to be put in place to enable single package lot sizes and guesstimate the implementation cost at $400,000. As a group they decide to look at the option value over a 5-year window. Because the market response to such a move is so uncertain, they want to see the option value for an annual standard deviation of 40% (or an upside of $600K and downside of $100K).

Given this preceding scenario, the team's estimates for the option pricing variables could be like those outlined in Table 16.

Exercise Price	Irreversible follow-on investment costs	Roughly estimated by the group at $400,000 mostly for infrastructural changes.
Time	Window to decide to invest	Estimated by the group as 5 years
Asset Price	Expected present value of cash flows from follow-on investment	Roughly estimated at 10% sales increase or cash flow PV increase of $2.5M * 10% = $250,000
Volatility	Uncertainty in Asset Price estimate over the time window	Because of the large market uncertainty, the group feels that 40% is a reasonable annual standard deviation.
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6% (all numbers are in nominal terms)

Table 16: For the HCX, Small Lot Sizes are Analogous to a Lost Stock Option

Applying these numbers to the Option spreadsheet reveals an approximate imbedded option in the current system of $72,000. This would be an opportunity cost of replacing the current machines with the HCX.

Increase Capacity

The option to increase capacity was detailed in an earlier chapter. The variables upon which this valuation depends could have been approximated as outlined in Table 17.

Exercise Price	Irreversible follow-on investment costs	Roughly estimated by the group at $85,000 for additional tooling and administrative costs for establishing the 3rd shift.
Time	Window to decide to invest	Estimated by the group as 3 years. The group believed that the value of the asset would begin to diminish after that point.
Asset Price	Expected present value of cash flows from follow-on investment	Approximated as 5% of potential 3rd shift output suggesting a PV of cash flows of .05 * $1.2M = $60K.
Volatility	Uncertainty in Asset Price estimate over the time window	Since the product is mature, the group felt an annual standard deviation of 20% was realistic. (That means the upside estimate could jump to $90K and the downside to $40K).
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6% (all numbers are in nominal terms)

Table 17: For the HCX, Increased Capacity is Analogous to Purchasing a Stock Option

Note that the Black-Scholes spreadsheet valuation indicates that the option to expand capacity that is imbedded in the purchase of the HCX by utilizing it for three shifts currently has an almost negligible value of about $4K.

Considerations for Options to Grow and Expand

As growth and expansion options can offer substantial strategic value to a given initiative (especially growth options), their estimation and inclusion in the decision-making process is essential to maximizing the value of a firm. When evaluating upside options, the following considerations need to be assessed:

- Capacity constraints could limit the upside potential for these options. For example, single lot sizes can only increase incremental sales $600K if the system can support it. Similarly, the HCX could only support the addition of another product assembly machine if it had the excess capacity to package that product. For this reason, those options that display surprisingly high (or low) values need to be analyzed further to understand the nature of the value.
- Some follow-on projects are heavily dependent on a set of initiatives like pieces in a puzzle. Unless the only uncertain piece is the one project being valued, the entire upside potential cannot be attributed to the one follow-on project alone. For example, if the value from the bar-coder is heavily dependent on the establishment of a new distribution system, the evolving uncertainty in the establishment of that system might account for much of the option attributed to bar-coding (not a centralized HCX). However, in these cases the entire group of initiatives could be assessed as a single follow-on investment option.
- In every case, the current situation provides the same option as the new option; however, in the most valuable of cases, the existing option is so far "out-of-the-money" (very low likelihood of ever being worth exercising at expiration) that it is essentially worthless. When it is not worthless, both the existing option and the new option must be computed and the differences can then be attributed to the original investment.
- Proprietary options (like patents) are very valuable while industry-shared options are only valuable if a company is in a strong enough competitive position to withstand similar moves by competitors. (Kester [43])

Further examples of growth and expansion option calculations can be found noted in the bibliography cross reference chart on page 100.

Downside Put Options: Options to Abandon and Contract

Options to Abandon and Contract are considered together here since they both reduce downside losses through the reclamation of some portion of the value of an asset should circumstances develop unfavorably in the future. Like the earlier call options, contracting and abandoning are merely different points on a continuum. Generally speaking, abandonment, as it sounds, represents the complete and irreversible termination of a project. Contraction refers to incremental down-sizing and does not preclude the option to reexpand. For the HCX machine scenario, the abandonment and contraction options outlined earlier might be more thoroughly considered as follows (Table 18):

Do	Can	Can't
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	If the HCX is a standard machine in the industry or if its design is highly modular such that portions of the machine are extractable and resellable then it offers a valuable real abandonment put option should demand for the current package (or its product) drop completely.	The current 10 machines are specialized, non-modular designs. They cannot easily be sold and so offer no value as a real abandonment put option.
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Since the HCX is a large centralized machine, it is probable that this system does not offer a real put option to contract (in increments). In fact, the current 10 machine system does offer this, so this facet will show up as a DoCan't.	The current arrangement of 10 separate machines does offer a real put option to contract one (or more) machine(s) at a time.

Table 18: The HCX Purchase Included the Purchase of at Least Two Puts

Using the Black-Scholes spreadsheet format, the approximate value of each of these options could be assessed as shown in Table 19.

To provide the reader with a methodical understanding of how these values can be obtained, the approximation for these two options will be illustrated step by step. Consider first the option to contract.

If you do this:	Option Type	*Addtl Value:* Created Option You will be able to do this:	*"Opportunity Cost:"* Exercised Option You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	Put
Do		Can	Can't	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Interest Rate]	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Contract		10 separate machines offers a real put option to contract one (or more) machine(s) at a time.	$25,000	3	$150,000	15%	6.00%	$0
	Abandon	The HCX is a standard machine in the industry; resellable. real put option		$600,000	4	$1,200,000	15%	6.00%	$63

Table 19: HCX Downside Puts Can be Evaluated Using the Black-Scholes Spreadsheet

Contract

To the extent that the firm can sell off the older machines one at a time as the market for their product declines, they have a potentially valuable option to contract. In the HCX scenario, in fact, the older machines are rather antiquated and of specialized, non-modular design; the likely resale value is nil. Nonetheless, that does not necessarily mean the exercise price of the call which corresponds to this put is necessarily $0.

Exercise Price	Recoverable investment costs	Age and specialization of machine imply no recovery cost; the group recognizes that the floor space would alleviate some of their material handling double moves. They estimate a $25K value over the foreseeable future in material handling savings.
Time	Window over which contraction could be considered	Estimated by the group as 4 years
Asset Price	Expected present value of cash flows from current employment of a single older machine	Estimated by the group as $200K; (If the product were severely hindered by its age, this number might be much smaller)
Volatility	Uncertainty in Asset Price estimate over the time window	Because the HCX will support an established product / package system, the uncertainty is low. Annual standard deviation by the group estimated at 15%.
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6%

Table 20: Purchase of the HCX Excludes an Option to Contract

If the space that could be made available by removing a single machine could be shown to have an estimated value, that value would be included in the exercise price and the put would not be worthless. (In this fact-based example, there was not another product in the pipeline that was demanding the floor space but there would have been some cost reduction in material handling; unfortunately, the material handling savings does not offer any substantive value to the real put option to contract).

Abandon

Because of the HCX machine's common design and utility, there exists a substantial resale potential for this machine should the company elect to abandon the operation. The variables for approximating the value of this option to abandon could be considered as outlined in Table 21.

Given these variables, the Black-Scholes estimate for the put option—the option to sell off the machine given a poor product performance in the market—is a minuscule $63. Why so low? Two reasons: first, the asset's estimated worth ($1.2M) is so much larger than its resale value ($.6M) that the put is far "out-of-the-money." This is compounded by a second factor: because this machine is being placed in service into a production system with a lengthy history of stable performance, the volatility of the asset value is low. Low volatility and low resale combine to minimize the value of this put. Accordingly, the resellability of the HCX is not a convincing argument to go ahead with the purchase, all else being equal.

Exercise Price	Recoverable investment costs	Estimated by the group at $600,000; unfortunately, much of the initial $1M investment was for installation and various investments in services that cannot be recouped.
Time	Window over which abandonment could be considered	Estimated by the group as 4 years
Asset Price	Expected present value of cash flows from current employment of the asset	This is the NPV for the machine (could be taken from NPV investment paperwork)
Volatility	Uncertainty in Asset Price estimate over the time window	Because the HCX will support an established product / package system, the uncertainty is low. Annual standard deviation by the group estimated at 15%.
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6%

Table 21: Purchase of the HCX Includes the Purchase of an Option to Abandon

To illustrate the conditions under which an abandonment put would be valuable, consider the Black-Scholes estimates for the preceding HCX scenario together with two examples under modified circumstances (Table 21).

Note that the first example uses the same parameters as the "standard" HCX calculation but with a relatively high volatility (50%). The change in volatility alone increases the value of the put to almost $67,000. This might be the situation if the purchase of the HCX were for a new product line for which the market response were relatively uncertain.

The second example illustrates a situation where the asset value is quite uncertain (volatility = 70%) while at the same time nearly all of the equipment cost can be reclaimed on the resale market. Such a situation might apply to a start-up operation that has very uncertain market demand and which uses a cutting edge equipment technology that they install at themselves minimal cost (therefore, most of the original investment can be reclaimed). Note that under these conditions, the value of the abandonment put becomes quite significant ($260,000).

The "actual" HCX abandonment put in combination with the two preceding examples clearly indicates that the value of an abandonment put is very situationally dependent. Nonetheless, regardless of its ultimate quantitative significance, the recognition and estimation of its potential importance is an essential element of any such asset investment.

Further examples of abandon and contract option calculations can be found noted in the bibliography cross reference chart on page 100.

If you do this:	Option Type	*Addtl Value:* Created Option You will be able to do this:	*"Opportunity Cost:"* Exercised Option You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	Put
Do		**Can**	**Can't**	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Interest Rate]	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Abandon	The HCX is a standard machine in the industry; resellable. real put option		$600,000	4	$1,200,000	15%	6.00%	$63
	Abandon	EXAMPLE #1		$600,000	4	$1,200,000	50%	6.00%	$66,915
	Abandon	EXAMPLE #2		$1,000,000	2	$1,200,000	70%	6.00%	$257,813

Table 22: Volatility and High Resale Would Make the HCX Abandonment Put Valuable

Combination Calls and Puts: Option to Switch

The option to switch pertains generally to the ability to accommodate different processes, different inputs or different outputs. Because of the complications resulting from the interrelationships of two different operating "modes," the mathematical models for calculating the option to switch are very complex and beyond the scope of this thesis. Nonetheless, some general concepts are outlined below to enable an understanding of the sources and magnitude of value for a given option to switch.

Consider the switching option inherent in the purchase of the HCX (Table 23):

Do	Can	Can't
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	If the HCX configuration can accommodate different kinds of packaging that may be valuable should the initial package type fall out of favor, then the HCX includes a real call option to switch.	The current machines are designed exclusively for one product / package configuration. They cannot readily be switched to another package or product. The current arrangement does not offer a real call option to switch.

Table 23: The Ability to Process Two Package Types on the HCX Is an Option to Switch

In general, for alternate outputs such as that described for the HCX, the following principles apply:

- The lower the correlation between the alternate outputs (the lower the demand correlation), the more valuable is the option to switch between outputs.
- An investment is always more valuable if it can accommodate multiple outputs as opposed to a single output.

A mathematically intense closed form solution for the option to switch (based on Black-Scholes) has been developed by Kulatilaka and Marcus [48]; an easier, broader development of the various options to switch are presented by Mahassney [50]. For situation specific references, see the bibliography chart on page 100.

Option to Wait

The option to wait exists with all investment decisions. It is considered separately from the preceding calls and puts in that it pertains to the initial investment itself. Because the emergence of information over time influences the decisions regarding investment, waiting for more information increases the value of an investment. If there were no costs for waiting, options theory states that it would always be more valuable to wait than to invest now. Of course, there is almost always a cost for waiting; for investments, the trade-off to waiting is the potentially lost opportunity for earnings that could have been obtained had the investment been made initially.

This section introduces the value of waiting under two conditions: when the opportunity will always be available (such that waiting several years means only that a firm is postponing those earnings) and when the opportunity is finite (such that waiting several years translates into several years of permanently lost revenue). If a firm holds unchallenged monopoly for a given product, it may be appropriate to consider the earnings as postponable. As most firms face competitive markets, the greater likelihood is that postponement is accompanied by foregone revenues.

The option to wait before going ahead with the HCX purchase is outlined in the following "DoCan/DoCan't" chart (Table 24):

Do	Can	Can't
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Until the money for the HCX is spent, there exists a real call option to wait; however, once it has been spent, that option has been exercised. This is a DoCan't.	The plant could continue to run with the current 10 machine system and save its investment until the NPV was more certain. When they buy the HCX, they give up this real call option.

Table 24: Like Any Other Investment, the HCX Purchase Can Wait

Assuming that the company in this scenario holds a monopoly position, the information for estimating the value of the option to wait can be outlined in Table 25:

Exercise Price	Initial investment costs	The cost of the HCX machine (including installation, training, etc.); quoted at approximately $1.2M.
Time	Window over which waiting for additional information seems appropriate	Estimated by the group as 3 years. (Later, it will be explained that this number can be computed for a range of years to find the optimum wait.)
Asset Price	Expected present value of cash flows from the HCX	Estimated by the group as $1.5M. (This can be taken from the original cost justification for the machine.)
Volatility	Uncertainty in Asset Price estimate over the time window	Because the HCX will support an established product / package system, the uncertainty is low. Annual standard deviation by the group estimated at 15%.
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate was taken as 6%

Table 25: The Variables of the HCX Option to Wait

Using these variables, the option to wait three years before investing in the HCX can be estimated using the Black-Scholes-based spreadsheet. The value of the HCX investment based on an option to wait three years is approximately \$506,000. That calculation can be seen in Table 26. Note that this represents the value of the entire investment. The opportunity cost of investing now is the difference between this value and the value of investing now (the NPV):

Opportunity Cost = \$506,000 - (\$1,500,000 - \$1,200,000) = \$300,000.

Therefore, a firm that holds monopoly power in that their revenues are essentially postponable would be foregoing \$300K to invest now as opposed to waiting for three years for the market to stabilize.

The much more common scenario is one in which postponement of an investment decision causes permanent forfeiture of the revenues that would have been generated by the investment during the time of postponement. The valuation of such a scenario corresponds to the valuation of a financial option on a stock that pays dividends. Since an investor who owns an option on a stock does not own the stock, any dividends paid out by the stock are opportunity costs to the investor for the purchase of the option as opposed to the stock. To value a dividend paying stock, Merton [58] developed the following modified form of the Black-Scholes equation:

$$C = Se^{-\delta t} * N(d1) - Xe^{-rt} * N(d2)$$

where:

$$d1 = \frac{\ln\left(\frac{S}{X}\right) + \left(r + \frac{1}{2}\sigma^2\right)t}{\sigma\sqrt{t}}$$

$$d2 = d1 - \sigma\sqrt{t}$$

C = Call value
S = Current stock price
e = 2.71828, the base of a natural log
δ = Annual dividend rate (continuously compounded)
X = Exercise price
r = Annual risk-free interest rate (continuously compounded)
t = Time to maturity of the option in years
σ = Annual standard deviation for the stock (continuously compounded)

If you do this:	Option Type	*Addt'l Value:* Created Option You will be able to do this:	*"Opportunity Cost:"* Exercised Option You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Revenue foregone until can/can't	Risk-free interest rate	Call
Do		Can	Can't	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Dividend Stream]	[Interest Rate]	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Wait		Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$1,200,000	3	$1,500,000	15%		6.00%	$505,907

Table 26: Waiting is Valuable if There are No Dividends

If you do this:	Option Type	*Addt'l Value:* Created Option You will be able to do this:	*"Opportunity Cost:"* Exercised Option You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Revenue foregone until can/can't	Risk-free interest rate	Call
Do		Can	Can't	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Dividend Stream]	[Interest Rate]	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year			Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$1,200,000	3	$1,500,000	15%	10%	6.00%	$135,910
			Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$1,200,000	1	$1,500,000	15%	10%	6.00%	$233,006
			Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$1,200,000	1	$1,500,000	15%	5%	6.00%	$300,818
			Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$1,200,000	3	$1,500,000	60%	5%	6.00%	$607,627

Table 27: High Volatility and Low Dividends Create Valuable Options to Wait

Note the addition of the "δ" term to account for dividends. This same equation can be used to estimate the value of real options that must forego earnings until an investment is implemented.[7] The first line calculation in Table 27 estimates the value of the HCX if the investment were delayed three years during which earnings (15% of the project value per year) were lost and are not recoverable. Note that the HCX is now worth only about $30K (as compared to $300K if implemented immediately). This indicates that the 20% volatility cannot remotely compensate for three years of lost earnings. The second line indicates that even just a one-year wait decreases the value of the project (by more than $100K).

Under what conditions would a wait be indicated? The option to wait is particularly valuable when the annual payout of the project is low or the volatility is high or (especially) both. The third line calculation in Table 27 shows that the if the HCX payout were just 5% annually, a one-year wait would be roughly equivalent to an immediate exercise. More striking still, the fourth line calculation shows that if project uncertainty (volatility) is high—in this case 60%—the option to wait is particularly valuable ($607K - $300K ≅ $300K).

As virtually all investments possess an option to wait, this is one of the most useful applications of options analysis to investment decisions. A review of the literature (reference bibliography cross reference chart, p. 100) provides a number of examples of the determination of optimal timing of investments derived from options-based break-even calculations. These examples demonstrate that, in some cases, even a positive NPV project should be postponed a given length of time to maximize the value of the project to the firm.

[7] Besides this method, Damodaran [17] recommends estimating the value of the lost dividends (earnings), discounting those dividends and subtracting them from the value of the stock.

4.2.4 Analyze the Options

The primary objective of this chapter is to enable a manufacturing decision maker to consider and estimate the sources of strategic advantage inherent in an investment decision. It has been shown that the value of an investment extends beyond the NPV projection for a project to include the imbedded options. With the aid of a suitable cross-functional team, the options imbedded in an investment can be identified and estimated using a "DoCan/DoCan't" framework and spreadsheet capabilities based on the Black-Scholes option formula.

The scenario described in this chapter, the purchase of a large, centralized packaging machine, was dissected with respect to its associated strategic options. The options were then estimated; the results are summarized in Table 28:

Addtl Value: Created Option	*"Opportunity Cost:"* Exercised Option	
You will be able to do this:	You won't be able to do this:	Value
Can	Can't	
Add bar-coder		$31,482
Apply HCX elsewhere within the corporate structure		$24,447
Purchase of a new product assembly machine without an accompanying packaging machine		$106,747
	Run very small lot sizes	($72,067)
The HCX can satisfy expected demand in 2 shifts, increasing output until constrained by the system max is a real call option.		$4,444
	Run with the current 10 machine system and wiat until the NPV for the HCX is more certain	$0
	10 separate machines offers a real put option to contract one (or more) machine(s) at a time.	$0
The HCX is a standard machine in the industry; resellable. real put option		$63

Table 28: The Aggregate Reveals the Few Prominent Options

One of the prominent advantages of the use of a Black-Scholes-based spreadsheet is the ability to readily perform sensitivity analysis. As option variables can be difficult to project, the ability to modify volatilities, times and costs proves to be very useful for understanding the range of potential values and the sensitivity of a given value to estimate errors. Consider the permutations for the bar-coding example calculated in Table 14. Figure 8 presents the same calculations for a range of volatilities and displays those values in graphic form.

Using the graph as a sensitivity tool (estimating the slope of a curve), it can be seen that the approximate sensitivity of the bar coding growth option to volatility errors is $350 per percent of error. While Appendix B presents the mathematical sensitivities of the Black-Scholes formula, this graphic technique is simpler and more readily useable.

In summary, the final step for evaluating decision options is to identify those options that are potentially significant and:

1. Perform sensitivity analyses
2. Further scrutinize the data

By gathering a cross functional team, using a "DoCan/DoCan't" chart for identifying options, applying a Black-Scholes-based spreadsheet tool for estimating the options and further investigating those options with high potential value, a decision-maker can quickly and effectively account for the strategic elements within a decision. With this understanding, the decision-maker is now prepared to restructure their decisions to fully utilize the value of options. This is the subject of Chapter 5.

If you do this:	Option Type	*Add'l Value:* Created Option You will be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	Call
Do		**Can**	**[Exercise Price]**	**[Time]**	**[Price of underlying asset]**	**[Volatility]**	**[Interest Rate]**	
Replace the 10 old machines with a high speed HCX packaging machine by mid next year	Grow	Add bar-coder	$70,000	3	$70,000	30%	6.00%	$19,533
	Grow	Add bar-coder	$70,000	3	$70,000	40%	6.00%	$23,589
	Grow	Add bar-coder	$70,000	3	$70,000	50%	6.00%	$27,592
	Grow	Add bar-coder	$70,000	3	$70,000	60%	6.00%	$31,482
	Grow	Add bar-coder	$70,000	3	$70,000	70%	6.00%	$35,218
	Grow	Add bar-coder	$70,000	3	$70,000	80%	6.00%	$38,774
	Grow	Add bar-coder	$70,000	3	$70,000	90%	6.00%	$42,130
	Grow	Add bar-coder	$70,000	3	$70,000	100%	6.00%	$45,271
	Grow	Add bar-coder	$70,000	3	$70,000	110%	6.00%	$48,189
	Grow	Add bar-coder	$70,000	3	$70,000	120%	6.00%	$50,877

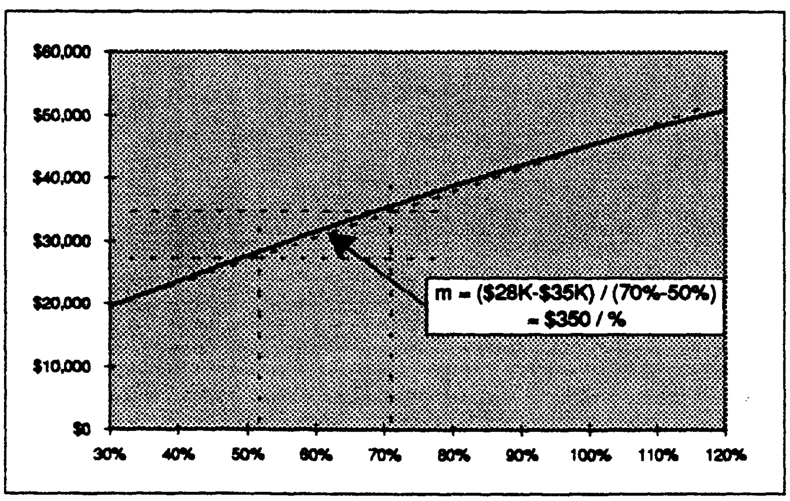


Figure 8: The Black-Scholes Spreadsheet Makes Sensitivity Analysis Easy

5.0 Options Analysis: Crafting Options

The second essential contribution of options analysis is its contribution to the development of strategic thinking—being able to identify and understand strategic value. As noted in the introduction to this thesis, the increasing complexity of manufacturing decisions together with the flattening of organizations demands the need for knowledgeable, capable strategists throughout the organization. The development of options analysis is an effort to create a methodology for learning and applying the strategic analysis skills necessary to regularly make economically valuable manufacturing decisions.

The content of chapter 3 provided a solid conceptual understanding of the application of options theory to real options. Building on that, chapter 4 introduced a framework for analyzing a given decision on the basis of options in order to understand imbedded strategic value. More broadly, chapter 4 demonstrated the process by which decisions can be strategically assessed. With the groundwork of these preceding chapters, this chapter will help develop in the reader the ability to restructure decisions to take advantage of real options. Such crafting of options enables the decision maker to minimize investment misjudgments.

5.1 Sources of Option Value

A financial option is valuable in that it allows its owner to be certain of its value when it is exercised. Consider, for example, an investor who buys a call option on a stock with an exercise price of $100; if when the option matures, the stock price is $110 the investor exercises her option and pockets the $10 difference. What creates value in an option is simply that the value of the underlying asset (the stock) fluctuates over time gradually increasing the certainty of the option value. Thus, two dynamics regarding the price of the stock / the value of the option occur during the life of an option:

1. The expected value of the stock drifts within the original range of outcomes
2. The range of expected values for the stock shrinks

For the example diagrammed in Figure 9, an investor purchases an option knowing that the stock's final price could be anywhere within the given distribution. The price of the option (its value at purchase) is essentially a break-even "bet" on how high the stock price could go (making the option more valuable and its exercise likely) vs. how low the stock price could go (making the option worthless) vis-à-vis a price set today. By maturity, the value of exercising the option is certain. If the no-longer expected but now certain stock price is higher than the exercise price, the investor exercises.

Stock Price Determination over Option Life

As the Expiration Date of an Option Nears, the Expected Price of the Underlying Stock Becomes More Certain vis-a-vis the Initial Expectation

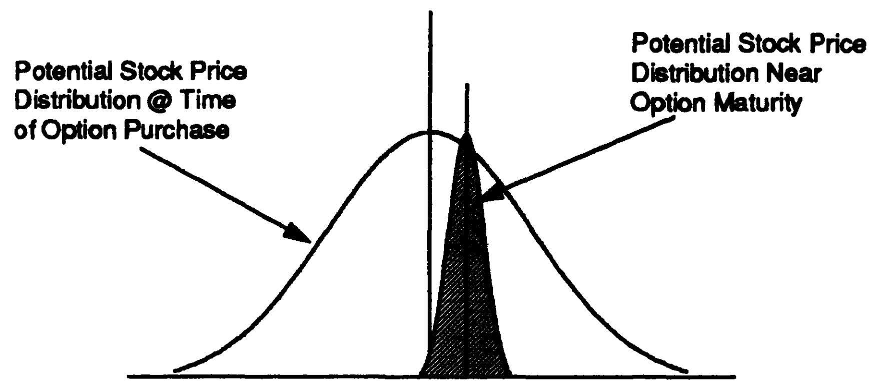


Figure 9: Options are Exercised at Maturity Because Their Value is Certain

These same dynamics face the holder of a real option. However, the holder of a real option can (and must) act to shape the value of a real option over time. In a financial option, the range of potential stock price outcomes reflects an aggregation of all the events in the stock market that can change. In a real option, the distribution of follow-on cash flows represents an aggregate of the uncertainty in all the market demand forces for a product and the uncertainty in the company's internal skills. For example, suppose a manufacturer would like to use a certain technology to automate a series of manual operations. The value of the automation is uncertain because of the uncertainty of the revenues and costs of the product produced on the machine and because of the companies uncertainty in their effectiveness in applying the technology.

By its actions, the company can reduce these uncertainties. Superb marketing and long-term materials contracts may lessen the revenue and cost uncertainty. More significantly, a focused effort to acquire automation skills and knowledge can almost completely remove uncertainty due to technology. This, in fact, is exactly what manufacturers do when they run pilot operations. The knowledge acquired via a pilot more precisely locates the probable outcome; the skills acquired during a pilot enable the exercise of the option to automate the rest of the factory and lessen the uncertainty of the automation's success.

5.2 Crafting a Real Option

With this understanding of options then, the manufacturing decision maker can take advantage of the structure of options to reduce the risks and increase the potential value of many decisions. Fortunately many decision makers already utilize options not because of their understanding of options theory but rather the intuitive logic behind them. Consider the basic messages of the preceding chapter:

All else being equal, invest in the initiative which:

- enables more upward growth and expansion
- handles more alternative inputs and outputs
- has higher resale

The benefit of options analysis is its ability to approximate these benefits when all else is not necessarily equal. Nonetheless, equal or not, while these options are often employed (based on intuition) they are not routinely considered with every long-term decision...and they should be. Consider the examples in Table 8:

Initiative:	Initiative as an Option:
A shop recently completed plant-wide training in Statistical Process Control (SPC).	The acquisition of skill from SPC training and its usefulness in lowering the cost of quality can be rather uncertain. Had the company first tested the particular SPC training in one area and used the learnings to identify key opportunities and improvements, the company would have acquired a valuable option to train the remainder of the workforce.
The production control group purchased a number of used computers to support their current planning needs.	While the NPV may still have justified the purchase of the used computers, it must be recognized that by buying used computers, the company excluded many growth options imbedded in the capabilities of a new computer.
A plant invested heavily to reorganize its factory equipment to take advantage of group technology cells.	Unless such a move has been tried internally before, the success of such a move is rather uncertain and the investment could be very large. The setup and development of one cell provides an option on reorganizing the remainder of the plant.

Table 29: Most Decisions Can be Reconsidered as Options

Had each of these projects been considered from an options perspective, they may have been restructured to take advantage of the upside potential of an option. To illustrate how this might have been assessed, consider again the last of the three examples above:

> A factory plans to invest $1.3M to reorganize its equipment (in labor, shop losses, support equipment, etc.) around a cell concept. Nonetheless, they hope for a PV of cash flows from the reorganization of $2.0M over the following five years. The project manager can tell that the salesman for the idea was very effective; she believes project is more likely to just break even and could be a lot worse. She wants to test the idea first for 6 months with a single cell. Afterwards, she believes she'll have the data to know with much greater certainty the probable value of reorganizing the entire plant. How much would that be worth to her? (In other words, how much should she be willing to invest to check the concept?)

The Black-Scholes approximation for this option is shown in Table 30. Given the project manager's concerns and based on her assumptions, options analysis indicates that it would be worth $250K today to run a 6-month pilot that would enable a reliable projection of the value of reorganizing the plant. If she can run the pilot for less than $250K, it would be an added value to the firm. Furthermore, to commit few resources in an effort to save money may cost far more than the savings if the necessary information to ensure an exercisable option is not obtained.

By applying a similar level of analysis, many typical decisions can be decomposed into valuable options. Part of the importance of understanding the concept of options is in developing a sensitivity to how options work and how they can be valuable. As with the factory reorganization example, in many cases, restructuring a decision as an option or to take advantage of options can yield dramatic value for the firm.

5.3 Conclusion

Virtually all investments within a company have the potential to be crafted to take advantage of the benefits of real options. Those projects which are particularly good candidates for the development of options share the following common traits:

- The investment and potential payback are large (relative to budget).
- The uncertainty in the expected present value of the payback is high relative to the time until which the investment must be committed.
- The NPV project for the project is marginal.

For companies to take advantage of the options that could be imbedded within the initiatives that share these traits, they must ask themselves three questions:

		Add'l Value: Created Option	*"Opportunity Cost:"* Exercised Option						
If you do this:	Option Type	You will be able to do this:	You won't be able to do this:	Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	**Call**
Do		**Can**	**Can't**	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Interest Rate]	
Reorganize one cell and launch a 4 month pilot	Grow	Reorgranize the remainder of the factory based on the cell conept		$1,300,000	0.5	$1,300,000	65%	6.00%	$252,020

Table 30: Options Analysis Reveals that a Pilot on the Factory Reorganization is Worth $250,000

1. Can this initiative first be considered on a small scale?
2. Can this initiative accommodate different inputs and outputs?
3. Can the assets required for this initiative be dismembered and the investment reclaimed?

For each of the preceding questions to which the answer is yes, the company can craft an option that will have value. The extent to which that option increases the value of the total project to the firm will determine the degree to which the project will be modified to incorporate an imbedded option. This ability to increase the value of an initiative by crafting it as an option represents a major benefit of options analysis to manufacturing decision makers. Furthermore, because of the simplicity of this approach, decision-makers at all levels within firm can employ the techniques of options analysis to increase strategic value and, hence, the total value of the firm.

6.0 Managing Options

The proceeding chapters have illustrated the options within a given decision and have demonstrated the means for crafting options. Once these options are identified and/or created, the task of ensuring the their value rests with those managing the options. Fundamentally, there are two facets of real options that require careful management:

1. the alignment of resources within one project between operational and strategic aspects; and
2. the acquisition of the knowledge and skills that constitutes an option and makes its exercise possible.

6.1 Alignment of Resources

In the introduction, this thesis analyzed the challenge to a decision maker when a strategically valuable project does not look financially good. It was noted that even when a strategically savvy manager does manage to justify a largely strategic project on operational payback, there is still a day of reckoning for the project leader when he is held accountable for the overly optimistic numbers needed to "justify" the project. The "hidden" aggregation of strategic value with operational (NPV) value impairs the effectiveness of the implementation team in that they are measured as if all the value of the project comes from operational value. Accordingly, the morale of the implementation team suffers and many project managers begin looking for new projects immediately after their last one is approved. Until managers begin to recognize and acknowledge those projects that have large strategic elements, results will also underwhelm expectations.

This thesis has shown that project value can be derived from two components: Operational value and strategic value. For project resources to be managed effectively, these two components must be identified and evaluated separately. This is the first key for effectively making strategic investment decisions and managing their implementation.

6.2 Acquisition of Skills and Knowledge

The second key for managing strategic initiatives is fundamental to options theory: For an option to actually have value on the order of that calculated at the onset of a project, the company must commit to acquiring the skills and knowledge upon which the option valuation is based. For example, to be able to assume the value of an option that is dependent on the acquisition of robotics experience (experience that would increase the reliability of future expected value projections), certain skills must be developed over time and certain data must be understood. If an option cannot be exercised or if the uncertainty in value is no smaller at the time of exercise than it is today, the option may have a calculable value but, in truth, it is worthless. It is incumbent upon decision makers and project managers to ensure that the skills that sustain an option are, in fact, being developed.

To summarize, the effective management of strategic options necessitates that they be separable from NPV and that they be exercisable.

6.3 Periodic Review of Options

One existent mechanism for monitoring and ensuring the value of a project's options is the quarterly review. Once a manager acknowledges the separate NPV and options values within a given project, she also must recognize that both facets require a means of control. As a project justification typically has NPV-based documentation for follow-up, it is suggested that valuable options have a summary sheet that can be reviewed as well. This summary sheet would include a description of the option, the calculations and assumptions, and objectives to be completed before the exercise date. An example of a possible option summary sheet can be seen in Figure 10 which summarizes the pilot option discussed in Chapter 5.

Note that the summary sheet lists the specific pieces of information that need to be extracted from the pilot to minimize the uncertainty at the time of exercise (at the time the money would need to be committed for reorganizing the rest of the plant). These pieces of data together with their respective measurements help define the deliverables for the pilot. Accordingly, these deliverables can be discussed in a periodic review session. More generally, two questions need to be asked periodically with regard to each option:

- What new information has become available and how does that affect the initial assumptions of exercise price, cash flows, timing and volatility?
- To what extent has the organization developed the skills that will ensure its ability to exercise the option?

A successful option implies that as the exercise date nears, a much more certain value can be attributed to the follow-on investment. Because real options are in actually analogous to

American options that can be exercised at any time, the strategic elements within a project (as identified by options) must be continually reassessed to determine whether or not to exercise. New information and alterations to assumptions should be noted and the option should be recalculated. Generally speaking, there are at least four conditions under which a company profits more by exercising growth options early rather than waiting (Kester):

1. When competitors have the same option
2. When the project has a high NPV
3. When the risk and interest rates are low
4. When competitive rivalry is intense

Perhaps the value is such that it should be exercised early; perhaps the option has retreated so far "out-of-the-money" that it can be ignored. An option summary with periodic reviews enables such ongoing assessments.

6.4 Conclusion

Real options must be managed in two ways: they must be identified and monitored in a similar (but separate) manor as NPV and they must derive information and skills which will both enable the exercise of the option and establishment with greater certainty the value at of the option at exercise. This can most easily be accomplished by preparing an option summary for each option which identifies the desirable deliverables of the option which support its exercise. These deliverables can then be reviewed periodically in conjunction with a standard review of operational targets (for NPV).

Figure 10: For Options to be Managed, They Must Be Recorded and Tracked

Option Summary Sheet

Project: *Factory Reorganization*

Option

Option Source	Type	Description
Growth	Call	The plant would wants to invest $1.3M to reorganize its equipment (in labor, shop losses, support equipment, etc.). Estimated PV of cash flows ranges from $800K to $2M. Plan to run 6-month, single cell pilot to verify savings.

Assumptions:

Exercise Price	Irreversible follow-on investment costs	Estimated at $1.3M to reorganize entire plant
Time	Window to decide to invest	Length of pilot: 6 months
Asset Price	Expected present value of cash flows from follow-on investment	Guesstimate of $1.3M (adjusted from optimistic $2.0M projection of senior management)
Volatility	Uncertainty in Asset Price estimate over the time window	65% annually (see calculation below)
Risk-free Rate	Risk-free Rate	The nominal risk-free interest rate estimated at 6%

Volatility Estimation:

expected value	$1,300,000
optimistic estimate	$2,000,000
pessimistic estimate	$800,000
time period (yrs)	0.5
upside multiplier	1.538462
implied % std dev	60.92%
downside multiplier	0.615385
implied % std dev	68.66%
est. % std dev/yr	64.79%

The Black-Scholes approximation for this option follows:

Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Risk-free interest rate	Call
[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Interest Rate]	
$1,300,000	0.5	$1,300,000	65%	6.00%	$25,2019

Objectives:

Sources of Uncertainty that could become clearer	Measure
Material handling savings	Mtl handling cost per part in pilot cell
WIP	Avg WIP in pilot cell / std hr
Labor savings	Avg. labor savings / std hr
Redux in cost of quality (scrap, etc.)	Avg. Quality cost redux per part
Factory Sales	Most recent mktg projection

7.0 Conclusions

As today's industrial world becomes more globally competitive, manufacturing decision makers are being asked to balance greater demands from more stakeholders than ever before. Compounding this challenge is the drive to create "lean" enterprises thereby pushing decision making responsibility closer to the operations level. Accordingly, an increasing cadre of decision makers are being called on to make decisions of substantial importance. This demands the sharing of information with them that enables such decisions. Additionally, it demands the development of new approaches and frameworks for analyzing decisions.

This thesis describes an emerging approach—real options—for identifying and analyzing the strategic elements imbedded within a decision. The work first discussed the dynamics of the product packaging operation as an illustration of the dynamics facing manufacturers today and as a problem domain for focusing the application of the techniques presented. This thesis then introduced the theory of financial options (stock options) and developed the analogy of stock options to options on real assets (real options). After demonstrating how real options can then be evaluated, a framework for applying options analysis generally to a manufacturing decision was presented. Building on this foundation, this thesis demonstrated how the understanding of options can be used to "craft" option value into decisions and how to then manage the resulting decisions.

7.1 Key Learnings, Contributions and Cautions

The key learnings of this thesis are summarized below:

- The value derived from virtually any initiative or project comprises operational value and strategic value. For a manufacturing initiative, operational value is determined using NPV. Strategic value can be assessed with the aid of options analysis, an extension of the theories behind the valuation of financial options.
- Inherent in nearly all decisions are several common types of real options: Upside call options (options to grow and expand), downside put options (options to abandon and contract), combination calls and puts (options to switch / exchange), and timing options (the option to wait). The value of each of these options captures the flexibility that a decision-maker has available to him to make future decisions that may add additional value. To the extent that

these future choices align with the strategic objectives, these options describe the value of such choices to the firm.

- The primary contributions of options analysis are its utility in revealing and (approximately) quantifying sources of strategic value. The ability to identify, assess and create additional options enables the decision maker to manage so as to add value to the firm.

As developed in this thesis, the dominant value of options analysis and an options approach to decisions for manufacturers is its contribution to three areas:

- The identification of options and their strategic significance
- The crafting of a decision to capitalize on potential options
- The management of the strategic value inherent in options

The prominent contributions of this work with regard to theses areas are can be summarized as follows:

- Option values for any initiative must be valued net of those excluded by the initiative. As a means of identifying all options potentially available and potentially unavailable, this thesis introduces the "DoCan/DoCan't" framework. This framework used in conjunction with the types of available options enables a decision maker to identify the marginal option sources inherent in a decision. In many cases, simply the recognition of the options via the "DoCan/DoCan't" framework is of significant value.
- This work outlines a process for estimating the value of an option including the approximation of the dependent variables as necessary. The "DoCan/DoCan't" framework can be extended in spreadsheet form to enable the quantitative approximation of the imbedded options. Based on the Black-Scholes option valuation formula, this spreadsheet allows expedient estimation of option values and enables simple sensitivity analysis.
- Once the workings of options are understood, the options approach can be applied to new decisions to craft-in potentially valuable options. This work illustrates the value of options thinking in developing project pilots. Other examples are given for building option value into manufacturing decisions.
- As nearly all initiatives offer both operational and strategic value, the need for managing these separately is essential. To be able to manage each facet, the value of each must be understood and periodically assessed. This work identifies the need for the differentiation of operational and strategic value and proposes an approach for managing the options that comprise a project's strategic value.

- Because of the copious variations and applications of option theory, this work serves primarily as an introduction to the field. Accordingly, a major contribution of this work is the inclusion of an extensive annotated bibliography for further reference. Additionally, a bibliographic cross-reference chart is included to index sources to specific options types.

Given the introductory nature of this work, it is important for the reader to recognize some general cautions:

- In order to provide an understandable yet useable analytical introduction to options valuation, this work has had to make several assumptions (detailed as made throughout the work). In addition, the Black-Scholes option formulation is based on an additional set of assumptions (also noted in the work). Accordingly, this thesis stands primarily as an introductory tool not as a blueprint for the general application of the technique. As presented in this work, options analysis provides a general approximation for real options; this approximation is useful in defining the direction in orders of magnitude. As potentially valuable options are identified, they need to be further analyzed and developed.
- Like all valuation tools (NPV included) options analysis can be biased to promote virtually any outcome. Accordingly, the greatest value of the analytical approach presented in this work is as a personal decision tool. If such an approach were to be formalized and used generally, agreement would have to be achieved on discount rates, means of determining variables, etc.

Despite these caution, the utility of options analysis cannot be overstated. Herein lies a tool for understanding, valuing, developing and managing the strategic element of decisions. As the markets become more competitive and costs drive organizations to become more lean, the importance of options thinking will continue to grow.

7.2 Polaroid Packaging: A Wider Options View

The representative problem domain for this thesis has been the instant film packaging operation at Polaroid. Accordingly, numerous examples within this text were are from operational decisions within a packaging operation: centralizing the packaging through a machine acquisition, drawing on additional production capacity and plant improvement projects. While this indeed speaks to an intended audience, it is appropriate now to expand the audience briefly and consider Polaroid packaging at the strategic level (as typically defined) given the dynamics of the packaging industry at large. What are the numerous customers' demands on packaging and how are these likely to change over time? How can Polaroid offer greater global value to its customers by redesigning its packaging "system?"

As Polaroid pursues projects to add value to its customers (and, therefore, the firm) via product packaging they can choose numerous channels both inside and outside the manufacturing facility. Though this thesis has focused primarily on the strategic value that can be added within the factory, a large portion—perhaps, the majority—of strategically valuable opportunities are driven by decisions outside, but integrally linked to, the manufacturing operation.

At Polaroid, a "strategic" focus on market segments largely accounts for the increasing proliferation of packaging variations to satisfy areas of perceived market demand. Since Polaroid management applies NPV techniques, the standard NPV for promotions or other focused initiatives is apparently positive. However, as indicated in the Venn diagram below, the impact of a seemingly isolated product distribution decision may have broader implications for the package design, the manufacturing operation or both. As the shaded overlap area in the diagram continues to increase (as the linkages between these areas increase), decisions in one facet of the packaging "system" are more readily enabling or constraining opportunities in other areas. These opportunities are options that can either be increasing the value of the firm (if new options are created) or decreasing the value of the firm (if potentially valuable options are prematurely exercised).

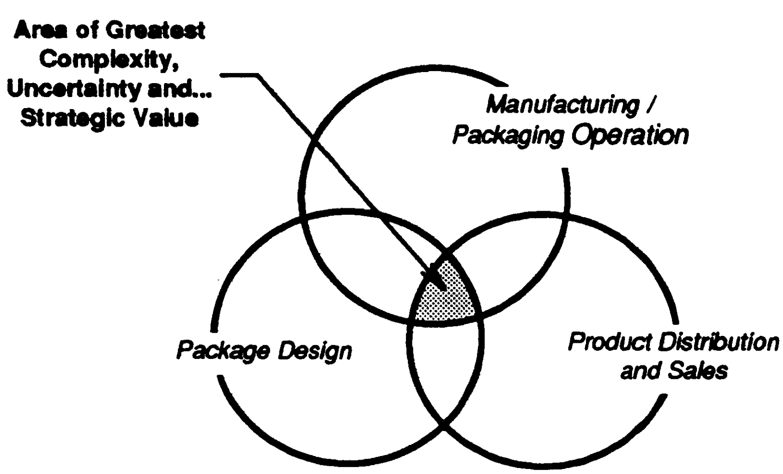


Figure 11: The Overlap of Functions Creates the Greatest Uncertainty

The chief concern is that as the package designer, the plant, and the sales and distribution force independently work to satisfy various customer requirements as they see them (to improve packaging's environmental impact, convenience to customers, cost effectiveness, performance, display, etc.), they may sub-optimize in that they limit the options for the entire system.

Under these circumstances, increased customer demands may contribute to greater sub-optimization which could, eventually, outstrip the company's capabilities as many valuable options are exercised without replacing them with new options. Consider the frustration of the salesforce when a solid NPV investment by manufacturing constrains their ability to reach new markets; or the difficulty manufacturers have when product (or in this case, package) developers by altering a design, exercise options that may have been valuable within manufacturing. The point is that the areas of greatest uncertainty in a firm are those that impact or are impacted by the largest number of functions within the firm. As options analysis suggests, these same areas of greatest uncertainty enable opportunities (options) of greatest value. However, if these options are prematurely exercised by a subset of the larger system, they limit the optimal result for the system as a whole.

The question then is how does Polaroid maximize the option value inherent in its investments in the packaging system? Most of the option value to manufacturing comes from external (product) standardization thereby enabling internal process flexibility; on the other hand, most of the option value to sales arises from (external) product flexibility given low-cost manufacturing (primarily through standardization). How to do both? The inherent understanding of the value of both standardization and customization has led to the growing emphasis on compromise strategies such as modularization.

As Baldwin and Clark [2] assessed in a product development strategy, the right collection of modular designs maximizes the value of a design. More broadly speaking, a collection of modular processes is one approach for maximizing the value of a system (such as packaging). Modularity is centered on the idea of options in that the interchangability of "modules" at relatively low cost represents the creation of potentially valuable investments with low exercise prices—options! Furthermore, modularity better enables a focus on the effectiveness of more "certain" facets of a product such that the traditional NPV can be increased as well.

One example of a modular approach to Polaroid film packaging might be the development of a single, generic film pack that is differentiated by the distribution system at the point of sale. Another example might include moving the manufacture and packaging of film to points within the distribution system that align with different customer segments (modularizing by customer, so to speak). With either of these approaches, it must be recognized that organizational designs which blur the traditional lines between functional expertise have a greater capacity to recognize the value and flexibility of interfunctional solutions. Such an environment makes the exercise of valuable options (such as those created by modularization) much more successful.

Regardless of the approach, the concept is simple: product packaging requirements are becoming increasingly dynamic (and, therefore, uncertain); uncertainty contributes to option values; the greatest areas of uncertainty in the packaging "system" are those that transcend multiple organizations and functions. A broad-based options analysis for such a scenario will likely yield new avenues of increasing value for such operations.

7.3 Future Areas of Research

Some promising areas of present and future research are listed below:

- The application of options theory to a wider range of disciplines within the firm: marketing, supplier relations, maintenance, organizations, etc.
- The development of new, unified approaches to options valuation
- The creation of new tools for evaluating interactions of real options
- Approaches for more precisely estimating the value of an extended series of follow-on options
- The investigation of new options variations such as the option to compete due to lower variable costs.

Annotated Bibliography

1. Agmon, Tagir, "Capital Budgeting and the Utilization of Full Information: Performance Evaluation and the Exercise of Real Options," *Managerial Finance* (May 1991), pp. 42-50.

    The prime value of this work is a detailed analysis of a joint venture in which both partners had options to purchase at the end of three years. Poor first and second year performances led to one partner selling out at a low price and profitability rose dramatically over time after the sale. Agmon pieces together the flow of information and how that information should have been evaluated from an options perspective. Essentially, he notes that the project was still within the expected standard deviation of outcomes and the option to buy out the other partner was virtually unchanged in value from the time the deal was struck. Agmon offers a lengthy analysis of this case and expands his discussion to options to switch currencies. Two of Agmon's key points appear to be the need for understanding underlying assumptions and dynamically evaluating projects from an options perspective as new information becomes available. 8 references.

2. Baldwin, Carliss Y. and Kim B. Clark, "Modularity-in-Design: An Analysis Based on the Theory of Real Options," Unpublished Draft, July 1994, 45 pages.

    This work describes a highly innovative, academic application of options theory to the product design process. Specifically, it uses options to value the benefits of modularity vis-à-vis the costs of designing and developing the modules. Using this framework, Baldwin & Clark conclude that if much of the cost in developing modules centers on the integration of the modules into the overall system then the option values created by the modules themselves are overwhelmed by the design and development costs for the numerous combinations. However, if the interfaces between modules are such that the modules can be designed and proven independently, the value of the options created by these modules adds to the value of the design significantly. They conclude with the management implications for their findings. The application of options is fascinating; the actual calculations are not obvious to the casual reader. 80 references.

3. Barone-Adesi, Giovanni and Robert E. Whaley, "Efficient Analytic Approximation of American Option Values," *Journal of Finance* (June 1987), pp. 301-320.

    This analytical work uses a quadratic approximation technique for developing a general American option formula based on the work of Black-Scholes. Barone-Adesi's formula requires the iterative determination of a "critical commodity price" which could easily be computed in a spreadsheet with mathematical solver capabilities. In addition, this work compares the effectiveness of other American option valuation techniques (finite-difference, compound-option and heuristic) via simulation. 21 references.

4. Barone-Adesi, Giovanni and Robert E. Whaley, "The Valuation of American Call Options and the Expected Ex-Dividend Stock Price Decline," *Journal of Financial Economics* 17(1986), pp. 91-111.

    This work analyzes the change in American option prices due to the disbursement of dividends. Confirms that American calls can be reasonably accurately used to project ex-dividend stock price decline. 33 references.

5. Black, Fischer, "Fact and Fantasy in the Use of Options," *Financial Analysts Journal* (July-August 1975), pp. 36-41,61-66.

Written by the co-developer of the Black-Scholes formulation, this article presents a thorough conceptual understanding of the behavior of financial options and the Black-Scholes formula. Fischer particularly discusses the trade-offs of options vs. stocks, using options as part of a hedge, and the influence on option values of volatility changes, interest rate changes, dividends, transaction costs and taxes. Of particular value to the readers of this thesis is Black's inclusion of an appendix of tables valuing an option with exercise price of $40 given different maturities (3, 6 and 9 months), different stock prices ($28 - $52), different standard deviations (20% - 90%), and different interest rates (.05 - .15). A few other items of note: Since volatility does change, additional weight should be given to recent months, the general market trend, and similar industry stocks. An increase in the interest rate always increases the value of an option since the present value of the exercise price is reduced with rising interest rates. Black also notes that the Black-Scholes formula tends to overprice way out-of-the-money options and underprice way in-the-money options. Also, options with less than three months to maturity tend to be overpriced. Black offers some potential explanations (which generally do not apply directly to real options). 10 references.

6. Black, Fischer, "How to Use the Holes in Black-Scholes," *Journal of Applied Corporate Finance* (Winter 1989), pp. 67-73

In this fascinating (yet simple and readable) work, Black details the assumptions under-riding the Black-Scholes option formula and describes how an investors can respond under non-assumed circumstances: when the investor suspects that a stock's volatility will not remain constant, when a stock price may change in jumps, when interest rates are likely to change, and when there are borrowing penalties, short-selling penalties, trading costs, taxes and dividends. 5 references.

7. Black, Fischer and Myron Scholes, "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy* (May/June 1973), pp. 637-659.

This work (one of the two seminal works on option valuation) introduces the Black-Scholes formula for option pricing. It presents the underlying assumptions: constant interest rate, random-walk stock price movement (lognormally distributed) with constant variance, no dividends, no early exercise of the option, no transaction costs, no borrowing costs and no penalties for short selling. The authors characterize the behavior of options and proceed to derive the Black-Scholes equation both from a hedge position and using the CAPM model. In addition, they repeat the earlier derivation of the put-call parity for the valuation of puts. They discuss the application of the Black-Scholes model to dividends and warrants and note that, in effect, stockholders hold an option on their company's assets. That is, when a company is financed by debt, the bond-holders "own" the assets of the company with the stockholders possessing an option to buy back the assets by paying down the debt. 24 references.

8. Brealey, Richard A. and Stewart C. Myers, "Corporate Liabilities and the Valuation of Options; Applications of Option Pricing Theory," *Principles of Corporate Finance*, 4th Edition, McGraw-Hill, 4th Edition. Ch. 20, 21: pp. 483-534.

Chapter 20 of this text provides an introduction to options based on position diagrams (perhaps a more useful right-brain approach). It then uses examples to depict the derivation of options based on the creation of a perfect hedge. If offers useful tips on spotting options, indicates the inadequacies of DCF for valuing option scenarios, and

introduces the Black-Scholes formula. Chapter 21 provides a number of easily understood real option examples valued by Black-Scholes and the binomial method. Examples include a growth option in product development, the option to abandon a risky technology investment and operating assets, and the option to defer investment in a factory for a product of high volatility. This work presents a formula for converting standard deviations for continuous distributions to lognormal-based "high" and "low" outcomes for a binomial option valuation. (This thesis uses this equation in reverse in Appendix D). As a whole, this is one of the broadest, most readable introductions to options in general and specifically to real options. 8 references.

9. Brennan, Michael J. and Eduardo S. Schwartz, "A New Approach to Evaluating Natural Resource Investments," *Midland Corporate Financial Journal* (Spring 1985), pp. 37-47.

Directed especially at financial analysts in natural resource industries, this work does an excellent job of presenting the weaknesses of the DCF evaluation approach and the usefulness of the options approach. Specifically, this paper illustrates two DCF assumptions that do not apply well to risky investments: uncertain future cash flows can be replaced by expected values and that a known, constant discount rate dependent solely on the risk of the project is assumed. To address these weaknesses in the context of gold/copper mines, the authors turn to options and measurable data: mineral prices, deviation in prices and convenience yield. Based on options, they develop a break-even chart for operating the mine—identifying at what mineral price it would be wiser to shutdown (or restart) the mine. This is presented in a readable conceptual form accented with some sample calculations. It does a nice job of accounting for taxes and start-up/shutdown costs but does not provide examples of the specific options calculations. The real value of their approach is that it is only dependent on the current spot price of gold, the cost of storing the gold until "maturity" of the option, and a measure of the variability of gold. (They do not even require an estimate of discounted future prices). 4 references.

10. Brennan, Michael J. and Eduardo S. Schwartz, "Evaluating Natural Resource Investments," *Journal of Business* (April 1985), pp. 135-157.

This work is a follow-up to the authors' Midland Corporate Financial Journal noted above and provides a more rigorous analytical analysis of the options approach. Using a copper mine example similar to that in the previous work, the authors determine the value to close and reopen the mine as the basis for a decision table for operating the mine. They extend their previous work by including an analysis of the timing option with regard to developing the mine. 34 references.

11. Brody, Aaron L. "Glass-Coated Flexible Films for Packaging: An Overview," *Packaging Technology & Engineering* (February 1994), p. 44-47.

12. Carr, Peter, "The Valuation of Sequential Exchange Opportunities," *Journal of Finance* (December 1988), pp. 1235-1256.

This analytical work derives a formula for valuing compound exchange options based on the works of Geske, Fischer and Margrabe. The particular interest of this work to this thesis is that Carr addresses specifically the application of his formula to the investment decision. He utilizes McDonald and Siegel's formula for valuing the European exchange option; unfortunately Carr notes that with "dividends" there is incentive to exchange early. He develops an approach for discrete time evaluations of the option to exchange. 10 references.

13. Chung, Kee H., "Output Decision under Demand Uncertainty with Stochastic Production Function: A Contingent Claims Approach," *Management Science* (November 1990), pp. 1311-1328.

In this highly analytical paper, Chung uses options valuation techniques to analyze the output decisions of a firm given demand and technology uncertainty (assuming nonstochastic production). In clear analyses, Chung demonstrates several key findings. As interest rates increase, the probability of under-producing increases; therefore, in times of high interest rates, companies should be aggressive in setting volume levels and vice versa. Companies should choose to produce products with the least demand volatility. Companies should produce products with the least production lead time when technological uncertainty (technical uncertainty regarding the production or function of a product) is absent. Perhaps the most striking of Chung's conclusion is the discomforting finding that "a somewhat surprising but nonetheless interesting finding of the study is that the effects of demand and technological uncertainty on the optimal output level are generally ambiguous." The chief value of this work to readers of this thesis is that this paper, via text and footnotes, provides some of the more thorough summaries of the analytical work in the field of options (financial and real). 42 references.

14. Chung, Kee H. and Charlie Charoenwong, "Investment Options, Assets in Place, and the Risk of Stocks," *Financial Management* (Autumn 1991), pp. 21-33

This paper examines the effect of a company's growth opportunities (its real growth options) on its systematic risk. It offers first an excellent summary of related work and begins with the valuation formula for a firms equity: equity value equals the value of assets in place plus the present value of growth opportunities (PVGO). The authors note that the existence of valuable investment options (PVGO > 0) presumes imperfections in the real market and they proceed to estimate the relative dependence of various companies on growth opportunities for their value. By showing that firm's with equity values that comprise relatively large percentages of growth opportunities also have higher betas, the authors conclude that "the greater the portion of a stock's value accounted for by future discretionary investment options, the higher the stock risk." 67 references.

15. Copeland, Tom, Tim Koller and Jack Murrin, *Valuation: Measuring and Managing the Value of Companies*, John Wiley & Sons, 1990, pp. 343-373. Ch. 12: "Using Option Pricing Methods to Value Flexibility."

Chapter 12 of this text notes that there are options on both the assets and liabilities sides of a balance sheet. The asset options section of Chapter 12 correlates with those defined in this thesis and is virtually identical to the materials found in Chapter 13 of Weston [92] except for the discussion of two additional case studies: OILCO (oil extraction) with abandonment and expansion options and MINCO (mineral lease) bidding on a lease with deferral options. The liabilities options section addresses the valuation of callable debt and convertible securities. No references.

16. Cox, John C., Stephen A. Ross and Mark Rubinstein, "Option Pricing: A Simplified Approach," *Journal of Financial Economics* (September 1979), pp. 229-263.

In this oft cited work, the authors do indeed present a simplified approach to option pricing. They start with the premise of replicating an option one period back. They extend this work to develop the general binomial approach to option valuation based on the risk-free rate. The binomial formula essentially works forward through a decision tree determining risk-neutral paybacks and then works backward based on preceding period option values. The authors prove that, in the limit, the binomial formula replicates the Black-Scholes formulation and that the Jump-process option formula is also a special

application (a log-Poisson distribution) of the binomial technique. Finally, this work illustrates the binomial pricing model's ability to accommodate dividend paying options by introducing a "critical stock price" such that should the stock price exceed the critical stock price, the owner of the option would exercise early. All else being equal, this critical stock price will be lower the higher the dividend yield, the lower the interest rate, and the lower the exercise price. 13 references.

17. Damodaran, Aswath, *Damodaran on Valuation: Security Analysis for Investment and Corporate Finance*, John Wiley & Sons, 1994, pp. 319-365. Ch. 15 and 16: "Option-Pricing Theory," "Applications of Option-Pricing Theory to Valuation."

This work offers one of the more user friendly approaches to understanding options and valuing them. It utilizes binomial and Black-Scholes methods with the emphasis on Black-Scholes. It walks through the valuation of various types of options and discusses modifications for dividend-paying options in Ch. 15. Chapter 16 illustrates the valuation of equity as an option, growth options for natural resource firms, and patents as a growth option. It provides many numerical examples and offers a very readable discussion of the assumptions and implications of the options model. No references.

18. Dimson, Elroy, "Instant Option Valuation," *Financial Analysts Journal* (May-June 1977), pp. 62-69.

19. Dimson, Elroy, "Option Valuation Nomograms," *Financial Analysts Journal* (November-December 1977), pp. 71-74.

One of the most intriguing frameworks for options evaluations is the set of nomograms prepared by Dimson. This work is based on the Black-Scholes formula and enables a quick, visual estimation tool for valuing options (calls & puts), determining hedge ratios and determining the likelihood of exercise. The accompanying text also describes methods for using the nomograms to value short-lived warrants, standby agreements and other options. 5 footnotes/references.

20. Dixit, Avinash K., and Robert S. Pindyck, "The Options Approach to Capital Investment," *Harvard Business Review* (May-June 1995), pp. 105-115.

This article provides an excellent overview of the application of real options to capital investments. The authors note that all business opportunities in general are options--rights but not obligations to take some action in the future. The authors" stated purpose for this work is to examine the shortcomings of the conventional approaches to decision making about investment and to present a better framework for thinking about capital investment decisions. They note specifically that NPV assumes one of two faulty assumptions: either that an investment is reversible or that if the investment is irreversible it is a now-or-never proposition. They define irreversible investments as those that are specific to a company or industry. As examples they list marketing and advertising costs, equipment that is industry specific; they suggest that most major investments are at least largely irreversible. This work emphasizes that when a company does make irreversible investments they exercise the option they had to make that investment; accordingly, the key question to the company is, "How does the company exercise that option optimally?" The authors then introduce the value of options to wait noting that "as long as there are some contingencies under which the company would prefer not to invest, that is, when there is some probability that the investment would result in a loss, the opportunity to delay the decision--and thus keep the option alive--has value." They illustrate real options with a drug company R&D project with uncertain costs and revenues by walking through the options approach to valuing the R&D project and follow-on projects. Of note, the authors point out that uncertainty prompts the hastening

of investments in R&D and other investments that allow a company to acquire additional opportunities to invest; on the other hand, uncertainty plays against the production launch of a product as it represents an exercise of the option to produce. Finally this work discusses the application of real options to investments in oil reserves, scale vs. flexibility in Public Utility planning, and price volatility in commodities. This article is a must read for those seeking a conceptual understanding of options. 7 footnotes/ references.

21. Dothan, Uri and Joseph Williams, "Education as an Option," *Journal of Business* (1981, vol. 54, no. 1), pp. 117-139.

This work presents an interesting illustration of the timing option and education (i.e.: what is the optimal time to leave school under given circumstances). "Our predictions about the student's optimal time to quit school possess some interesting properties. In general, all factors increasing the personal value of continued education relative to immediate employment also induce the student to leave school later. For example, individuals planning professional careers involving either greater specialization, and hence greater risk, or profiles of labor earnings more highly peaked over the life cycle choose to stay in school longer. Similarly, students enrolled in programs which, like liberal arts provide broader training and thereby permit entry into more diverse occupations also prefer to remain in school longer. Moreover, other things equal, programs charging lower tuition induce student t to stay in school longer." 22 references.

22. Edleson, Michael E., "Real Options: Valuing Managerial Flexibility (A)," *Harvard Business School course note* N9-294-109 (March 31, 1994), Harvard Business School, Boston, MA, 8 pages.

This is a nice, concise introduction to the shortcomings of traditional DCF/NPV and the use of options for valuing managerial flexibility. This paper outlines options in general and offers some sample calculations. It discusses real options, explaining the typical forms and giving examples of calculations. Is uses primarily the binomial method but introduces Black-Scholes in table format. This may be the simplest introduction to the mechanics of options and would, therefore, be a good base for further investigation. There is also a Part (B). 2 footnotes / references.

23. English, J. Morley, "The Rate of Return and Assessment of Risk," *The Engineering Economist*, (Spring 1966), pp. 1-12.

English develops an iterative approach for determining individualized rates of return for an investment within the context of a given business as a whole. 5 references.

24. Felts, John T. "Plasma Deposited Transparent High Gas Barriers," presented at 3rd International Conference on Vacuum Web Coating, November 12-14, 1989, San Antonio, TX.

25. Felts, John T. "QLF Coating Technology: Overview," presented at AIMCAL Fall Meeting, October 14, 1993.

26. Felts, John T. "Transparent Gas Barrier Technologies," presented at Society of Vacuum Coaters Annual Meeting, May 2-4, 1990, New Orleans, LA.

27. Fine, Charles H. and Robert M. Freund, "Economic Analysis of Product-Flexible Manufacturing System Investment Decisions," MIT Working Paper, no. 1757-86, 42 pages.

This paper examines the investment in flexible manufacturing systems under conditions of uncertain product demand. As this issue has been repeatedly mentioned in the option context, this work assesses the investment decision using a convex quadratic optimization program. A specific example is presented based on an automotive plant engine line. The authors' model enables the calculation of a "flexibility value" per unit cost of flexible capacity. This calculation is based on linear demand curves for various engine sizes with intercepts dependent on macroeconomic factors such as oil prices and GNP growth. The determination of flexibility values allows the firm to select the mix of technologies that offers the greatest aggregate value to the firm. 22 references.

28. Geske, Robert, "The Pricing of Options with Stochastic Dividend Yield," *Journal of Finance* (May 1978), pp. 617-625.

Geske develops a Black-Scholes adjustment for stochastic dividends which builds on the work of Merton [58] and Rubinstein (1976) who developed an adjustment for constant dividends. The author models the stochastic dividend yield on a lognormal distribution based on management's hesitance to change dividends together with the possibility of firm bankruptcy. The adjustment takes into account that the dividend yield adds to the variance of the stock return as does the covariance between stock yield and dividend yield. Geske's adjusted variance minimizes the Black-Scholes equation bias for underpricing deep out-of-the-money options. This work is focused on financial options and is rather analytical though it does offer a nice example contrasting option estimates for no dividend yield, constant dividend yield and his adjustment for stochastic dividend yield. 6 references.

29. Geske, Robert, "The Valuation of Compound Options," *Journal of Financial Economics* (March 1979), pp. 63-81.

Geske notes that an option on a common stock is an option on an option as the debt-equity financing of a firm is, itself, an option. He proceeds to develop a formula for valuing a call option as a compound option which includes the effects of leveraging on the price of the option. The other interesting insight Geske offers is that while the option formulas of Black-Scholes and Merton assume a log-normal distribution for stock returns, that assumption is not consistent with Modigliani-Miller theorem in that at some point the stock could be worthless (according to M-M but not lognormal distributions). Geske's compound option model allows for a non-constant elasticity of variance as well as the Black-Scholes constant elasticity of variance assumption. This work is focused on financial options and is analytical in nature. 27 references.

30. Geske, Robert and Kuldeep Shastri, "Valuation by Approximation: A Comparison of Alternative Option Valuation Techniques," *Journal of Financial and Quantitative Analysis* (March 1985), pp. 45-71.

The authors compare the estimates and the required computation time for valuing options (calls and puts / with and without dividends) using Black-Scholes, binomial, and the finite difference option pricing techniques. This work includes a good discussion with references for the various techniques including Monte Carlo simulation. It offers an overview of the underlying diffusion processes, jump processes and combination diffusion-jump processes. This work is focused on financial options and is primarily analytical but is somewhat more understandable to the average reader than Geske's other works. 33 references.

31. Hanemann, W. Michael, "Information and the Concept of Option Value," *Journal of Environmental Economics and Management* 16 (1989), pp. 23-37.

This work cites a number of applications of real options to the environment and the determination to develop or preserve land. It presents a technical introduction to the value of options thinking regarding irreversible and indivisible development. It reviews the condition under which deferring development for the acquisition of more information does and does not create option value. It raises the point that under some circumstances the notion of option value as a correction for cost-benefit analysis (like NPV) is ambiguous and less useful. 29 references.

32. He, Hua and Robert S. Pindyck, "Investments in Flexible Production Capacity," MIT Working Paper, no. 2102-89, 33 pages.

This interesting work analyzes a problem similar to that of Fine and Freund earlier but uses options to account for the irreversibility of the investment decision. It makes the important point that the optimum capacity choice is when the present value of the expected cash flow from a marginal unit of capacity equals the total cost of the unit (total cost including purchase, installation and opportunity cost of exercising the option to buy the unit). The authors proceed to demonstrate how the value of an extra unit of capacity can be determined for a firm that produces two outputs and can choose two different technologies (flexible and non-flexible); they then value the option to invest in a unit of each capacity. Drawing these together, they then develop tables for various standard deviations indicating the value of the assets in place plus the value of the growth options available to them to invest further depending on demand. This work does show that as volatility increases, the value of flexible capacity increases. They explain that this analysis would apply to input-flexible capacity as well. Unfortunately this is a very analytical work and will not be comprehensible to the average reader. 14 footnotes / references.

33. Hertz, David B. and Howard Thomas, "Decision and Risk Analysis in a New Product and Facilities Planning Problem," *Sloan Management Review* (Winter 1983), pp. 17-31.

This work provides a practical overview of risk analysis including how to consider investment alternatives and assign probabilities. While it does not take into account the options available (other than by repeated NPV calculations by pursuing different options), it does offer an excellent step-by-step approach for assessing project risk (akin to assigning volatility to the options model presented in this thesis). This article is very readable and very useful as a tool to foster strategic thinking and, therefore, options thinking. 21 references.

34. Hespos, Richard F. and Paul A. Strassmann, "Stochastic Decision Trees for the Analysis of Investment Decisions," *Management Science* (August 1965), pp. B244-B259.

This early work combines risk analysis with decision tree analysis to shape decision making for a series of follow-on investments (sounds like an option). Using a method similar to dynamic programming, the authors compute the expected NPV's for a series of investment choices. By placing distributions around each decision and computing the expected outcomes for a number of decision paths, the author's begin to work around the problem of valueless investments that would not be pursued. However, such an approach requires (at least initially) the articulation of all possible outcomes. This reveals one of the advantages to an options based approach. This is a very readable explanation of risk analysis and decision trees that still has application today. 18 references.

35. Howe, Keith M. and George M. McCabe, "On Optimal Asset Abandonment and Replacement," *Journal of Financial and Quantitative Analysis*, vol. 18, no. 3 (1983), pp. 295-305.

This work reviews three abandonment models: the pure abandonment model where abandonment should occur when the cost of holding an asset is less than or equal to the cost of capital, the infinite-cycle replacement model where an asset is replaced by a similar asset at periodic intervals, and the N-cycle replacement model....The authors note that in the replacement models, the effect is a greater opportunity cost of not retiring an asset at a given date and, therefore, shorter optimal asset lives. They discuss the implicit assumptions in each model. 11 references.

36. Hull, John C. , *Options, Futures, and Other Derivatives*. Prentice-Hall, Englewood Cliffs, NJ., 1993. Ch. 10.

Chapter 10 of this work is the best general overview of the Black-Scholes formula and its underlying workings and assumptions available. It is beyond the technical novice but it is ideal for the engineer who has a basis in statistics and engineering mathematics. Additionally, it discusses the lognormal distribution, the dependent variables for Black-Scholes, the estimation of volatility, etc. It offers numerous examples all pertaining to financial options. No references.

37. Hunt, Robert G., Jere D. Sellers and William Franklin, "Resource and Environmental Profile Analysis: A Life Cycle Environmental Assessment for Products and Procedures," preliminary manuscript accepted for publication in Spring 1992 *Environmental Impact Assessment Review*, Massachusetts Institute of Technology.

38. "Information on the Environment," PKL Verpackungssysteme GmbH, D-5172 Linnich.

39. Jarrow, Robert A, and Andrew Rudd, *Option Pricing*, Richard D. Irwin, Inc.: Homewood, IL, 1983. Ch. 7-9: pp. 83-145,181-208.

This is a very thorough technical work which details the derivation of Black-Scholes and provides many useful examples. One particularly useful feature is the discussion of three methods for estimating stock volatility (p.137). It also notes the mathematical sensitivities of the Black-Scholes formula to the variables (p. 119), provides modifications to Black-Scholes for dividends, and discusses the calculation of compound options. Chapter 13 provides an explanation of the binomial technique for options pricing and Chapter 14 discusses other methods including: Monte Carlo simulation and finite difference methods. No references.

40. Kambil, Ajit, John C. Henderson and Hossein Mohsenzadeh, "Strategic Management of Information Technology Investments: An Options Perspective," MIT Working Paper, no. 3319-91, pp. 1-18.

This paper reviews the general methods of IT investment analysis and introduces options as a means of capturing the real options of managerial flexibility. It discusses the generic real options of follow-on investment, abandonment and waiting. This work uses a health center's acquisition of hand-held computers as an example and demonstrates how a pilot program offers the real option of waiting for more information. A good discussion of managing the investment process from an options perspective is included. This paper specifically notes several key distinctions regarding real options: (1) "To identify real options, managers must systematically examine key areas of business uncertainty to

determine if IS investments provide real options for business growth or security against downside risks from market and environmental changes. Real options from technological features can also be valuable..." (2) "...real options are a real capability to exercise a growth or adaptive strategy...a real IS option includes the acquisition of rights or control over a specific bundle of distinctive competencies and resources...This is a major difference between financial and real options. While an options perspective may be used for a conceptual justification of an IS project, the real option must reflect a real capability of the firm to exercise the option. Hence the management process must carefully assess proposals for acquiring real options from the perspective of organizational capabilities." 15 references.

41. Kemna, Angelien G. Z., "Case Studies on Real Options," *Financial Management* (Autumn 1993), pp. 259-270.

Kemna's work provides some much needed real examples of the use of real options in industry. He notes that the impetus for this work was one manufacturer's desire to study the utility of option pricing for real asset investments. This work details three real (though altered) examples: A timing option for offshore oil field development, an unspecified pioneer venture growth option, and a crude distiller abandonment option. The greatest value in this work is in its illustration of the approaches (which equations and how to estimate the variables) taken in each case. The timing option uses Merton's formula for a dividend paying option, the growth option introduces compound options and uses Geske's [29] compound formula option, and the abandonment option walks through a series of American puts following a formula developed by Geske and Johnson. This work concludes with a summary of major insights from the survey of cases. This is a very helpful source beyond the conceptual introductions to options for applying options. 22 references.

42. Kensinger, John W., "Adding the Value of Active Management into the Capital Budgeting Equation," *Midland Corporate Financial Journal* (Spring 1987), pp. 31-42.

Typical of Midland articles, this is a very understandable presentation of the option to exchange (the option to switch). Kensinger particularly notes 3 strategic "truisms" that his exchange model captures: 1) the more volatile the relationship between the prices of input and output commodities, the greater the difference between the true project NPV and the DCF-NPV; 2) The difference between the true project NPV and the DCF-NPV is greater the more innovative the project, and the stronger the barriers to entry for potential competitors; and 3) A company which has the same uses for a system as another company, plus additional operation options, will gain a higher NPV by purchasing the system. That is, the more flexible the system being considered for purchase, the greater the difference between the true project NPV and the DCF-NPV. Kensinger also provides a brief explanation and example of Margrabe's [52] modification to Black-Scholes for measuring the valuing of an option to exchange one asset for another. He computes an example of owning a machine which gives a firm the option into convert soybeans to a beef substitute. 28 footnotes / references.

43. Kester, W. Carl, "Today's options for tomorrow's growth," *Harvard Business Review* (March-April 1984), pp. 153-160.

This work conceptually introduces growth options; it uses anticipated earnings for a set of companies to identify the portion of typical companies' values attributable to growth options as opposed to income streams. Kester explains the dependency of option value on time, risk, interest rates and exclusivity of ownership. Some specific insights include: (1) higher discount rates, while they lower NPV's, they lower the cost of future capital to exercise an option. This can give projects which can create additional new growth opportunities a substantial comparative advantage over NPV-dominant projects. (2) A distinction is made between option exclusivity as to whether it's proprietary or shared. While proprietary options (from patents and the like) are quite valuable, shared options are only valuable if a company is in a strong enough competitive position to withstand similar moves by competitors and still reap most of the market value of a project. (3) "When capital is scarce and interest rates rise, projects that create new growth options may be less adversely affected than those that generate only cash." (4) There are at least four conditions under which a company profits more by exercising growth options early rather than wait: when competitors have the same option, when the project has a high NPV, when the risk and interest rates are low, and when competitive rivalry is intense. A framework for categorizing options according to three factors is outlined: simple or compound option, expiring or deferrable option, shared or proprietary option. Simple option (cost reduction and maintenance projects) benefits are obtained primarily through cash flows; compound option benefits are higher due to new investment opportunities. Expiring options require an analysis of only the gained or lost value from the project; deferrable options require an analysis of the value of waiting as well. The article concludes with a call for the integration of capital budgeting and long-range planning to ensure projects are selected with the sole intent of increasing value. This article is a must read for those seeking a conceptual understanding of options. No references.

44. Kogut, Bruce, "Joint Ventures and the Option to Expand and Acquire," *Management Science* (January 1991), pp. 19-33.

This interesting and quite readable article analyzes joint ventures as real options to eventually acquire the venture altogether. Kogut discusses real options and indicates how joint ventures satisfy the requirements to function as options for their joint owners. To verify his hypothesis that joint ventures are in this sense options, Kogut analyzes 92 manufacturing joint ventures and notes that, as market signals implied the ultimate success of the venture, "call" participants generally exercised their options and acquired the entire venture. On the other hand, with no signals of success, partners still maintained their investment in the venture. Apparently the market functions as if joint ventures are options. Kogut notes that with regard to investments in joint ventures perhaps the riskier the better for the total value of the firm. This, of course, agrees with the assessment of options. 41 references.

45. Kogut, Bruce and Nalin Kulatilaka, "Operating Flexibility, Global Manufacturing, and the Option Value of a Multinational Network," *Management Science* (January 1994), pp. 123-139.

In an innovative application of option theory, Kogut and Kulatilaka analyze global manufacturing operations as options to switch manufacturing between national sites on the basis of international uncertainties. For simplification, they select exchange rate as the sole source of international uncertainty and, through dynamic programming, analyze the value to the firm of the option to switch between sites. The authors remind the reader that investment in foreign companies generates two kinds of options: "within-country" growth options and "across-country" operating flexibility options. Interestingly, they emphasize that real options face at least two constraints that are not placed on financial options: "A firm must be able to gather the appropriate information to know when the option should optimally be exercised; even when the information is known, exercise may be hindered by organizational features that obstruct flexibility." They value flexibility under no-cost switching and costly switching. They run simulations and demonstrate that the value of switching is, indeed, significant especially when the exchange rate is "at the money" and volatility is highest. "The value of multinationality increases with greater volatility." They discuss the implications of this finding on flexible labor systems, internal international accounting practices and transfer pricing. 52 references.

46. Kulatilaka, Nalin, "The Value of Flexibility: The Case of a Dual-Fuel Industrial Steam Boiler," *Financial Management* (Autumn 1993), pp. 271-279.

Kulatilaka presents a detailed example of applied options theory, specifically the option to switch, for a steam boiler which can utilize two different inputs to generate power. He uses a generalized dynamic programming model and values a project in a risk-neutral market and shows how is could accommodate a risk averse market. Of interest, the author notes the hysterisis band (a bias towards maintaining the status quo) increases with increasing volatility and higher switching costs. 14 references.

47. Kulatilaka, Nalin, "Valuing the Flexibility of Flexible Manufacturing Systems," *IEEE Transactions on Engineering Management* (November 1988), pp. 250-257.

This work discusses the limitations of typical methods for evaluating flexible manufacturing systems. It introduces the idea of options, considering a flexible manufacturing system (FMS) as a set of compound options. The author rejects typical financial options formula assumptions of no arbitrage opportunities and log-normal uncertainties for a production system and turns instead to the development of a dynamic programming model. This model allows alternative "modes" of operation thereby accommodating the FMS's ability to switch inputs or outputs as well as alternating modes such as waiting to invest, shutting down, abandoning, etc. Kulatilaka uses a mean reverting stochastic process to value the options. While acknowledging the weaknesses of this approach regarding utility, the author suggests that the dynamic programming, options-based technique is a substantial improvement over current FMS valuation methods. Finally, he notes that as the value of flexibility is inherently dependent on the design of the manufacturing system, the design and justification must be conducted simultaneously. 18 references.

48. Kulatilaka, Nalin and Alan J. Marcus, "General Formulation of Corporate Real Options," *Research in Finance*, Volume 7, 1988. JAI Press, Ed: Andrew H. Chen, pp. 183-199.

The authors demonstrate that all real options generally can be thought of as options to switch operating modes and that a single formulation using dynamic programming can be used to calculate multiple inputs, outputs and timing. Building on the work of Geske and Johnson [1984], they demonstrate that the options to abandon, wait, shutdown, etc. are merely special cases of their more general formulation for valuing real options. They illustrate the valuation of a two output, three time period option and discuss expansions of these variables. 12 references.

49. Laughton, David G. and Henry D. Jacoby, "Reversion, Timing Options, and Long-Term Decision-Making," *Financial Management* (Autumn 1993), pp. 225-240.

This work investigates the effect of long-term mean reversion in a project's cash flows and the effect of this characteristic on the investment as a "now-or-never" investment and as an option. They assume the firm is a price-taker, that output prices are the only element of future uncertainty, and that the production opportunity is independent of when the project is initiated. They note three "effects" of reversion: risk-discounting effect (reversion decreases long-term price uncertainty, increases call options and decreases put options), variance effect (less uncertainty reduces all long-term option values), and future-reversion effect (effects American options differently with respect to in- or out-of-the-money status). The authors conclude that at-the-money American options have an increased early exercise premium with increased reversion (neglecting reversions gives a bias against long-term investment timing options). Additionally, if reversion is neglected in the presence of an initial timing option, there is a bias against long-term duration projects; however, with longer timing options (greater considered delays), there is a favorable bias to the project. The effect of risk-discounting and variance effects on

European options lead to conflicting results. This is an interesting work on Timing Options and is fairly readable. 14 references.

50. **Mahasseny, Amr Marwan, "Options as a Tool for Investment Decisions in Physical Assets; Restrictions and Applications," Master's Thesis, Civil Engineering, MIT, 1989, 97 pages.**

This work provides an overview and history of financial options including their various valuation techniques and variables. It introduces Contingent Claims Analysis on physical assets and outlines generic forms of real options: option to wait (including conditions of stochastic investment requirements and jumps in value to zero), option to expand, option to convert to different use, option to abandon, and options on the max/min of two risky assets (like compensation bonus plans). This work presents three analytical illustrations: (1) the option to convert is illustrated by the conversion of a nuclear power plant to a gas-fired cogeneration plant, (2) a call option on the maximum of two risky assets in demonstrated by the choice of land development between a residence and an office-building, and (3) the trade-off between the option to produce and the option to shutdown is demonstrated in an exhaustive analysis of managing gold mines. Weaknesses in the Black-Scholes assumptions and the model assumptions are outlined in the conclusion. The appendix includes a program in BASIC for calculating call and puts using Black-Scholes. 38 references.

51. Majd, Saman and Robert S. Pindyck, "Time to Build, Option Value, and Investment Decisions," *Journal of Financial Economics* (March 1987), pp. 7-27.

This work illustrates the shortcomings of NPV for valuing projects for which the timing of an investment is uncertain and is, therefore, described by options. The authors emphasize the importance of sequential, irreversible expenditures over time as prerequisite to contingent claims (options). Specifically, they model a project that requires an investment of $6M invested no faster than $1M/yr. Additionally, they assume a payout rate "delta" of 6% (this is the opportunity cost). By valuing the option on the project together with its expected value, they create a table indicating at what level for given remaining investments, a firm would break even by "buying" the option on the next option and the remainder of the project. Additionally, they show how sensitive the cut-off values are to changes in σ and δ. The value of the option appears to increase geometrically for very low delta's. A useful contribution of this work is a general discussion of δ, the "dividend" rate and how that applies (and does not apply) to real options. 23 references.

52. Margrabe, William, "The Value of an Option to Exchange One Asset for Another," *Journal of Finance* (March 1978), pp. 177-186.

Margrabe develops a closed-form solution based on the Black-Scholes equation for determining the value of an options to exchange one risky asset for another. He shows how these apply to financial assets such as performance incentive fees, margin accounts, and share exchange offers. His valuation hinges on the variance of the ratio of the assets not on the assets themselves. Accordingly, assets with no correlation in their value will yield the highest exchange option value. 15 references.

53. Mason, Scott P. and Carliss Y. Baldwin, "Evaluation of Government Subsidies to Large-Scale Energy Projects: A Contingent Claims Approach," *Advances in Futures and Options Research*, Vol. 3, 1988. JAI Press, ed: Frank J. Fabozzi , pp. 169-181.

The authors look at the total value of a project (including options) and investigate the alignment of government subsidies with the value of a project. Though this work has some analytical discussion, most of the discussion is easily understood and offers an interesting insight into the interaction of subsidies and operating options. For example, the authors note that if the subsidy is paid up front, the private sponsor of a project is more inclined to exercise their option to default as the payback becomes more certain at the end of the project when they, the sponsor, must decide whether to exercise and continue with their own money. The authors provide a good overview of other work in the areas of real options and make a case for contingent claims as a means of valuing the managerial flexibility imbedded in a project. 18 references.

54. Mason, Scott P. and Robert C. Merton, "The Role of Contingent Claims Analysis in Corporate Finance," *Recent Advances in Corporate Finance*, 1985, Chapter 1. Richard D. Irwin, ed: Edward I. Altman and Marti G. Subrahmanyam, pp. 7-54.

This often cited work describes in fairly understandable terms the history of option pricing, the development and function of the Black-Scholes equation, and the use of Black-Scholes for valuing all liabilities of a firm. The authors then discuss at length the application of contingent claims to capital budgeting decisions. They provide an excellent overview of the literature up to that date regarding options and capital budgeting and they introduce one non-numeric (formula-based) case study of a company being invited into a consortia with a given debt structure and dependent on government subsidies. One interesting point brought out in this work is that even though the underlying asset in real options is an aggregate variable which cannot be traded, if the financial markets are complete (in that the securities traded are sufficient for dynamic spanning of the underlying asset) the option valuation method can still be applied. 81 references.

55. Mauer, David C. and Steven H. Ott, "Investment Under Uncertainty: The Case of Replacement Investment Decisions," Working Paper Draft, September 1994, pp. 38.

The authors note that annually the investments to replace assets far outstrip the investment in expansion assets. Accordingly, they analyze the factors that affect replacement decisions using contingent claims analysis. Specifically, they account for maintenance and operation cost uncertainty and tax effects (including depreciation tax shields, investment tax credits and taxation of the capital gain or loss on the sale of equipment). The authors model these scenarios and present their data in tabular form; based on their data, they conclude that the optimal time between replacements increases with the volatility of operating cost, purchase price of a new asset and the corporate tax rate; it decreases with the drift rate of the operating cost, the correlation of operating cost with the stock market, the salvage value of the asset, and the investment tax credit. Depreciation has dual effects on either side of a given threshold. The authors then conceptually consider the effects of technological and tax policy uncertainty on replacement decisions. With regard to technological uncertainty, a technology innovation that would reduce maintenance and operation costs lead to a significant reduction in replacement investment; as technological uncertainty increases the optimal time between replacements increases. 22 references.

56. McDonald, Robert L. and Daniel R. Siegel, "Investment and the Valuation of Firms When There is an Option to Shut Down," *International Economic Review* (June 1985), pp. 331-348.

The authors develop an options-based approach for including in an investment analysis the option firms have to temporarily and costlessly shut down production whenever variable cost exceed operation revenues. They model a risk-neutral, price-taking value maximizing firm which is owned by risk-averse investors. (They note that the risk-averse investors affect the cost of capital for the firm.) This work is a highly analytical in nature. 17 references.

57. Merton, Robert C., "The Impact on Option Pricing of Specification Error in the Underlying Stock Price Returns," MIT Working Paper, no. 829-76, 18+ pages.

In this work, Merton reports on simulations used to indicate the error induced in the Black-Scholes pricing of options when the mechanism of stock dynamics are in reality a combination of lognormal and jump processes. Merton develops an equation with gamma as a variable indicating the extent of the log-normal process and the extent of the jump process. He then plots data for a variety of variable values and concludes. His conclusions: incorrect process appraisal give too low a value for deep in- or out-of-the-money options and give too high a value for options whose underlying stock price is around the exercise price. The distortion is not dramatic for in-the-money or even-money options until the jump component accounts for more than 40% of the variation. However, in deep out-of-the-money options, very little error had to be accounted for by jump processes before the estimate error exceeded 5%. "These tables demonstrate the enormous percentage errors possible with deep out-of-the-money options." 3 references.

58. Merton, Robert C., "Theory of Rational Option Pricing," *Bell Journal of Economics and Management Science* (Spring 1973), pp. 141-183.

This work together with Black-Scholes [7] is the seminal work on the theory of options pricing theory. Above and beyond Black-Scholes, this work develops the formula for valuing a dividend-paying option.

59. *Modern Plastics*, Industry Overview, (Mid-December 1992).

60. *Modern Plastics*, Mid-October Encyclopedia Issue, (October 1993).

61. Myers, Stewart C., "Determinants of Corporate Borrowing," *Journal of Financial Economics* (November 1977), pp. 147-175.

This landmark work is the first to suggest the applications of options theory to investments in real assets. It essentially coins the term "growth options" and specifically discusses the equity / debt relationship on real investment decisions. Myers notes that firms with substantial growth options are penalized by the issuance of risky debt and beta-based hurdle rates for capital budgeting; accordingly, corporate borrowing is inversely related to the proportion of market value accounted for by real options.

62. Myers, Stewart C. and Saman Majd, "Calculating Abandonment Value Using Option Pricing Theory," MIT Working Paper, no. 1462-83, 40 pages.

This work counteracts the conventional capital budgeting approach of estimating an assets life and its salvage value by recognizing the potential for abandoning the asset/project early. The authors use option theory to calculate the option to abandon as an American put option on a dividend paying stock. They illustrate the option value for varying dividend yields and exercise prices and generalize the equation for broader application. A major contribution of this work is a simple, conceptual walk-through of the analogous real option terms to financial option terms. (For example, the paper distinguishes between physical, economic and project life of an asset and explain that the physical life is the appropriate maturity for the abandonment put option.) This is a rather readable work that does an excellent job of walking through the impact of the abandonment option; it concludes with a qualitative example regarding two different manufacturing plants for production of a product and the value of abandonment to each plant construction. 19 references.

63. Nichols, Nancy A., "Scientific Management at Merck: An Interview with CFO Judy Lewent," *Harvard Business Review* (January-February 1994), pp. 89-99.

This piece is a light, interesting article in question and answer format that conceptually introduces many emerging financial analysis techniques for industrial applications. Regarding options, the sidebar, "Option Analysis at Merck" by Gary L. Sender offers some utility as a succinct, conceptual introduction to an application of real options for investments in the drug industry. Sender defines an option, notes two factors (time and volatility) that account for its value and describes Merck's assumptions for the Black-Scholes variables necessary to value the options. Of note is the revelation that Merck used an investment bank's calculation of annual standard deviation for biotechnology stocks as an approximation for project volatility. Accordingly, Sender notes that a conservative range of volatility for the project was set at 40% to 60%. No references.

64. *Packaging Encyclopedia & Technology Directory* (1989), published by Packaging Magazine, Newton, MA.

65. *Packaging Strategies* (October 21, 1994), newsletter published by Packaging Strategies, Inc, West Chester, PA.

66. *Packaging Strategies* (April 30, 1995), newsletter published by Packaging Strategies, Inc, West Chester, PA.

67. Paddock, James L., Daniel R. Siegel and James L. Smith, "Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases," *Quarterly Journal of Economics* (1988), pp. 479-508.

These authors discuss the specific shortcomings of DCF/NPV with regard to valuing petroleum leases and introduce options as a tool to compensate for these shortcomings. They characterize the lease tract as a series of options to explore, then develop, then extract the mineral resources. The authors emphasize that, unlike stock options, for a petroleum lease option it is necessary to understand the equilibrium in the market for the asset. The authors then develop a model for the value of the asset given the need to compensate reserve owners for the opportunity cost of investing in the reserve and combine that model with option pricing theory. They meticulously demonstrate the analogous real option - finance option variables and how they determined those variables. Using empirical data, the authors compare option value assessments with geological survey assessments and reveal that options may more effectively model market assessment of value. 36 references.

68. Pindyck, Robert S., "Investments of uncertain cost," *Journal of Financial Economics* 34 (1993), pp. 53-76.

Using nuclear power plant construction as a problem domain, this work addresses irreversible investments under conditions of technical uncertainty (uncertainty over the physical difficulty of a product) and input cost uncertainty (uncertainty over construction costs). The first cost is internal to the firm, the second is external. The author notes that technical uncertainty makes the investment more valuable while input cost uncertainty makes the investment less valuable. He further develops option based valuations for the

project in light of each uncertainty and determines a critical expected cost to serve as a decision rule for investing. When applied to the construction of power plants in the early 1980"s, the author notes that the value is most sensitive to cost uncertainty even though there is substantial technical uncertainty. He concludes that this would pertain to the bulk of large investments except for R&D. This work is heavily analytical; nonetheless, the example and discussion offer useful insights into the valuing of future uncertainties and the incorporation of these uncertainties into an options valuation model. 19 references.

69. Pindyck, Robert S., "Irreversibility, Uncertainty, and Investment," *Journal of Economic Literature* (September 1991), pp. 1110-1148.

This work provides an excellent middle ground between conceptual and analytical introductions to the applications of options theory to real assets. The introduction to this paper is a particularly readable, concise overview of the circumstances for and utility of real options. The author's stated intent is to show how options can be used to determine optimal investment rules, to survey recent applications, and to discuss policy implications. Accordingly, this work discusses optimal timing options and the effect on investments of changes in dependent variables. This work is especially insightful in its explanation of the intuitive and theoretic value of δ. Additionally, Pindyck provides an overview of options work with respect to sunk costs, sequential investments and capacity choices. Finally, Pindyck notes that options theory indicates that for government policy to stimulate investment, option theory suggests that policy should drive to reduce market variability (thus lessening the value of holding options to defer investment). This article (and its excellent bibliography) is one of the best, general overviews of the field of real options. 57 references.

70. Pindyck, Robert S., "Irreversible Investment, Capacity Choice, and the Value of the Firm," *American Economic Review* (December 1988), pp. 969-985.

Pindyck discusses the effect of future market uncertainty on investments decision particularly in the way that the uncertainty affects operating options (which determine the value of capital in place) and options to add more capital (which, where investment is irreversible, determines the opportunity cost of investing). In this analytical work, the underlying model assumptions are that investment is a continuous process, there are no adjustment costs or delivery lags, and there is only one source of uncertainty. Based on this model, Pindyck concludes: "In markets with volatile and unpredictable demand, firms should hold less capacity than they would if investment were reversible or future demands were known. Also much of the market value of these firms is due to the possibility (as opposed to the expectation) of increased demands in the future." Pindyck discusses the implications of these options for firm investments and cites examples to explain how firms have been compensating for the misvaluation of typical NPV approaches. 24 references.

71. Rendleman, Richard J. Jr and Brit J. Bartter, "Two-State Option Pricing," *Journal of Finance* (December 1979), pp. 1093-1110.

This work describes a development of the binomial pricing theory (simultaneous to Cox & Rubinstein). The authors develop a mathematically simple binomial approximation and present comparative data of these approximations with Black-Scholes valuations for non-dividend paying European calls and puts, non-dividend paying American puts and dividend-paying American and European puts and calls. 11 references.

72. Rizika, Adam, "Vapor Coating with SiOx: The Flexible Glass Barrier," presented at Pack Expo '92, November 8-11, 1992, Chicago, IL.

73. Robichek, Alexander A. and James C. Van Horne, "Abandonment Value and Capital Budgeting," *Journal of Finance* (January 1971), pp. 577-589.

This very interesting work uses a binomial structure and Monte-Carlo simulation to value the abandonment options for investment in an asset. It discusses the weakness of the NPV approach in its assumption of predetermined decisions. This work demonstrates that capturing the investment option increase the NPV (IRR increases), decreases the standard deviation and shifts the skewness of NPV distribution from negative to positive. Additionally, the results reinforce the assertion that abandonment is particularly valuable to marginal projects. 16 references.

74. Sachdeva, Kanwal and Pieter A. Vandenberg, "Valuing the Abandonment Option in Capital Budgeting--An Option Pricing Approach," *Financial Practice and Education* (Fall 1993), pp. 57-65.

The greatest contribution of this work is its simplistic framework for analyzing the abandonment option. It methodically analyzes risk (noting that investment cash flows should be discounted at the risk free interest rate), the application of the binomial option pricing model, the effect of the option on capital budgeting, and multiple abandonment options and optimal timing. This work is very well documented and very easy to follow. [My only hesitation is that in several exhibits I am not convinced that the calculations are correct (specifically Exhibits 5 & 6).] 15 references.

75. Sanchez, Ronald A., "Strategic Flexibility, Real Options, and Product-Based Strategy," Doctorate Dissertation, MIT Civil Engineering, 1991, 317 pages.

This exhaustive dissertation has one of the best bibliographical listings of all options sources available. This work has two basic objectives: to develop a more structured concept of strategic flexibility and to analyze the importance of this flexibility to the produce development strategy of a firm. In his early chapters, Sanchez provides the most thorough discussion of strategic flexibility available (based on contingent claims analysis). He then discusses the various types of options available to firms specifically grouping them as options of what, when and how to implement. He analyzes the options as affected by three different competitive market contexts: competitive immunity, value erosion by imitation and value erosion by diffusion. The remainder of his dissertation is spent in analyzing product development strategies that maximize the value of the firm particularly through strategic flexibility. Sanchez shows that the success of these strategies (the value of the dependent options) relies largely on an aligned set of core competencies within the firm that enables them to exercise the options in such a way as to derive competitive advantage. He notes that when markets are characterized by uncertain technological outcomes and market preferences, the real options framework provides an invaluable tool for assessing the value to the firm of the core competencies which enable them to compete. This work is both a broad and deep treatise on the utility of options valuation to a firm. It discusses and illustrates and, in some cases provides case studies for, all of the "standard" option types: growth options, options to defer, to abandon, to contract, etc. It also discusses each as part of a series of interrelated or compound options. 294 references.

76. Sawhill, James W., "Evaluating Utility Investment Decisions - An Options Approach," MIT Sloan Masters Thesis, 1989, 76 pages.

This thesis presents a rigorous analysis of Public Utility investments in plants of different inputs and capacities. It notes that large-scale facilities may be less inexpensive in scale but that smaller more expensive (relative to capacity) plants offer switching options (switching of power generation inputs) that are valuable to the firm. 9 references.

77. Siegel, Daniel R., James L. Smith and James L. Paddock, "Valuing Offshore Oil Properties with Option Pricing Models," *Midland Corporate Financial Journal* (Spring 1987), pp. 22-30.

> This work has as its specific purpose to illustrate how financial options can be used to value the real option of offshore oil properties. With general details and sufficient data to reproduce the methodology, the authors step through the parallels of financial option calculation and real option calculation. They include data for break-even analysis and estimate confidence levels. The authors specifically note that "...operating options arise when management can defer its choice of action until a future date when some important uncertainty is resolved....an undeveloped oil reserve gives its owner the right to "acquire" a developed reserve by paying the development cost." This paper provides an excellent step-by-step determination of the factors to calculate the option value. In the conclusion, the authors state that "... as a general rule, then, the big advantages of the option valuation technique over the conventional DCF method appear to be in valuing those properties that are marginal or sub-marginal." Finally, they show how options would have performed historically in bidding on offshore oil leases. 10 footnotes / references.

78. Smit, Han T.J. and L.A. Ankum, "A Real Options and Game-Theoretic Approach to Corporate Investment Strategy Under Competition," *Financial Management* (Autumn 1993), pp. 241-250.

> This work uses the binomial technique to evaluate an investment in production facilities given the uncertain market development for a new product. The unique contribution of this work is the analysis of the option (a real call option) using game theory given various market structures: monopoly, duopoly and perfect competition. It draws four conclusions: if a firm has a dominant market position, it can safely postpone the project and invest only if the market develops favorably or if the weaker competitor invests first; Projects with high NPV will prompt the dominant firm to invest early; a weak firm considering a project with low NPV may be better to wait until the market develops; and, while a weak firm might invest immediately in a high NPV project in hopes of preempting a stronger competitor, its stronger competitor could erode the project's NPV. The central theme of this work is that the exclusiveness of a financial option does not apply to a real option and, therefore, the market structure must be accounted for in valuing real options. 14 references.

79. Smith, Clifford W., Jr, "Applications of Option Pricing Analysis," *The Modern Theory of Corporate Finance*, McGraw-Hill, pp. 345-387.

> This work provides an overview of options pricing including a review of the Black-Scholes formula and its derivation (and sensitivities). It specifically details the application of options to European calls and puts. Additionally, it examines the utility of options theory in valuing financial assets (warrants, convertible debt, insurance contracts, leases, etc.) Of note is the inclusion of an appendix: An introduction to stochastic calculus. Its purpose is to explain the subject in a simplified, intuitive way. (It is somewhat successful in this goal.) 23 references.

80. Smith, Clifford W. Jr., "Option Pricing: A Review," *Journal of Financial Economics* 3 (1976), pp. 3-51.

> The work (focused on finance) is often cited because of its summary nature. It reviews the Black-Scholes model and its various modifications and provides empirical evidence of the utility of these models. The work presents options based on normally distributed stock prices, log-normally distributed stock prices, and the jump process. It then reviews

applications of these models to financial assets (debt/equity of a firm, the risk structure of interest rates, dual purpose mutual funds, etc.)

81. "Summary Report: Energy & Environmental Impact Profiles in Canada of Tetra Brik Aseptic Carton and Glass Bottle Packaging Systems," April 1991 study by Deloitte & Touche commissioned by Tetra Pak, Inc.

82. Testin, Robert F. and Peter J. Vergano, "Packaging in America in the 1990s: Packaging's Role in Contemporary American Society--The Benefits and Challenges," August 1990, a publication of the Institute of Packaging Professionals, Herndon, VA.

83. "The Search for the Perfect Package," *COPE Backgrounder*, published by the Council on Packaging in the Environment (March 1994), Washington, D.C.

84. Triantis, Alexander J. and James E. Hodder, "Valuing Flexibility as a Complex Option," *Journal of Finance* (June 1990), pp. 549-565.

This work builds on the efforts of Myers, Pindyck & He, McDonald & Siegel and others for valuing a real option and extends the approach to allow downward sloping demand curves for the underlying asset (not a perfectly competitive market) and for increasing marginal production costs (exercise prices). They apply their model to a two-product case and a flexible manufacturing system. While the initial mathematical presentation is complex, the example is well explained and easy to follow. They present data for flexible production systems in tabular form comparing outputs for various standard deviations and market beta correlations, various frequencies of product switching, and varying capacities. 24 references.

85. Trigeorgis, Lenos, "A Log-Transformed Binomial Numerical Analysis Method for Valuing Complex Multi-Option Investments," *Journal of Financial and Quantitative Analysis* (September 1991), pp. 309-326.

In this work, Trigeorgis notes the obstacles of valuing multiple real options and proposes a numerical method based on the log-transformed (a diffusion process) binomial method. He compares his algorithm with alternative methods (Black-Scholes, Compound Analytic, Quadratic, Johnson, Finite-Difference, Numerical Integration, and Cox-Ross-Rubinstein Binomial) for valuing a European put. Trigeorgis adjusts for dividends and option interaction and provides a numerical example of a chemical company undertaking an R&D project. In this example, he accounts for five options (defer, abandon, contract, expand, switch) and notes that the actual option value is not the sum of these options but, rather, about 70% of that sum due to interactions. 31 references.

86. Trigeorgis, Lenos, "Anticipated Competitive Entry and Early Preemptive Investment in Deferrable Projects," *Journal of Economics and Business* (May 1991), pp. 143-156.

In this work, Trigeorgis shows that the impact of anticipated competitive arrivals on the value of an investment (when investing can preempt competitive moves) can be analyzed as an American call option. He specifically analyzes five scenarios: preempt competition by exercising immediately, immediate exercise with simultaneous entry of competitor, no competition, competition enters while deferring, and exercising just before the expected entry of competitor. Building on these scenarios, Trigeorgis investigates the dominance relationships of the scenarios to better characterize the optimal exercise. He

concludes by expanding his approach to include the random arrival of competitors. 28 references.

87. Trigeorgis, Lenos, "Real Options and Interactions With Financial Flexibility," *Financial Management* (Autumn 1993), pp. 202-224.

This work provides the most comprehensive literature review available. One particularly useful exhibit lists the key analytical works broken down by real option types. It further suggests useful areas of future research. In addition, this article uses an oil company's lease on a drilling site to conceptually introduce the valuation of the option to defer, the option to default construction, the option to expand, the option to contract, the option to shut down, the option to abandon, the option to switch use and the interrelated corporate growth options. Using the binomial technique, deferral, abandonment, expansion and default are all calculated. Trigeorgis then further develops the new field of options resulting from operations and financial interactions. Specific examples illustrate limited liability option to default on debt, interaction between operating and default flexibilities, venture capitalists' option to abandon via staged debt financing and debt-equity venture capital financing. One of the great values to this work is its extensive bibliography. 112 references.

88. Trigeorgis, Lenos, "The Nature of Option Interactions and the Valuation of Investments with Multiple Real Options," *Journal of Financial and Quantitative Analysis* (March 1993), pp. 1-20.

This excellent work illustrates the value of interactions on investments with multiple real options. Trigeorgis builds on his earlier work, "A Log-Transformed Binomial Numerical Analysis Method for Valuing Complex Multi-Option Investments." He notes that the value for collection of available options is not necessarily additive and uses an example of a project with defer, abandon, contract, expand, and switch options to illustrate this point. Specifically, he demonstrates that "the degree of interaction and (non)additivity of option values--and the extent to which the underlying asset for a prior or subsequent option is altered--will be seen to depend on a) whether the options are of the same type (e.g., tow puts or two calls) or opposites, b) the separation of their exercise times (influenced by whether they are European or American options), c) their relative degree of being 'in or out of the money,' and d) their order or sequence." He discusses the effect of each of these relationships in detail. In general, when two options are of different types and both out of the money, their interaction is small (they are additive); if their is a low probability of both options being exercised, they are additive. 34 references.

89. Trigeorgis, Lenos and Eero Kasanen, "An Integrated Options-Based Strategic Planning and Control Model," *Managerial Finance* (May 1991), pp. 16-28.

This insightful work draws options pricing theory into the manager's role of strategic planning and control. It introduces the various types of options, presenting particularly interesting examples on the increased option value due to parallel projects each of which may have a negative NPV. The authors also present a very easy to follow example of growth options as sequential project interdependencies over time. They emphasize the importance of designing value maximizing financial controls in light of option values of projects. This work summarizes by noting that capital budgeting cannot be static (particularly as viewed using options); they note that constant attention is necessary on the part of managers to look for opportunities to exercise imbedded options in investment projects and to create new options. This work is particularly interesting in its global perspective of options as a key cog in strategic planning. 12 references.

90. Trigeorgis, Lenos and Scott P. Mason, "Valuing Managerial Flexibility," *Midland Corporate Financial Journal* (Spring 1987), pp. 14-21.

This paper presents a basic conceptual overview of real industrial options with some simple examples. It suggests that there are two elements of added value inherent in an investment that are not captured by traditional NPV calculations: "first, the "operating flexibility" available within a single project which enables management to make or revise decisions at a future time...and second, the "strategic" option value of a project resulting from its interdependence with future and follow-up investments." It introduces as a framework the connotation of "expanded NPV" being equal to "static NPV" (or standard NPV) plus the option premium. This work has as its purpose to illustrate that options can be practically used to value flexibility and to demonstrate that options are an economically corrected use of decision tree analysis appropriate for the asymmetrical payback inherent in options. Using a generic plant investment, this paper applies the binomial technique to illustrate simple valuations for the option to defer investment, the option to expand, the option to contract and others. 11 footnotes / references.

91. Weston, J. Fred and Thomas E. Copeland, *Managerial Finance*, 9th ed., Dryden/HBJ, 1992, Ch. 13 "Capital Budgeting under Uncertainty", pp. 473-515.

Chapter 13 of this text uses decision trees to illustrate project evaluation by NPV techniques using the Capital Asset Pricing Model (CAPM) and Arbitrage Pricing Theory (APT) to value a project. It concludes by illustrating the binomial option pricing technique as applied to decision trees for valuing the option to defer and the option to abandon. The option to abandon is also computed using Black-Scholes. As part of its options presentation, this chapter discusses the general types of options (abandonment, deferral, growth, contraction and switching). It provides a nice decision tree outline for illustrating how each of these options behave: a pharmaceutical R&D investment with abandonment options, an oil lease deferral option, a capacity expansion option, a generic option to contract, and two examples of options to switch, a flexible manufacturing system (FMS) and a mine operation. It further discusses abandonment decision rules noting that: "Maximum NPV should be used whenever capital rationing or mutually exclusive choices are involved. Accept-reject can be used to reduce the cumbersomeness of the problem whenever one decision is independent of all others." 36 references.

92. Wood, John P., Robert G. Hunt and Michael H. Levy, "The Role of Flexible Packaging in Municipal Solid Waste," August 1990 Report prepared for Flexible Packaging Association by Franklin Associates, Ltd., Prairie Village, KS.

Real Options Cross Reference Chart

Bibliographic references which discuss (D) and/or present calculations (C) for the option types outlined in this thesis are identified in the following chart with a checkmark (✔). A double check (✔✔) in the calculation column (C) indicates that the particular source applies some form of the Black-Scholes equation.

	Upside Call Options (Options to Grow / Expand)		Downside Put Options (Options to Abandon / Contract)		Combination Options (Options to Switch / Exchange)		Timing Options (Option to Wait / Defer)	
Source	**D**	**C**	**D**	**C**	**D**	**C**	**D**	**C**
Agmon [1]			✔	✔			✔	✔
Brealey and Myers [8]	✔	✔✔	✔	✔			✔	✔
Brennan and Schwartz [9]	✔	✔	✔	✔	✔	✔		
Brennan and Schwartz [10]					✔	✔	✔	✔
Carr [12]					✔	✔✔		
Chung [13]	✔	✔✔						
Copeland, Koller and Murrin [15]	✔	✔	✔	✔			✔	✔
Damodaran [17]	✔	✔✔						
Dixit and Pindyck [20]	✔	✔					✔	✔
Dothan and Williams [21]	✔	✔						
Edleson [22]	✔	✔	✔	✔	✔		✔	✔
Hanemann [31]							✔	✔
He and Pindyck [32]	✔	✔			✔	✔		
Kambil, Henderson and Mohsenzadeh [40]	✔	✔						
Kemna [41]	✔	✔✔	✔	✔✔	✔	✔✔		
Kensinger [42]			✔	✔	✔	✔✔		
Kester [43]	✔							
Kogut [44]	✔	✔						
Kogut and Kulatilaka [45]	✔				✔	✔		
Kulatilaka [46]					✔	✔		
Kulatilaka [47]			✔	✔	✔	✔	✔	✔
Kulatilaka and Marcus [48]	✔		✔		✔	✔	✔	
Laughton and Jacoby [49]							✔	✔
Mahasseny [50]	✔		✔	✔✔	✔	✔✔	✔	
Majd and Pindyck [51]	✔	✔					✔	✔
Mason and Baldwin [53]	✔		✔					
Mason and Merton [54]	✔		✔		✔			
Mauer and Ott [55]							✔	✔
McDonald and Siegel [56]			✔	✔				
Myers [61]	✔							
Myers and Majd [62]			✔	✔			✔	✔
Nichols [63]	✔							
Paddock, Siegel and Smith [67]	✔	✔✔						
Pindyck [68]	✔	✔					✔	✔
Pindyck [69]	✔	✔					✔	✔
Pindyck [70]	✔	✔					✔	✔
Robichek and Van Horne [73]					✔	✔		
Sachdeva and Vandenberg [74]							✔	✔
Sanchez [75]	✔	✔	✔	✔	✔	✔	✔	✔
Sawhill [76]	✔	✔			✔	✔		
Siegel, Smith and Paddock [77]	✔	✔✔					✔	✔✔
Smit and Ankum [78]							✔	✔
Triantis and Hodder [84]					✔	✔		
Trigeorgis [85]	✔	✔	✔	✔	✔	✔		
Trigeorgis [86]							✔	✔✔
Trigeorgis [87]	✔	✔	✔	✔	✔	✔	✔	✔
Trigeorgis [88]	✔	✔	✔	✔	✔	✔		
Trigeorgis and Kasanen [89]	✔	✔	✔		✔			
Trigeorgis and Mason [90]	✔	✔	✔	✔	✔		✔	✔
Weston and Copeland [91]	✔		✔	✔✔	✔		✔	

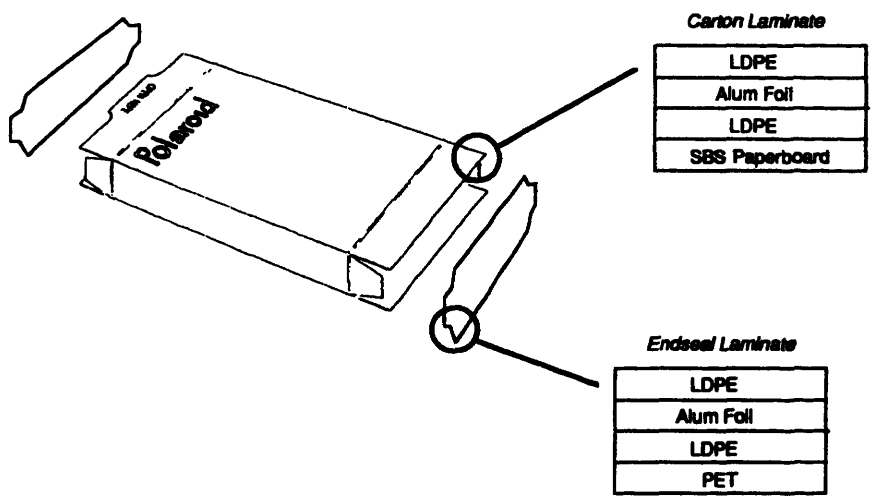
Appendix A

A.1 Background

This appendix offers some background to specific material solutions to the packaging market dynamics outlined in Chapter 2 of this work. The attention will focus primarily on the materials and containers which may apply particularly to the packaging of Polaroid film. As an introduction, this appendix will start with a brief summary of Polaroid's current package and the specific industry dynamics that are leading Polaroid (and others) to consider alternative packaging material / design solutions.

Polaroid's Current Filmpack

A Laminate Carton with Laminate Endseals



As see in the preceding diagram, the current Polaroid film pack uses a paperboard/foil laminate carton with polymer/foil laminate endseals to maintain the required barrier protection for instant film. This design, originally under patent protection, is unique in the packaging industry and the equipment supporting the packaging operation is of a special, proprietary design. As the design emerged nearly three decades ago, the aging of the equipment is one consideration for Polaroid's focus on alternative packaging solutions.

Of a more prominent consideration is the rising emphasis on the environmental impact of packaging. Most similar to the aseptic juice containers (manufactured by Tetrapak), Polaroid has watched with more than passing interest the prevailing opinion swings towards the environmental friendliness of these containers. Driven by green concerns over the recyclability of the aseptic containers' paperboard/aluminum foil laminate, the state of Maine outlawed the packages several years ago and similar legislation was pending in parts of Europe. To combat this, manufacturers developed new methods for extracting the materials from aseptic laminates for recycling. On this evidence, the state of Maine and other areas have withdrawn their prohibition of the package. Interestingly, industry leaders believe the aseptic containers were removed from prohibition largely for the wrong reason. While they agree that these containers should not be banned, they point to indications showing that such laminates are one of the most resource effective packaging materials on the market. They point to recent life cycle analysis results supporting this belief. [81]

A complicating factor to the aseptic discussion is the widely help perception in Europe of the environmental wastefulness of aluminum in general. Because of this perception, many aluminum or aluminum-based material's have received lukewarm reception in Europe.

This environmental focus compounded by increased cost pressures, new distribution and configurational demands, and very high physical requirements has simply heightened the desire within Polaroid to investigate alternative packaging solutions.

A.2 Appendix Overview

This appendix will concentrate on the specific materials that may satisfy many instant film packaging requirements (including their properties, recyclability, costs, market acceptance, etc.) and the container alternatives based on these materials. This appendix concludes with a comparative chart of four prominent approaches to the package of instant film regarding the eight characteristics outlined in Chapter 2: Environmental impact, cost effectiveness, product configuration, customer convenience, physical performance, display, supplier availability and packaging process.

A.3 Materials

The dominant force behind packaging technology initiatives is the food industry. Accordingly, Polaroid and other producers who require packaging with moisture and other gas barriers follow on the developments of those made for the food industry. This happens largely for two reasons: The food manufacturers have the collective R&D budget to expand the envelope to packaging materials and process technology and they have the collective volume to develop a supplier base.

In outlining some of the potential material solutions for packaging instant film, the primary constraint is moisture barrier. Accordingly, the following discussion will be limited to those material solutions that can provide the minimum moisture barrier protection and withstand the rigors of distribution and handling. This barrier can be obtained by a single bulk material (such as steel, aluminum or plastic) or a laminate / extrusion material with a base and a barrier material. The following variations of these materials will be outlined in this appendix:

Bulk Materials:
- Aluminum
- Polyethylene Terephthalate (PET)
- High Density and Low Density Polyethylene (HD/LDPE)
- Polypropylene (PP)

Laminates / Extrusions:

Bases	Barriers
Paperboard PET Oriented PP (OPP)	Aluminum Foil / Metallization Flex Glasses PET Polyvinylidene Chloride (PVdC)

These materials will be reviewed individually by class: polymers, metals, paper, and ceramics. Each section below reviews some of the properties, processes, characteristics and other relevant information pertinent to the dynamics of the packaging industry:

Polymers

Polyester (PET: polyethylene terephthalate, biaxially oriented polyester)

Film is produced form PET resin which is the polycondensation product of ethylene glycol and terephthalic acid; film is formed by a stretching operation giving the material is biaxial orientation.

Because of its high molecular orientation, PET has high tensile strength, clarity, stiffness, chemical resistance and barrier properties. It can be used in applications over a wider temperature range than most common packaging films. (It can withstand prolonged use over the range between -70° and 150°C)

Melt point: 250°C
Raw Material Cost: 50 ¢/lb. (bottle grade)
Not susceptible to humidity
Shrinkage (30 min. @ 150°C): 1.5%

Because of the strength and durability of PET, it is often used as a base for metallization and/or PVdC coating. Such coatings substantially increase the barrier strength of the material. (Metallized / PVdC coatings account for 50% of PET volume in flexible packaging.) The following chart details the barrier properties of PET with these coatings:

Typical Barrier Properties of 48-Gauge Polyester Film Types

	Uncoated	**PVdC Coated**	**Metallized**
Water Vapor Transmission Rate (g/100 in^2/day)	2.7	0.5-0.	0.03-0.10
O2 Transmission (cc/100 in^2/day)	6.1	0.3-0.4	0.02-0.10

[64], p.23

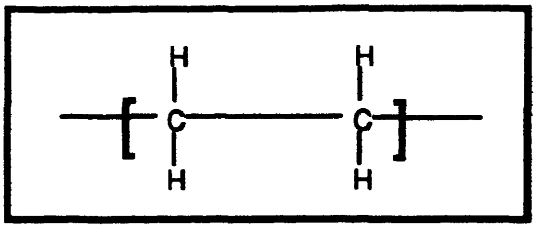
PET is one of the most recycled materials. For a comparison of recyclabilities, see the chart at the end of the Polymer section.

Polyethylene (LD: low density, HD: high density, LLD: linear low density)

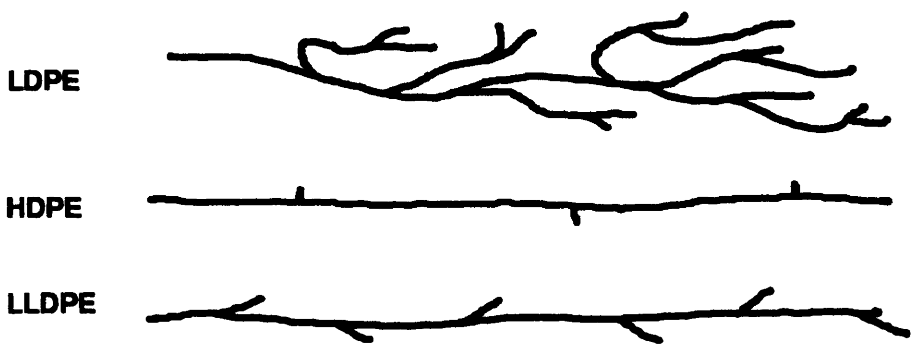
Polyethylene is a partially crystalline polymer composed of crystalline and amorphous regions. As a group, they comprise the largest volume plastic produced in the USA, accounting for 33% of all plastic sold. Three variations of polyethylene films are widely used to provide material solutions to the set of challenges similar to that facing instant film: LDPE, HDPE and LLDPE.

While polyethylene comprises chains of ethylene as diagrammed below, different orientations of those chains is a distinguishing characteristic of the different density polyethylenes:

The Polyethylene Base:



Molecular structure of Polyethylenes:



Adapted from Packaging Encyclopedia [64], p. 27.

LDPE is produced by polymerizing ethylene at high pressures (up to 45,000 psi) and temperatures (150°-300°C) using free radical catalysts. On the contrary, HDPE & LLDPE are both polymerized at low pressures (300-700 psi) and temperatures (100°C) in the presence of a metal catalyst. The density of each material is a measure of its crystallinity. Typically, the higher the crystallinity, the greater the barrier properties. LLDPE, however, is able to retain excellent properties with less material by virtue of is its ethylene combinations with butene-1, hexene-1, octene-1 or 4-methylpentene-1 comonomers.

The densities of these materials are:

	Density	Approximate % crystallinity
HDPE	.941 - .965	80 - 95
LDPE	.910 - .925	60 - 70

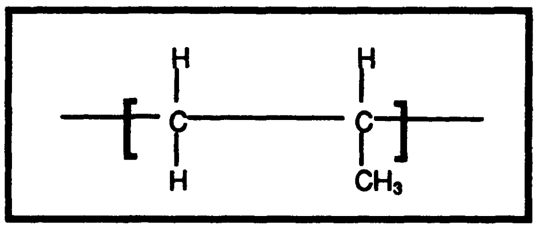
Polyethylene properties can be measured by density and melt index. The melt index is the amount of molten resin (in grams) that flows through an orifice in time (minutes at a given temperature and pressure). Accordingly, the higher melt index, the lower the average molecular weight and, therefore, the shorter the average polymer chain length. In general, the higher the chain length, the greater the film toughness and the poorer is the film processability.

PE films often include slip antioxidants to control a film's coefficient of friction and to allow easy-opening characteristics. Film can be either blown or cast and can be found in thicknesses ranging from .00035" to .01". Blown films allow a wider range of film thicknesses and a better balance of properties while cast films offer higher production rates and greater clarity. With cast films, however, there is a toughness decrement. Co-extrusion offers improvement in all areas.

Demand for LDPE and HDPE has pushed prices up 60% and 49%, respectively, in just the past year.

Polypropylene (regular and BOPP: biaxially oriented polypropylene)

Polypropylene is a gas monomer by-product of the refining process of natural gas, heavy oils and naphtha (ethylene is the other by-product). When polymerized, it takes on a structure very similar in form to the polyethylenes:



Very popular as a packaging material, polypropylene offers a wide range of packaging uses at reasonably low cost. For bulk package stock, polypropylene offers an inexpensive container with reasonable thermal stability, excellent durability and moisture barrier protection. For these reasons, this is the likely material of choice for an instant film package comprising a single polymer container. (For details on how each of these materials compares with regard to rigid packaging, see the comparison chart at the end of the polymer section.)

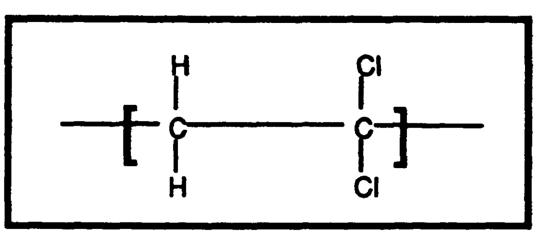
As a flexible film, PP offers an excellent base for metallization, enables a wide range of seal strengths, is extremely machinable and provides durability and flex-crack resistance. For these reasons, PP is second only to LDPE as a leading flexible packaging film. Its transparency vis-à-vis LDPE may enable it to overtake that material as well.

PP films are either blown or made by what is called tenter-frame production. As tenter-frame enables the production of a wider range of material thicknesses, it is currently the more popular (and faster growing) method. In the tenter-frame method, molten polypropylene resin is extruded from a flat die, quenched to create a thick film, stretched lengthwise on the machine and then heated in a tenter frame and stretched crosswise.

Demand for Polypropylene has pushed prices up 43% in the last year.

Polyvinylidene Chloride (PVdC)

One of the oldest barrier materials, PVdC (known widely by its "Saran" trade name) is very high in chlorine content and very crystalline in structure.



The upside is that the highly crystalline structure provides a very high barrier to gases, water, vapors, odors, etc.; the downside is that chlorinated materials are coming under fire for health and environmental reasons and, accordingly, this barrier material tends to be giving way to newer materials. PVdC has high tensile strength, is resistant to chemicals, and resists stretching. It can be formed in thicknesses ranging from: .0005" - .006".

Plastic Bottles / Containers: A Comparison of Material Properties

Properties	*LDPE*	*HDPE*	*PP*	*OPP*	*PET*
Resin density (specific gravity)	0.91-0.925	0.94-0.965	0.89-0.91	0.90	1.35-1.40
Clarity	Hazy transparent	Hazy translucent	Moderate Haze	Clear	Clear
Permeability to water vapor (g-mil/100in²/day)	1.0-1.5	0.3	0.7	0.25-0.4	1.0-1.3
Permeability to Oxygen	Very high	High	High	High	Low
Resistance to acids	Fair to very good	Fair to very good	Fair to very good	Fair to very good	Fair to good
Resistance to solvents	Poor to fair	Poor to good	Poor to good	Poor to good	Good
Resistance to heat	Fair	Fair to good	Good	Good	Poor to fair
Resistance to cold	Very good	Very good	Poor to fair	Very Good	Good
Temperature at which product distorts	160°-220°F	160°-220°F	250°-260°F	250°-260°F	100°-160°F
Thickness range (inches)	.0003 & up	.0003 & up	.0075-.01	.00045-.004	.00008-.014
Tensile strength (psi)	1500-4000	2000-4000	4500-10000	7500-40000	20000-35000
Tearing strength (psi)	65-575	n/a	n/a	1000-1500	1000-3000
Stiffness	Low	Moderate	Moderate to high	Moderate to high	Moderate to high
Resistance to impact	Excellent	Good to very good	Poor to good	Very Good	Good to excellent
Unit cost	Low	Low	Moderate	Moderate to high	Moderate

Adapted from Packaging Encyclopedia [64], p.62 and from Modern Plastics [60]

The following recycle comparison was taken from Modern Plastics [59] issue and includes recycling projections through the end of the century:

Item	1977	1982	1989	1994	2000
Total plastics demand	30,698	33,501	56,978	69,000	86,000
• recycled %	-	0.1	0.7	3.3	8.0
Plastics recycling by resin					
• PET	-	40	195	800	1,400
• HDPE	-	0	130	780	3,050
• PVC	-	-	15	140	400
• LDPE	-	-	10	250	850
• PS	-	-	5	60	150
• PP	-	-	5	40	100
• Others	-	-	10	230	950
Total	-	40	370	2,300	6,900

Metals

Aluminum

Aluminum appears in packaging in three forms: as sheet formed into cans, as foil in laminates and as a metallized coating on polymer bases.

Sheet: .006 - .249" thick
Foil: <.006" thick
Raw Material Cost: .74 \$/lb. - .073 $\$/in^3$

Can/sheet stock

- Accounts for 99.8% of all Beverage cans sold in U.S.
- Highest recycling rate of any package in the world (approx. 60%)
- Can forming methods include 2-pc: Draw-and-Iron and Draw-Redraw and 3-pc: soldered, cemented and welded side seams.

Foil

- Only absolute barrier to gas, moisture and light [independent of gauge]
- Lidding stocks are formed from coextrusions with Al thicknesses: .001-.003"
- Composition: near pure, small amounts of silicon, iron, copper, magnesium or manganese.
- Classic laminate structure: paper/PE/foil/PE
- Susceptible to flex cracking, pinholes (when thinner than .001") and chemical attack
- typically used in laminations in range from .00025-.002"

Metallization

- Processes include: electron-beam, evaporative and sputtering metallizers
- Aluminized layers of any laminate/extrusion is the most expensive layer

Paper

Paperboard

- Basic weight: weight in pounds per 1,000 ft^2 or 3,000 ft^2 of paper
- Paperboard is made hydrophobic by the addition of size (a natural resin) which is set by adding aluminum sulfate (alum)
- Bleached packaging board is called SBS (solid bleached sulfate) signifying is composition entirely of 100 % bleached kraft or sulfate fibers; often coated with wax, polymers or foil to obtain barrier qualities

Ceramics

Flex-glasses

The so-called flex-glasses represent a much hoped for breakthrough in packaging materials technology. Comprising SiOx, or other ceramic compounds, these materials can yield a very high barrier (to both oxygen and water), are at least perceived as more compatible with plastic recycling than metallization, and are transparent. Essentially, these materials are based on glass: an amorphous mix of inorganic oxides containing about 75% Si and 10-12% each of calcium carbonate and sodium bicarbonate along with traces of other metallic and non-metallic oxides. The barrier strength of glass is derived from its amorphous structure and the accompanying tight bonding of atoms. (On the other hand, polymers derive their barrier strength from high cohesive energy density and polar attractions between chains of monomeric components which do not yield to molecules.) One manufacturer of the coating claims the following potential improvement in barrier:

	Moisture Transmission Rate (gm/100 in^2/day)
Uncoated PET	2.90
SiOx Coating (QLF)	0.06
SiOx Coating (2-sided)	0.005

From Rizika [72], p. 2

As noted in the body of this thesis, if the cost becomes competitive, this material could lessen the dependency of packagers on foils and metallizations and on thicker polymer barriers. Flex-glasses have been in production in Japan for more than a decade but are gaining adherents only slowly due to its high cost. In this decade, Airco in the US developed a plasma enhanced chemical vapor deposition product that they call QLF (quartz-like film). They claim that at production rates, the cost of this coating could be \$.08/ft^2.

Below is a brief outline of flex-glasses and several tables characterizing the barrier potential of the materials and the comparative properties of various barrier coatings:

- Oxide coatings: SiOx (most promising), Al_2O_3
- Applied through evaporation, sputtering, and chemical plasma vapor deposition
- Amorphous, coatings less than 600Å
- SiOx requires x>1.7 for material clarity

Barrier Material / Processor	*Moisture Vapor Transmission Rate (g/100 in²/day)*	*Deposition Process*	*Film Compensation*
QLF Coating (single-sided)	0.05	PECVD	SiOx
GL (or GT) (Toyo Ink Japan)	0.08	Evaporation	SiOx
PET/GL/CPP	0.03	Lamination	
Optical Coating Lab	0.03	Evaporation	SiOx
Aluminized PET (single-side)	0.02-0.1	Evaporation	Al
Base PET (48 gauge)	4.17		
Indium Oxide (on 200 gauge PET)	0.20	Sputtering	InOx
Base PET (200 gauge)	1.00		
Al_2O_3 on OPP (Brody, p46)	0.01	Electron Beam	Al_2O_3

adapted from Felts [26, p.10, Brody [11], p.46

	PVdC	*EVOH*	*Foil*	*Metallization*	*AlOx*	*SiOx*
Recycle	-	-	-	-	?	+
Incineration	-	+	-	-	+	+
Clarity	+	=	-	-	-	+
Microwaveability	+	+	-	-	+	+
Metal interference	+	+	-	-	+	+
Dead fold	-	-	+	+	-	-
Barrier	-	=	+	+	-	=
Process speed	+	-	n/a	+	+	+
Energy content	?	+	-	-	?	+

Adapted from Felts [25]. (Employed by Airco, Felts should not be considered without bias).

A.4 Conclusion

The preceding materials provide an outline of the key material technologies available to Polaroid and others in pursuit of high moisture barrier, low cost packaging solutions. The difficulty in selecting packaging materials and designs is not simply in the physical requirements of the package (though these difficulties can be substantial), rather the challenge to manufacturers today is to select a package which also provides favorable environmental impact, lowest total cost, excellent display, convenient customer interfaces, configurational flexibility and manufacturability.

Accordingly, the following matrix provides a rough trade-off analysis for four alternative material selections (paperboard/foil laminate, polymer/foil laminate, bulk polymer, bulk metal) and two basic packaging concepts (integral carton, bag-in-box).

Primary Film Package Material Candidates

Scores and Rankings are based on Internal Focus Group Perceptions; these are averaged scores for 3 Groups.

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	Paper/Foil Laminate	Flexible Pouch & Paperbd Box	Plastic Box	Metal Box
Probable Materials	Current: SBS paperboard LDPE Al foil LDPE Membrane - PET LDPE tie layer Al foil LDPE sealant	Bag - HDPE/LDPE LDPE Al foil LDPE Primer / Ink PET Box - SBS paperboard	Polypropylene	Aluminum Seal - • Foil top w/plastic reseal • Full panel, easy-open end (like peanut jars); no sharp edges
Environment Impact How does this package help our environmental position? Have we source reduced, used more desirable (recyclable) materials or materials made from recycled products? i.e. have we made it easier to sort / separate/ dispose or return?	Score: 1.7 Rank: 4 • Use of recycled board is improbable due to product contamination	Score: 2.8 Rank: 1 • Box can use recycled board • Two potential configurations: Attached vs. separate each have different envir. impact	Score: 2.6 Rank: 3 • greater opportunity for reusability • well established recycle stream if PET or HDPE; less so if PP or other copolymer	Score: 2.6 Rank: 2 • greater opportunity for reusability • well established recycle stream • 60+% Al containers recycled; Al beverage cans highest recycling of all packages • aerosols now in stream • Note: Al industry opposes deposits; 10 states w/deposits, Al containers have lowest relative sales in those states
Cost Effectiveness Are costs appropriate for value received? In comparison, is the package low, medium, moderate or high on the cost scale?	Score: 3.1 Rank: 1	Score: 3.0 Rank: 2	Score: 2.0 Rank: 4 • PET Soda (20 oz): ~7-8¢ per bottle • label/bottle/closure: $95 per 1000	Score: 2.0 Rank: 3 • high volume to be cost effective • Cat food tins ~7¢ • as thinning in beverage cans progresses: mil is more costly; less mil is used--overall cost redux

				• Soda cans: $58-60 per 1000 (can & lid)
Product Configuration Does the package lend itself to multiple production? i.e., 2,3,4 packs? If so, are the multiples cost effective? i.e. Is two-pack lower in cost than two singles? Is the package conducive to inserting, overwrapping, banding, attachments, promotional inserts, etc.? Does it allow postponed package customization? Is this primary package conducive to bulk formatting? i.e. Tens or more?	Score: 2.9 Rank: 4 • multiple boxes in outer box or sleeve	Score: 4.1 Rank: 1 • one box with multiple pouched product (physical protection limits to 3 pouched products in a box)	Score: 3.4 Rank: 2 • one box - multisized	Score: 3.0 Rank: 3 • single can cost ≅ twin can cost
Customer Convenience Consider opening features, ease of disposal and customer / component interface, i.e. is it one step, two step, three step opening?	Score: 2.5 Rank: 4 • Legendary opening difficulty	Score: 3.0 Rank: 3 • Legendary opening difficulty (though easy-open bags exist in marketplace)	Score: 3.9 Rank: 1 • psychologically difficult to dispose in trash barrels • not easily collapsed for storage until disposition • numerous lidding stocks are available w/ well controlled opening force	Score: 3.3 Rank: 2 • psychologically difficult to dispose in trash barrels • not easily collapsed for storage until disposition • numerous lidding stocks are available w/ well controlled opening force

Physical Performance How well does this package protect our film product from the physical rigors of handling during: (1) secondary packaging operations, (2) Dealer stocking / shelving / racking, etc. and (3) End-user touch, go, throw, etc. Also consider package durability, i.e., denting , etc. How does this package function as a moisture barrier when compared to others? i.e. poor, good, moderate, excellent. Can seals be maintained, is it puncture resistant and provides protection from harmful photographic contaminants? Do we need to	Score: 3.9 Rank: 4 • Environmental goal to eliminate foil flex glass? • Inadequate MVTR protection for tropical climates • Occasional inadequacies in venting	Score: 4.7 Rank: 2 • Environmental goal to eliminate foil flex glass? • Concept separates physical and barrier protection features • no protective cushion like laminate box, others (crushable) • no more than 2paks to a box • contamination in metallized and full foil structures without vent	Score: 4.6 Rank 3 • Polyprop: best water barrier to weight ratio • cushioning required • Numerous lidding stocks available w/ well-controlled opening force. • Must accommodate venting	Score: 4.9 Rank: 1 • Numerous lidding stocks available w/ well-controlled opening force. • visible denting • cushioning required • Current thin-wall beverage cans (.004" @ min) cannot be unpressurized (about 60psi) • Must accommodate venting

be concerned about flex cracking, bending, etc.? Can packages of multiples be resealed? * MVTR * Gas venting				
Display Is this package an effective merchandiser / communicator. Does it stack well, rack well, etc.? Can it be easily combined with other products for Sales promotion programs, cross selling, etc.? Does this package denote quality? Overall, is it better than, same as or worse than our photographic competition?	Score: 3.9 Rank: 4	Score: 3.9 Rank: 2	Score: 4.3 Rank: 1 • Cannot readily print on	Score: 3.9 Rank: 2 • limited to flexo print • odd shape will probably require post-form decoration (certain w/ 2pc design). Round beverage cans painted @ 2000 can/min [shrink wrap labeling becoming popular]
Supplier Availability Can the package / package materials be purchased worldwide or is the manufacturing capability limited to only a few sources of supply? i.e. is the structure / material so special that only one or two vendors are capable of supply?	Score: 2.5 Rank: 4 • only pack of its kind in world	Score: 4.4 Rank: 1	Score: 3.9 Rank: 2 • commodity raw mtls • ~12 major ww extruded plastic suppliers	Score: 3.4 Rank: 3 • * commodity raw mtls • 50million required to get attention • 4-5 first tier Al suppliers ww / ~6 second tier supplier
Packaging Process How complex is the filling and closing? Does it require extremely complex machinery? How flexible is it? Can it run more than one size? Is change over easy or difficult? Are the capital costs extremely high? Can machines be purchased worldwide, off the shelf or must they be specially built (one of a kind)? Can the package be run at high speeds (150-300 / min)? Can it be practically date coded / bar coded / labeled? Can it be easily transported / conveyed from station to station? Does it	Score: 2.7 Rank: 4 • only one working equipment design for this package in the last 15 years • membrane sealing is the rate limiting operation • packaged twin costs more than two packaged singles	Score: 3.8 Rank: 1 • rate estimate: 200/min • candy bars bagged @ 900/min • packaged twin costs less than two packaged singles	Score: 3.3 Rank: 2 • no metal interference w/Checkpoint electronic article surveillance (EAS) tag • difficult package storage & handling requirements • molded parts may be made in-house or outsourced • tooling costs are high	Score: 3.0 Rank: 3 • difficult package storage & handling requirements • cans stacked: 389 cans / layer 21 layers high (7-8') 8169 cans in 5X5 pallet • Shipping: 45K lb truck hold 2K lb cans • cans typically conveyed (using:) 1. moving mat 2. air (blown conveyor)

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lend itself to security device application? Does this package require a high degree of technology to produce? Is it cutting edge, require high cost tooling or complex multi-operations? Are lead times excessive for equipment materials and / or finished parts? (Is it multi-material, multi-process, multi-operational?)				• beverage cans: bodies made on std machine @ 300+/min • capital to start a beverage can operation (250million cans/yr): ~$20 - 25 million
Miscellaneous				configs: 3 piece - decorated sheet body 2 piece - enormous scrap - paper label overall costs: approx. equal

Appendix B

From Jarrow and Rudd [39], the mathematical sensitivities of the Black-Scholes equation to its dependent variables are listed as follows:

$$\frac{dC}{dS} = N(d1) > 0$$

$$\frac{\delta C}{\delta X} = -e^{-rT} N(d1 - \sigma\sqrt{t}) < 0$$

$$\frac{\delta C}{\delta T} = \frac{S\sigma}{2\sqrt{t}} N'(d1) + Xe^{-rt} rN(d1 - \sigma\sqrt{t}) > 0$$

$$\frac{\delta C}{\delta \sigma} = S\sqrt{t}N'(d1) > 0$$

$$\frac{\delta C}{\delta r} = tXe^{-rt} N(d1 - \sigma\sqrt{t}) > 0$$

Where:

$$d1 = \frac{\ln\left(\frac{S}{X}\right) + \left(r + \frac{1}{2}\sigma^2\right)t}{\sigma\sqrt{t}}$$

$$N'(d1) = \frac{1}{\sqrt{2\pi}} e^{-\frac{d1^2}{2}}$$

Jarrow notes that the first derivative listed above (the derivative with respect to stock price) is also the hedge ratio, which indicates the exposure of the call to the underlying stock.

Appendix C

Standard Black-Scholes Spreadsheet Formulas:

	Option Type			Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Revenue foregone until can/can't	Risk-free interest rate
Do		Can	Can't	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Dividend Stream]	[Interest Rate]
				E3	F3	G3	H3		J3

d1 K3 =((LN(G3/E3))+((J3+.5*(H3^2))*F3))/(H3*SQRT(F3))
d2 L3 =K3-(H3*SQRT(F3))
N(d1) M3 =NORMSDIST(K3)
N(d2) N3 =NORMSDIST(L3)
Call O3 =(M3*G3) - (N3*(E3*EXP(-J3*F3)))
Put P3 =((M3-1)*G3) - ((N3-1)*(E3*EXP(-J3*F3)))

Dividend-Adjusted Black-Scholes Spreadsheet Formulas:

	Option Type			Irreversible costs of can/can't	Time window for can/can't	Expected PV of can/can't cash flows	Uncertainty in can/can't cash flows	Revenue foregone until can/can't	Risk-free interest rate
Do		Can	Can't	[Exercise Price]	[Time]	[Price of underlying asset]	[Volatility]	[Dividend Stream]	[Interest Rate]
				E3	F3	G3	H3	I3	J3

d1 K3 =((LN(G3/E3))+((J3+.5*(H3^2))*F3))/(H3*SQRT(F3))
d2 L3 =K3-(H3*SQRT(F3))
N(d1) M3 =NORMSDIST(K3)
N(d2) N3 =NORMSDIST(L3)
Call O3 =(M3*(G3*EXP(-I3*F3))) - (N3*(E3*EXP(-J3*F3)))
Put P3 =((M3-1)*G3*EXP(-I3*F3))-((N3-1)*(E3*EXP(-J3*F3)))

Appendix D

As in the calculations in Chapter 3, the real option data required are those which are analogous to the data for computing financial options:

Financial Options	Real Options
Stock Price	Expected Present Value of the upside opportunity
Time	Time (window of opportunity)
Exercise Price	Irreversible Monetary commitment to enable upside opportunity
Volatility	Uncertainty in PV of upside opportunity
Risk-free Interest Rate	Risk-free Interest Rate

This data can be estimated as follows:

Irreversible Monetary Commitment to Initiate Future Opportunity [Exercise Price]

The exercise price of a real option is the value of the irreversible investments to enable the exercise of the option. As in the capacity example is Chapter 3, while the purchased machine had additional capacity, that capacity could only be tapped by buying tooling and other necessary support equipment. Similarly, adding a third shift at a facility would require certain non-recoverable administration expenses. If the investment item can readily be resold (at minimal loss), then it is not included in the exercise price. As an example, temporary workers (or even permanent workers to layoff minded companies) would not be included in an exercise price because these costs are reversible. Exercise price, then, can be estimated by totaling all costs which meet the following two rules:

Exercise Price Rules:

1. Costs are initial, one-time investments that are required to "activate" the option.
2. Costs are irreversible; they are not readily recoverable (via resale, for example) with minimal loss.

In sum, the exercise price includes all unrecoverable, fixed costs tied to the activity of exercising the option; this does not include variable costs tied to the output of the exercised option. Consider the following examples:

Real Option	Included in Exercise Price
Machine with additional capacity. Option: to utilize upside capacity	Facilities, equipment, tooling improvements necessary to run full capacity
Cross-training. Option: to "cover" for employee absences	Organizational/union changes to enable multiple machine coverage.
Pilot testing a new package design. Option: to change-over to new design	All costs for design changeover including new equipment & materials, initial advertising costs, distribution costs, etc.

Because of the breadth of investment costs, the usefulness of a broadly skilled, highly experienced cross functional team contributes much to the determination of exercise prices.

Time [Time]

The time for a financial option is set at the date of agreement. For a real option, however, the window of opportunity for exercise must be estimated. If the option is based on a justification in an NPV payback (or that would be in an NPV payback), the time used for the evaluation of the option should match the time used to determine NPV. Many companies have an established policy for estimating the life of equipment, products, etc. If the time is not prescribed, the simple rule for guesstimating is:

- Over what period of time is there a reasonable opportunity for exercising an option that still permits the estimated payback?

It should be noted that Myers and Majd [62] note that with regard to abandonment options, the time to maturity is the physical life of the asset.

Expected Present Value of Future Opportunity [Stock Price]

With a stock option, the basis for the value of the option is the known price of the stock today together with an estimate for the likelihood of that price to change over time. Accordingly, the "known" value of a real option today is the estimate (in today's dollars) of the value of the optional future opportunity. For those options which are operationally derived (that is, upside opportunities based on elements of the NPV justifications), the process for determining the expected PV of the future opportunity is relatively easy:

1. Use the data and assumptions that are (or would be) contained in the NPV analysis to identify the total potential value of the cash flows tied to the upside opportunity. Just as with NPV, these cash flows need to be discounted to estimate today's value. If a specific discount rate is not apparent, the company's cost of capital is a reasonable discount rate. (footnote other means of identifying risk)
2. Draw on the insights and experience of the team to estimate the percentage of the upside opportunity value that could reasonably be expected. This presents a good opportunity for identifying the range of uncertainty in this estimation as well. (This second piece of information is used to determine volatility; see below)

An example:

Cost of Capital	18%		
Year	1	2	3
Cash In-flows	$2,000	$2,500	$1,800
Cash Out-flows	$1,200	$1,400	$900
Difference	$800	$1,100	$900
PV of Difference	$678	$790	$548
Total PV	$2,016		

Possible upside percentage:	5%
Expected upside =	$ 101

For less certain, more strategic options (such as the ability to apply a new packaging equipment technology in the future), the present value of expected upside is very dependent on a good, team-developed guesstimate. The logical starting point is the expected value of the current implementation. With that information, the team must identify what are the probably follow-on options that are made possible almost exclusively by the success of the initial project.

Uncertainty in Present Value of Cash Flows [Volatility]

Since uncertainty in the potential value of the of the cash flows from a future opportunity accounts for a substantial portion of the option's calculated value, a reasonable estimate for uncertainty is essential. In stock options, uncertainty is typically estimated from a stock's historical performance. For manufacturing purposes, there is not necessarily history to draw on. For expediency, however, a good estimate of uncertainty today is immeasurably better than a great estimate next week; this is where the power of a knowledgeable cross-functional team may be most valuable. The fundamental definition of the volatility required for the Black-Scholes real option calculation is the answer to this question: "What might the projected value of the initiative become between now and the time we have to decide to invest (divest)?"

Below are two approaches for translating the grammatical answers to this question to numeric approximations for uncertainty:[8]

Approach 1:

Having identified and discussed the major elements of uncertainty in the project's estimated value, that could become clearer over the time window, have the team consider the following questions: "With reasonably favorable information emerging between now and the time we must decide to invest, what might the estimated value of the project become? With reasonably unfavorable information emerging, what might the value of the project become?" By reversing an equation typically used in converting standard deviations to upside and downside values, these values can be compared to today's estimate for the value of the project to determine an estimate for the standard deviation of the value of the future opportunity: (ref. binomial)

Example:

Estimated (expected) value of the following-on project = $5000

Option time window = 2 yrs

Agreed upon favorable estimate in 2 years = $8000

Agreed upon unfavorable estimate in 2 years = $3000

[8] This approach assumes that all uncertainty surrounding a given option can be aggregated into a single normally distribution. In fact, uncertainty distributions around every aspect (even if all are normal) cannot theoretically be aggregated into a single normal distribution. If a precise uncertainties would have to be quantified and then aggregated via a software tool such as At Risk©.

The optimistic percent increase (the upside multiplier) is computed by dividing the optimistic value by the expected value yielding 1.4; similarly, the downside multiplier equals .7. Using the following equations, implied standard deviations can be determined for both estimates which can then be averaged for an estimate:

σ_{up} = ln(upside multiplier) / sqrt(t) = ln (1.6) / sqrt(2) = 33% per year

σ_{down} = - ln(downside multiplier) / sqrt(t) = -ln(.6) / sqrt(2) = 36% per year

Thus, using this approximation, a volatility estimate for the Black-Scholes equation would be the average of the two estimates, or 35% per year.

Approach 2:

While not as analytically accurate, a simpler approach (for call options) may be simply to ask the team: "What is the likelihood that the estimate for the value may double over the suggested time window?"

Assuming that the distribution of outcomes is approximately normal (a safe assumption with continuous cash flows over time), the group's agreed upon answer to this question can be used to estimate the standard deviation of the value of the future opportunity:

Example:

Today's estimated (expected) value of the following-on project cash flows = $5000
Option time window = 2 yrs
Agreed upon likelihood of value estimate doubling over 2 years = 5%

Applying a normal distribution, a 5% expectation translates to 2.1 standard deviations for the "doubled" $5000 which represents the potential upside value. Accordingly, an estimate for the standard deviation over the life of the option would be the upside potential ($5000) divided by the number of standard deviations that upside potential represents (2.1) = $2331. As a percentage of the original expected value of the opportunity (also $5000), one standard deviation represents a growth of 47% ($2331/$5000) over two years or 33% for one year.

Thus, using this approximation, the volatility estimate for the Black-Scholes equation would be 23% per year.

See the following spreadsheet examples for a summary of these approaches:

Estimating Standard Deviation

Approach 1:

expected value	$5,000
optimistic estimate	$8,000
pessimistic estimate	$3,000
time period (yrs)	2
upside multiplier	1.6
implied % std dev/yr	33%
downside multiplier	0.6
implied % std dev/yr	36%
est. % std dev/yr	35%

Approach 2:

expected value	$5,000
upside potential	$5,000
likelihood of obtaining	5%
time period (yrs)	2
Z (# std dev's)	2.144853
implied std dev value	2331.162
implied % std dev	47%
est. % std dev/yr	33%