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## "Hedging Future Uncertainty: A Framework For Obsolescence Prediction, Proactive Mitigation And Management"

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**"HEDGING FUTURE UNCERTAINTY: A FRAMEWORK FOR  
OBSOLESCENCE PREDICTION, PROACTIVE MITIGATION AND  
MANAGEMENT"**

A Dissertation Presented

by

CRAIG L. JOSIAS

Submitted to the Graduate School of the  
University of Massachusetts Amherst in partial fulfillment  
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

February 2009

Mechanical and Industrial Engineering

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Approved as to style and content by:

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Janis Terpenney, Chair

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Richard Giglio, Member

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Mario Rotea, Department Chair  
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## **DEDICATION**

To my wife, Desiree Lalbeharie-Josias and children, Keegan, Kyle and Olivia for their understanding, encouragement and support I received during this dissertation.

To my parents Melville and Ingrid Josias who taught me that hard work and perseverance always pays off.

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I am grateful to my parents, Melville and Ingrid Josias, who encouraged me to pursue my studies in the United States and taught me that I could be whatever I wanted to be even when the political climate in South Africa meant "*beating the odds*".

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## **ABSTRACT**

### **"HEDGING FUTURE UNCERTAINTY: A FRAMEWORK FOR OBSOLESCENCE PREDICTION, PROACTIVE MITIGATION AND MANAGEMENT"**

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Component obsolescence in the “high-tech” electronics industry has become a problem that cannot be ignored. Although recent attention has been given to component obsolescence, in general this issue is still dealt with reactively. This often results in sustainment of a long-life system such as ships, airplanes, power plant, and space based programs to be extremely costly. In addition, delayed schedules, extended downtimes, and technology lags are common occurrences in approaches that deal with obsolescence as it occurs. In wake of the rapid pace of technology innovation, turbulent markets and growing globalization, developing proactive approaches for dealing with obsolescence is a necessity for companies to remain competitive in the marketplace. Thus this dissertation focuses on three fundamental objectives that

highlight the importance, provide new insight, and offer solutions to the problem of component obsolescence.

The first objective concentrates on the importance of prediction models in determining the life cycle of a component. Obsolescence prediction is key in identifying the items most vulnerable and allows the company to effectively hedge against future uncertainty long before the problem arises.

The second objective concentrates on proactive management approaches. This is accomplished through a case study with an industry partner. The purpose of an obsolescence management strategy is to ensure that, issues of obsolescence are anticipated, identified, analyzed, mitigated, reported, and dealt with in a cost effective and timely manner. In addition, it provides life cycle “*support and guidance*” to the management team.

Dealing intelligently with flexibility and uncertainty is characteristic of the Real Options Pricing approach. Thus, the third objective concentrates on options pricing as a decision making tool for mitigating the effects of obsolescence. Making strategic decisions about when to invest, what technology to invest in, waiting until a future point in time when a new technology may be available, are all complex questions to answer. Real options pricing offers a novel approach to addressing issues of obsolescence in sustainment based technologies. Thus this dissertation demonstrates that obsolescence prediction, proactive management and mitigation and the use of real options is key in determining optimal decisions and staying competitive in the “high-tech” electronics industry.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Motivation

*No capability is unassailable, no lead is uncatchable, no kingdom is unbreachable. Indeed, the faster the clockspeed, the shorter the reign. Sustainable advantage is a slow-clockspeed concept; temporary advantage is a fast-clockspeed concept. And, clockspeeds are increasing almost everywhere [30].*

Companies today are constantly forced to readjust their strategies in wake of the rapid pace of technological innovation, turbulent markets and growing globalization. One way of keeping up with the changes especially in the electronics industry where changes are becoming more and more pervasive is to proactively manage obsolescence through life-cycle forecasting, thereby allowing the company to develop mitigation strategies for dealing with obsolescence before it occurs. Another way is to embed flexibility into the architectural design of products and systems [29], [33], [48], [49], [50]. A combined approach of embedding flexibility in the architectural design as well as developing prediction models allows providers and customers to hedge against future uncertainty. Uncertainty presents itself in many different ways. For example, market dynamics spurred by the quick pace of technological development can render any system obsolete quickly and cause the biggest companies to fail. Technological innovation and competitive intensity are the two leading causes of why industries fail [16]. Thus having the ability to foresee future changes and develop strategies for proactively addressing those changes are becoming a necessity.

In the age of global markets where consumers have many preferences, companies who influence consumer preferences and respond to consumer requirements at the right

time are rewarded. Those who cannot adjust to the market pressures quick enough are becoming “*remnants of the past*” [29]. There are many examples that illustrate this such as the remnants left behind at Cape Canaveral from the “*race to the moon: concrete launch pads, bunkers, and steel gantries in ruin from the Mercury, Gemini, and Apollo missions*” [29]. Another example is the Aerospace Maintenance and Regeneration Center (AMARC), also known as the aircraft cemetery, located outside Tucson in the Arizona desert. The AMARC is another stark reminder of failed decisions as 4,000 planes sit rotting in the sun, as systems are no longer upgradeable [29]. The satellite space station of the 1990s is yet another example of a failed approach that cost more than \$3 billion and 15 years of work. The space station was unprepared to meet the challenges of the future as newer technologies emerged and consumers quickly shifted their preferences to the newer emerging market of cellular technology that the space station design architecture could not accommodate even on a future generation of upgrades [29].

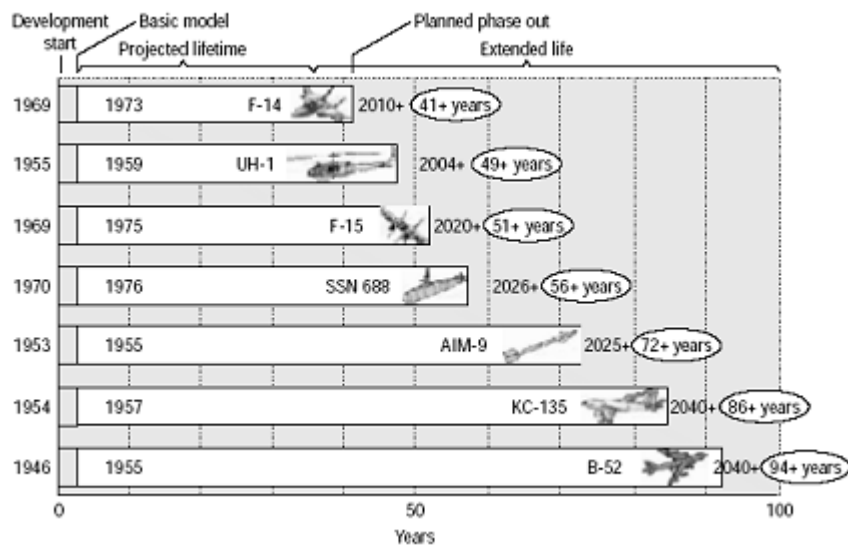
As we live in an era where technology is evolving rapidly with quick clock-speeds racing along faster and faster, anticipating changes, proactively managing obsolescence and incorporating flexibility for upgrades and maintenance into the initial design architecture is becoming a necessity. However, this does have an impact on the initial cost a company may be willing to invest.

Unfortunately, the traditional methodologies industries often use to make strategic design decisions to address and anticipate future risks and opportunities fall short and often lead to design approaches where products become outdated much sooner than what was anticipated. Thus, the most difficult questions to answer are; what level of flexibility is needed, at what cost, and what are the associated present and future risks? These are

fundamental questions that require investigation, and are core to this research.

Developing forward-looking proactive approaches will reduce the firefighting and reactive nature industry currently uses in dealing with risk and uncertainty pertaining to issues of component obsolescence of systems with typically long life-cycles also known as sustainment-dominated systems.

The intense competition in consumer electronics has also caused a major shift in the types of components manufacturers are likely to produce. As a result of economies of scale, electronic component manufacturers have shifted their focus away from low volume products to the more profitable high volume consumer electronics market. Thus, this quick pace of new consumer electronic components has resulted in older parts being discontinued at a rapid rate. Manufacturers and system developers of systems, products, and platforms that are sustainment-dominated are most affected. Military and avionics systems are especially vulnerable as a result of their typical long life cycles. As an example Figure 1.1 depicts the life-cycle of weapon systems for the military.



**Figure 1.1:** Weapon system life cycles [8].

The B-52 bomber for example has a planned service until 2040. This is over 90 years of service life! As one would expect, obsolescence is a major factor due to technology changes that have brought new opportunities for achieving functionality [47]. Perhaps less anticipated for the military was the plague of obsolescence issues since migrating away from the use of military specification components (custom) to commercial off-the-shelf (COTS) components. The rapid growth of the commercial sector due to increased technology content in consumer products has caused many manufacturers to stop producing low volume products for the military as they shift their production to the high volume consumer electronics markets. The problem of component obsolescence is widespread and not limited to military and avionic products. Sandborn (2005) points out that,

*“...technology obsolescence is quickly eclipsing the boundaries of military and aviation systems and starting to affect industrial controls, computer networks, traffic lights and basically all product sectors that are long field life and depends on high-tech materials, parts, software, and/or intellectual property” [23].*

Thus, dealing with obsolescence as it occurs or after the fact is becoming a big problem as it can lead to schedule delays, excessive over-budgeted costs, and catastrophic failures that can force even the biggest companies to fail.

Efforts to solve or mitigate issues of obsolescence have traditionally been reactive and thus have caused sustainment of a long life system to be extremely costly. In addition the current focus is on short-term gains and not long-term benefits and strategic solution. Traditional discounted cash flows that are static in nature are predominantly used to make investment decisions. There are many efforts underway to develop proactive management approaches to deal with component obsolescence; however there

still exists a void and opportunity that lends itself to continued research and analysis in the area of obsolescence prediction, proactive obsolescence management, and dynamic investment decisions. Developing robust products and processes that are flexible in nature and proactively deal with obsolescence will lead to minimized costs of compliance and sustainment. In addition these synergies will help reduce the risks of obsolescence and lead to maintaining a competitive edge in the marketplace with minimal disruption of service as possible.

## **1.2 Research Objectives**

Technology obsolescence has become a problem that cannot be ignored. In response, this dissertation, aims to contribute to advances in 3 fundamental areas that will highlight the importance, provide new insight, and offer solutions to the problems of technology obsolescence. These areas include:

- 1) obsolescence prediction,
- 2) proactive mitigation and management, and
- 3) real options pricing models to determine optimal decisions.

## **1.3 Approach and Methods**

### **1.3.1 Obsolescence Prediction**

Reacting to obsolescence as it occurs comes with a high price and results in delayed schedules, expensive mitigation, extended downtimes, and technology lags. Obsolescence prediction is a proactive management approach that aids systems developers and manufacturers in identifying component obsolescence and discontinuances before they occur. Systems developers and manufacturers can better

plan, design, and sustain their products and systems by understanding the life cycles of the components they utilize.

The traditional methods employed in obsolescence forecasting are extremely limited and involve using scorecard approaches and a single factor; the availability factor. The scorecard approach assigns a life cycle code and weight to each attribute of the component.

*“The disadvantages of this approach are that it does not capture market trends accurately because it commonly relies on unquantifiable, technological attributes such as technology complexity and soft market attributes such as usage” [6].*

It is also assumed in this approach that all integrated circuits are alike and follow the same life cycle characteristics. In addition, standard approaches attempt to forecast obsolescence of one part by predicting obsolescence of other similar parts, which can be very misleading.

The typical product life cycle data model is defined by the electronics industry to consist of 6 stages as listed below [4]:

- i) Introduction
- ii) Growth
- iii) Maturity
- iv) Saturation
- v) Decline
- vi) Phase-Out

The factors responsible for the length of each of the above phases include sales, price, usage, part modification, competitors, and profitability. For example, sales of a typical product are usually low and increases slowly when a product is in its introduction phase. Sales start increasing rapidly in the growth phase and become stable in the maturity phase, subsequently leveling off in the saturation phase. Once sales starts declining, the product is said to be in decline and headed to the phase-out phase where it is discontinued

or obsolete. There are however exceptions to the above life cycle stages and Livingston asserts that not all parts behave in the same manner. He argues that products that do not conform to the above life cycle stages include, but are not limited to, products phased out in the introduction stage as a result of a false start, products produced for a niche market, or products that failed to reach the intended market [10].

Based on historic data, a prediction model of the product's life cycle can determine the time to discontinuance. Prediction models are not perfect and are sometimes prone to error as a result of the vast amount of factors that may be influencing it. In addition there is uncertainty about how a product will behave. However doing nothing and reacting to obsolescence after the fact have become too risky. Hence, the first objective will focus on prediction models as a means of identifying issues before they occur. There are many different prediction or forecasting models that can be used. The following list are some common methods which include; regression analysis, time series analysis, trend analysis, moving averages, and exponential smoothing. The method selected usually depends on the characteristics of the part and the available data.

In this dissertation a generalized approach for predicting the obsolescence risk is presented at the bill of materials level. An algorithm consisting of four key variables including market share, number of manufacturers producing the component in question, life cycle stage, and a qualitative risk rating of components by the company was identified as significant. The result is a classification of the level of risk of all products in the companies' bill-of-materials. Subsequently, allowing the company to identify high risk items for mitigation which is explained in later sections. In addition to this algorithm, obsolescence prediction can also be done on individual components.

Microprocessors serve as the basis of example problems on an individual component, since the impact of obsolescence that microprocessors have on sustainment-dominated systems is significant. This is as a result of newer versions being constantly introduced to keep up with the consumer electronics and computer markets and older versions becoming obsolete at a high rate. Since microprocessors have complex architectures its obsolescence impact on sustainment-dominated system with long life cycles can be very significant. Typically, it results in expensive mitigation that includes retesting, requalification, reprogramming and possibly redesign. Thus life-cycle prediction of microprocessors is significant in assessing the risks and providing alternative options early in the development cycle. In this research data on the life cycles of various processors were gathered. In addition factors such as clock speed, number of transistors and manufacturing process size were identified as significant. Prediction models is developed and explained in greater detail in later sections of the document.

### **1.3.2 Proactive Obsolescence Management and Mitigation**

Being proactive about issues of technology obsolescence is paramount to system developers and engineers in the design, maintenance, and management of product development. Proactively managing obsolescence involves a management initiative in dealing with issues of technology obsolescence in order to continue to have an innovative and competitive product. Companies that do nothing often lag behind and this is evident today among the top 3 automotive manufacturers in the United States; Ford, Chrysler, and General Motors. In December 2008 Ford, Chrysler and General Motors faced serious financial challenges as sales of its vehicles continue to plummet and all indicators point to bankruptcy requiring a possible government bailout in order for them to remain

in business. On the contrary, sales of Honda vehicle rose in the United States during the same time period as customers' demand for energy efficient vehicles rose. Linebaugh points out that Honda has flexible manufacturing production processes that can easily switch between different automotive models in a matter of minutes and has become a key strategic advantage for Honda [97]. Thus as the price of fuel rose and demand for smaller energy efficient vehicles rose, Honda was able to easily switch its production processes to capture the new demand. Unlike Honda, US automakers do not have the flexible manufacturing processes of switching between models. A typical manufacturing line switch can take US automakers more than a year and in excess of \$100 million [97]. In addition, US automakers have lagged behind with regard to its energy efficient vehicle technology. This lack of proactive management by US automakers has led to obsolete business models and practices. Thus the need for restructuring to remain competitive is paramount especially since demand for gasoline-electric hybrids are surging amidst volatile fuel prices.

Hence, the second theme of this dissertation focuses on proactive management and mitigation approaches. Proactive managing and mitigating obsolescence requires a management plan that is unique to the company and part of the company's strategic decision making processes and vision. This initiative should be the company's unique response to identifying issues of technology obsolescence, assessing the risks, performing analysis, and mitigating the effect in a cost effective manner. In order to address the second objective an industry case study provides the basis. As described in Chapter 7, a multi-pronged approach is put forward that includes obsolescence prediction, proactive

mitigation and management, and investment models utilizing the real options framework. This multi-pronged approach is explained in detail later in this dissertation.

### **1.3.3 Real Options Pricing Models to Determine Optimal Decisions**

Companies are constantly faced with the difficult strategic decision of determining the timing, the technology, and the extent of their investment decision to hedge against future uncertainty as well as creating a competitive edge in the marketplace. Rushing into an investment decision, to keep up with newer emerging components and technologies, may not always be the best outcome. Yet, delaying an investment decision today may pose a risk that may lead to adversaries gaining a competitive edge as an early adopter thereby eroding future market share. Furthermore, technology obsolescence of a subassembly or component may lead to issues of sustainability for the purpose and duration for which the end product was initially intended. Thus, manufacturers and systems developers are faced with the difficult decision of deciding on whether to invest in the new technology currently available today or to postpone the revision/redesign of the end product to an unknown future time when a more advanced technology is available. Dealing intelligently with risk and uncertainty is characteristic of the real options approach. This dissertation will explore and demonstrate that using real options analysis in evaluating the decision of several different alternative scenarios offers significant value in strategic decision making for a company in arriving at their investment decisions. Real options analysis is a departure of the traditional discounted cash flows (DCF) approaches that are typically employed in technology investment decision making. The binomial and trinomial generalized models are introduced and discussed in later chapters.

## **1.4 Organization of the Dissertation**

This dissertation is divided into eight chapters and three major focus areas. Chapter 2 consists of a literature review covering the foundation and thrust of this dissertation as it pertains to obsolescence in the high-tech industry, the challenges and solutions employed. Primary focus is on current approaches in dealing with obsolescence management, obsolescence mitigation, and obsolescence forecasting. Chapter 3 is an overview and methodology of the Real Options Pricing approach based on the groundbreaking work by Fischer Black and Myron Scholes in 1973. The Call and Put options are described and the Binomial model is introduced. In Chapter 4 a numeric example and results using the binomial approach are presented. This model utilizes hypothetical data and explores the notion of risk and uncertainty in decision making. Chapter 5 presents the same hypothetical example, this time utilizing the trinomial approach. In Chapter 6 we present an overview of the computer processor and prediction model. Because of its complexity, computer processors obsolescence is a significant problem and challenge for industries such as avionics and military. Thus an overview of the challenges and potential solution is presented. Chapter 7 consists of a case study. In the case study the 3 major themes of this dissertation are applied to a real industry problem. Chapter 8 is the conclusion and outlines the contribution of this dissertation and future work that this approach can have. In conclusion, technology obsolescence is a fact that cannot be ignored. Developing early obsolescence detection indicators and robust investment models to proactively manage and address these issues are paramount.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

This chapter is a review of the literature and past research conducted in the field of high-technology obsolescence, its risks, and the current approaches for mitigating and managing technology obsolescence. The chapter is divided into sub-sections that deal with different areas of obsolescence. In the first section, a discussion on the risks associated with technology obsolescence is presented.

#### 2.2 Risks of Obsolescence

Component obsolescence is not a new phenomenon; in fact, it has been around as long as the electronics industry. However, with the rapid technological advancements in recent years the pace of introductions of newer products has been quicker than manufacturers are able to respond. Thus risks associated with obsolescence in new products are expected. Dasgupta, et al., characterize these risks into 4 categories namely; technological risks, business risks, societal risks, and national risks which he groups as follows [7]:

- 1) *Technological risks typically arise from the potential inability to meet design functions over any or part of the life cycle, or from difficulties in manufacturing to consistently high quality standards, leading to problems of reliability, quality, and safety.*
- 2) *Business risks results from shifts in the supply and demand balances in the marketplace, and in the cost of the system.*
- 3) *Societal risks consider factors such as environmental hazards and life style changes, and is generally difficult to quantify in terms of economic or engineering units.*
- 4) *National risks focus on matters of national economic and military well-being.*

The risks listed above can affect and be affected by design, development, and manufacturing decisions [7]. Dasgupta asserts that life cycle expectations can be better understood by several key perspectives which he lists as follows:

*“functionality and performance, physical morphology, and topology (such as size, weight and shape), complexity and maturity of technology, manufacturability and quality, testability, reliability, maintainability and supportability, development cycle, obsolescence cycle, reconfigurability, affordability and profitability, and marketability” [7].*

These perspectives are different across the supply chain and functional areas in a company. For example, the manufacturer of component  $x$  may be more concerned with its reliability; however the manufacturer that uses component  $x$  in its final assembly operation, is more concerned with its maintainability. The consumer also views this from a maintainability perspective, however is also concerned with minimizing downtime as a result of system errors or failures. Some perspectives can be quantified numerically; however others cannot be expressed in quantitative terms. Dasgupta highlights that the non-quantifiable or conceptual perspectives can be combined with the quantitative perspectives which is known as synthetical engineering and is paramount in developing successful systems and products. He further stipulates that,

*“...even quantifiable perspectives are treated in a conceptual manner early in the development cycle, and gradually transition to more quantitative expressions, as development progresses and design concepts are firmed up” [7].*

Synthetical engineering approaches can be used throughout the supply chain and can be extremely beneficial in developing successful programs and products. The perspectives are different for different industries and are categorized into two main areas by Dasgupta as follows:

- i) Low volume complex electronic systems (LVCES), and

ii) Volume-driven complex electronic products (VDCEP).

LVCES are further divided into two main categories. On the one hand it consists of very low-volume applications such as military systems, space-based systems, down-hole drilling systems. These systems require substantial testing to qualify parts as a result of extreme requirements. On the other hand it can consist of higher volume applications such as commercial avionics, medical devices, automotive electronics, which are more mature with lower development and manufacturing risks associated with it. System failure in a LVCES environment can have catastrophic consequences that could have significant financial consequences. Reliability and maintainability are also significant factors in LVCES. Finally, VDCEP are large volume products with short and aggressive product cycles such as consumer electronics with personal computers as an example. A world-wide survey with participation of 35 LVCES and 45 VDCEP manufacturing companies were conducted to assess life cycle perspectives [7]. The results are highlighted in Tables 2.1 and 2.2 below [7].

**Table 2.1:** “Summary of Responses from the LVCES

Life cycle perspectives	Criticality in low-volume complex electronics system (LVCES)
Obsolescence cycle	•
Reconfigurability	•
Maintainability and Supportability	•
Reliability	•
Marketability	•
Affordability and Profitability	•
Development cycle	
Functionality and Performance	
Manufacturability and Quality	
Complexity and Maturity	
Testability	
Morphology and Topology	

The “.” Symbol Is Used To Indicate Which Perspective Reveal Most Problems and Challenges Requiring Corrective Resources”

The results in the life cycle perspectives among the low volume (LVCEP) manufacturers and high volume (VDCEP) manufacturers were very different. The LVCEP manufacturers found that the perspectives most important to them were; obsolescence cycle, reconfigurability, maintainability and supportability, reliability, marketability, affordability, and profitability. LVCEP manufacturers produce systems and parts that have very long life cycles and have a small market and have to contend with supplies from VDCEP manufacturers as well as more and more military-specification (mil-spec) parts that are replaced by commercial manufacturers.

**Table 2.2:** “Summary of Responses from the VDCEP

Life cycle perspectives	Criticality in volume-driven complex electronics product (VDCEP)
Obsolescence cycle	
Reconfigurability	
Maintainability and Supportability	
Reliability	
Marketability	
Affordability and Profitability	•
Development cycle	•
Functionality and Performance	•
Manufacturability and Quality	•
Complexity and Maturity	•
Testability	•
Morphology and Topology	

The “.” Symbol Is Used To Indicate Which Perspective Reveal Most Problems and Challenges Requiring Corrective Resources”

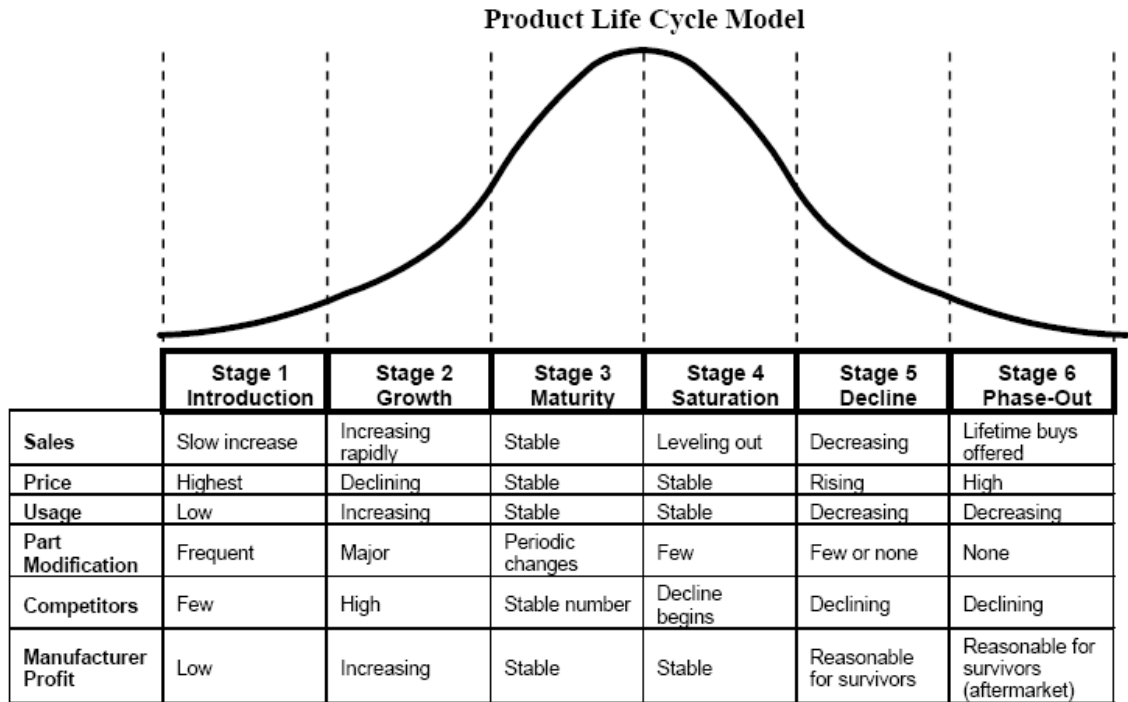
On the other hand VDCEP manufacturers chose affordability and profitability, development cycle, functionality and performance, manufacturability and quality, complexity and maturity, and testability as their main life cycle perspectives.

Affordability and profitability were key perspectives for both manufacturers. Thus the

perspectives highlighted above, Dasgupta et al., [7] argues are the main sources of risk that the electronics industry has to contend with.

### **2.3 Product Life Cycle Stages**

It is first important to understand the different stages in the product life cycle. Not all products and systems behave the same. Certain products are introduced for a niche market while others have false starts due to changing market dynamics and die out long before they reach maturity for a variety of reasons, which include introduction of superior competing devices. On the other hand some products may be revived in the declining stages with newer technologies and once again see increasing sales and market share. Thus it is established that different products behave differently and may in retrospect have very different product life cycle stages. Figure 2.1, however depicts the typical product life cycle stages and characteristics as described by the “Government Electronics and Information Technology Association [10]”.



**Figure 2.1 : Product Life Cycle Model Stages [10]**

As can be seen from the figure above, there are 6 stages, which show the evolution of a typical product life cycle. Understanding the life cycle phases is a huge step in developing strategies and management approaches to finding solutions to obsolescence issues. Developing prediction models and forecasts of different devices through analysis of historic data is paramount in estimating the time to a device's phase-out in order for management to seek out solutions long before the problem exists. The average life cycle from introduction to phase-out is also different for different device categories. As an example, the average life cycle across all quality ranges is approximately 10 years with military microcircuits averaging 12.5 year and commercial microcircuits averaging 8.5 years [10]. Table 2.3 depicts the average introduction rates of commercial integrated circuits, which most recently have continued to shrink even further.

**Table 2.3:** Average introduction rates for new generation commercial ICs [10].

Device Category	Average Introduction Rate
Logic Families	6 years
Memory Families	9 months
Microprocessors	2 years
Digital Signal Processor (DSP)	3 years
Programmable Logic Device (PLD)	1 year
Linear Interfaces	8 years
Gate Arrays	2 years

Thus as a result of mismatches in the life cycles of products and components that it is comprised of, spare part inventories of the components are typically required to maintain the product through its life cycle or until a design refresh can be performed.

As pointed out before, the problem of components obsolescence is widespread and not limited to a specific industry. Table 2.4 depicts the products and service lives of a few industries that are high-tech in nature and also feeling the burden of obsolescence.

**Table 2.4:** Life cycle of obsolescence categories [14]

Types	Products	Service Life (years)
Avionics	Military and aerospace electronic equipment	20-30
	B-52 Bomber	90+
	F-15	50+
Telecommunications	Data communication equipment	3-5
	Desktop terminal equipment	4-7
	Broadcast and studio equipment	5-8
	Public telecom equipment	6-10
	Mobile communications	3-5
Medical	Medical equipment	7-15
	In-car entertainment	3-6

Automotive	Body control electronics	5-10
	Power train system	5-10
	Safety and convenience system	5-10
Computers	Computer system	2-5
	Personal computers	2-3
	Supercomputers, mainframes, workstations	3-5
	Central processing units	2-3
	Graphic boards	2-3
	Single in line memory modules	1-2
	Memory cards	1-2
	Data storage	2-3
	Input/output devices	3-5
Consumer	Audio equipment	5-10
	Appliances	5-10
	Other consumer equipment	5-10
Industrial	Security/energy management	5-10
	Manufacturing systems	7-10
	Other industrial equipment	5-10

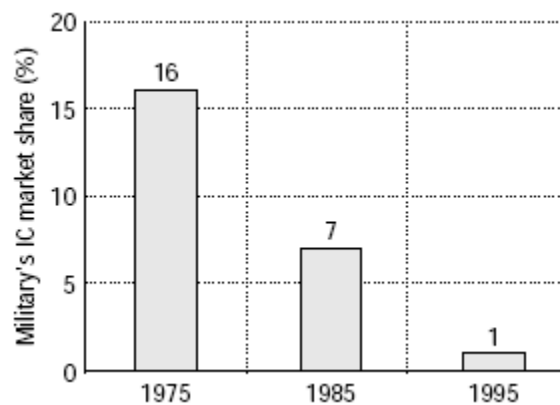
Avionics and military products listed above have service lives of several decades. It is thus without question that these industries would be most impacted by technology obsolescence. The question is, how big is the problem, what are they currently doing to manage and mitigate issues of obsolescence and what are their future plans to cope with it. The avionics and military industry has been very slow in reacting and developing proactive approaches to deal with technology obsolescence. Usually, they add additional costs to their budgets to deal with it reactively, as it occurs. This has led to expenditures that far exceeded their budgets and in many cases the sustainment costs end up exceeding the initial cost of purchase. Also worth noting is that, “...until recently, permanence was an underlying assumption of aerospace electronic equipment...” [25]. Condra et al., also points out that the designs of the electronic equipment in the avionics industry were planned to happen once and assumed to be static [25]. Additionally, the different cultures within the aerospace industry, “...allowed each equipment designer to be optimized

*independently, with little regard for commonality, modularity, reuse, scalability, or extendibility to other applications* [25]. Furthermore, the migration from military specification (mil-spec) parts to components off the shelf (COTS) had a significant impact and rapidly advanced the plague of obsolescence in the avionics industry, clearly not anticipated.

To understand why the migration to COTS proved to be disruptive to the avionics industry requires some discussion. The avionics/aerospace industries as well as the department of defense (DoD) which were previously unaffected by obsolescence before the 1980s as most manufacturers produced low volume products and systems with long term availability of military specification components. Competition between manufacturers were low, thus the avionics industry and DoD systems evaded issues of obsolescence in the 1960s and 1970s as there were always manufacturers ready to produce components for those industries. However, as the consumer electronics industry boomed in the 1980's manufacturers quickly shifted their resources and focus on the high volume, fast moving, and more profitable consumer electronics sector. COTS became more and more popular replacing mil-spec (low-volume) components for the high volumes products such as personal computers, cell phones, and audio & visual equipment. These are a few of the products that have revolutionized the semi conductor industry in the 1980's and led the rapid migration from mil-spec to COTS.

It is important to understand the reason that led to the migration of mil-spec to COTS components. Throughout the 1960s and 1970s the department of defense and NASA were among the largest consumers of electronic components. They were thus able to determine control design specifications and requirements. In a sense they were able to

monopolize the industry and faced no competition always having a manufacturer ready to produce the part they needed. The 1980's was the turning point as manufacturers started producing for the consumer electronics industry and started phasing out their older part previously produced just for the DoD and the avionics industry. The military market share declined drastically in the 1980s and 1990s depicted in Figure 2.2. From 1975 to 1985 the military's IC market share decreased by more than double and further decreased from 7% to just 1% from 1985 to 1995 [8]. With this sharp decline in the IC market share of the military, manufacturers have migrated away from producing just for the military as the low volume industry is not profitable and thus manufacturers produce mainly high volume products to remain competitive in the marketplace. Many low volume military manufacturers have stopped producing military parts altogether further exacerbating the component obsolescence issues for the military as they react to the changing markets and the need to incorporate commercial components into their designs.



**Figure 2.2:** The military's decreasing share of total IC market [8].

Stogdill [8] highlights the fact that the development cycle processes for the foremost IC manufacturers have narrowed to between 12 to 18 months. These manufacturing process changes result in manufacturers discontinuing production on its earlier models as it is often too expensive to maintain continuing production on outdated products that is low volume and non-profitable in nature. Shortened life cycle of commercial components integrated into military applications that typically have life cycles of many decades have further exacerbated obsolescence in the avionics and military applications and systems. Singh and Sandborn [9] highlight that the mismatches in life cycles of sub components and the end product has resulted in high sustainment costs.

The assumption that systems developers in the avionics industry were under, that their designs were static in nature were seriously flawed. As can be seen above, the service life of most airplanes are often many decades. For example, the B-52 bomber is expected to have an overall system life of 94 years and the F-15 bomber in excess of 50 years. With these long service lives obsolescence is a major factor due to technology changes that continues to bring new opportunities for achieving functionality and thus dynamic approaches are needed.

## **2.4 Ramifications**

As a result of the high costs and long cycle times, technology insertion or redesign of product sectors, usually lags the technology wave. Prolonged downtime is a significant consequence of obsolescence in the low volume avionics industry.

Technology insertion or design changes usually require safety and quality standards that entail very expensive qualification and certification cycles for even minor design

changes. Sustaining this type of product over its life cycle usually is much more expensive than the original cost of the product. The current policy in the commercial jetliner industry where the number of components averages 250,000 with over 100 electric boxes; redesign of the boxes at 5 year intervals are prohibited as it can run in the millions of dollars [25]. It is said that more than 10% of the typical avionics manufacturer's component budget is spent on obsolescence problems. In the Boeing 777 flight management system, for example, the Intel 80486 microprocessor was obsolete before the FAA completed the certification of the system. The avionics industry also spends million of dollars on lifetime buys to guarantee availability of the parts. Three avionics companies spent \$6 million with Intel alone on lifetime buys of computer processors [14]. The inventory costs, maintenance cost, and interest costs are extremely significant and estimated at 20% per annum for avionics industries [14]. The F-22 program typically budgets well over 1\$ billion to react to issues of obsolescence as it occurs.

Solution strategies have included obtaining the components from an after market supplier or redesigning the part. When parts are obsolete there may be an opportunity of obtaining it from a broker. However, it usually comes at a premium price. Integrated circuits are often 15 times the price of its original cost at a broker. Additionally, the timing required to locate and procure obsolete parts, often disrupts the manufacturing and maintenance schedules. For example if the integrated chip is available at a broker the turnaround time is estimated to average 14 weeks [25]. Alternatively, if the product is not available and needs to be reverse engineered, six to nine months are typically

required. If a complete redesign is necessary, the cost could easily range from \$500,000 to \$3 million [14] per redesign.

In the telecommunication industry, “...*the ability to offer the latest technology is not an option, but a necessity. If you can’t provide your customers the high speed Internet access they crave, for example, rest assured somebody else will come along who can – and will*” [28]. Certain products in the medical industry have also been significantly impacted. Service delivery of a heart pump for example is delayed as a result of research and development including the food and drug administration (FDA) approval process, taking in excess of 10 years. When components are obsolete redesign often needs to go through the long re-approval process, thus delaying the introduction of the product. The impact can be costly to the consumer/patient whose quality of life could be improved sooner or chances of survival could have been increased by having the product sooner. The literature indicates that similar effects are felt in other industries including automotive, consumer, and industrial. Thus high-tech component obsolescence should not be taken lightly as the cost impacts are a growing concern that requires robust solutions.

## **2.5 Solutions to Obsolescence**

Commenting on current approaches for dealing with obsolescence, Sandborn states,

*“Unfortunately a business culture that has valued quarterly performance over long-term business sustainment has resulted in a poor fundamental understanding of the obsolescence problem where reactive solutions abound, i.e., immediate cost savings are a bigger driver (and easier sell) than longer term cost avoidance [23]”.*

The current focus on obsolescence is on reactive management involving expensive and time-consuming mitigation [4],[7],[8]. The pros and cons of the current obsolescence management approaches are depicted in Table 2.5 below:

**Table 2.5:** Pros and Cons of Current OM approaches

<b>Current Approaches</b>	<b>Pros</b>	<b>Cons</b>
<p><b>Reallocate Stock:</b> Residual stock is available in-house to satisfy the requirements of anticipated future use.</p>	<ul style="list-style-type: none"> <li>Existing stock may be used as an intermediate step to complement another solution.</li> <li>Easiest, less costly, high degree of confidence in compatibility</li> </ul>	<ul style="list-style-type: none"> <li>There may not be stock available.</li> <li>Taking away stock dedicated for another program can have negative ramifications.</li> <li>This is a temporary “band-aid” and not a solution.</li> </ul>
<p><b>Replacement Part with Alternate Supplier</b> A replacement part is available from the original manufacturer or the same part type is available from another manufacturer.</p>	<ul style="list-style-type: none"> <li>Form, fit, or function remains unchanged.</li> </ul>	<ul style="list-style-type: none"> <li>A qualification process may be required to qualify this manufacturer.</li> <li>Replacement part/alternate supplier may require detailed testing to determine compatibility.</li> <li>Baseline documentation may be affected.</li> </ul>
<p><b>Substitute Part</b> A different part is chosen to replace the original.</p>	<ul style="list-style-type: none"> <li>Form, fit, or function remains unchanged.</li> </ul>	<ul style="list-style-type: none"> <li>Next Higher Assembly (NHA) testing or qualification testing may be required to verify the substitute part.</li> <li>Baseline documentation at some level is affected.</li> <li>The substitute part may or may not be supplied by the same manufacturer.</li> <li>Form, fit, or function may vary from the original.</li> </ul>
<p><b>Repair Part</b> Repair may be done in conjunction with an alternate supplier or substitute part at the component level</p>	<ul style="list-style-type: none"> <li>Repair of item is possible.</li> </ul>	<ul style="list-style-type: none"> <li>NHA testing or depot capabilities have to be assessed to determine if this option is the optimum recommendation.</li> </ul>
<p><b>Lifetime/Bridge Buy</b></p>	<ul style="list-style-type: none"> <li>It guarantees current</li> </ul>	<ul style="list-style-type: none"> <li>This solution can be</li> </ul>

A one-time purchase of an item required for producing and supporting the projected life of a specific system configuration for a set period of time.	configuration and material availability for a set period of time.	expensive. <ul style="list-style-type: none"> <li>• The potential for under-purchase creates a risk window; potential for over-purchase spends excess dollars.</li> <li>• Shelf life and carrying cost must be considered.</li> </ul>
<b>Reclamation</b> Salvaging or cannibalizing used items that have not lost their functionality.	<ul style="list-style-type: none"> <li>• Availability of the part</li> </ul>	<ul style="list-style-type: none"> <li>• Possible degradation of items or limited life must be considered.</li> </ul>
<b>Redesign</b> The NHAs that contain the obsolete item must be modified to maintain the same system functionality.	<ul style="list-style-type: none"> <li>• Part made available for continued sustainment of system.</li> </ul>	<ul style="list-style-type: none"> <li>• Impacts cost, schedule, baseline documentation, and logistics support.</li> </ul>

Obsolescence management consists of pro-actively managing the redesign of a system based on forecasted obsolescence dates, production and support plans, and employing mitigation strategies that are effective. There are a variety of strategies to plan for obsolescence mitigation to make sure that the application or processes remain operable. Livingston describes a variety of approaches that can aid in minimizing future obsolescence issues as listed below [4]:

- 1) System Architecture Approaches
- 2) Technology Independence
- 3) Software Portability
- 4) Technology Roadmapping
- 5) Technology Insertion
- 6) Planned System Upgrades
- 7) Life Cycle Analysis and DMSMS Monitoring
- 8) Part Selection Guidelines

- 9) Part Documentation
- 10) Alternate Source
- 11) Substitution
- 12) Emulation
- 13) Life-of-Type (LOT) Buy
- 14) Redesign/ Design Modification

### **2.5.1 System Architecture Approach**

Modular, open, and integrated systems architecture allows developers and designers flexibility when dealing with rapid technology changes and allows new products to be replaced easier. Livingston points out that, “*military electronic systems have traditionally been closed and largely platform-unique [4]*”. However, today’s military platforms and systems are open in nature which enables commercial technology and products to be used with much more ease as well as allows for flexibility when dealing with upgrading, expanding, and replacing a platform or system.

### **2.5.2 Technology Independence**

Technology independence also allows devices to be substituted or replaced by newer next generation products without affecting the existing products and modules, which is very important in light of the fact that commercial products have high turnaround times. Livingston asserts that modern languages like Hardware Description Languages (VHDL) and Programmable Logic Devices (PLDs) are cost-effective means of dealing with obsolescence as it allows for technology independence and thus is much more flexible for transitioning new technologies and redesign.

### 2.5.3 Software Portability

Software portability refers to software that is compiled independent from a target hardware device as to allow the software to be executed on a replaced device without having to rewrite the entire code. This is especially important in obsolescence management as hardware is constantly being replaced in long life platforms, which if compounded with software obsolescence can intensify the maintenance costs and sustainment of a platform.

### 2.5.4 Technology Roadmapping

Technology Roadmapping involves strategic planning to determine the opportune technologies to be used in product selection, which ultimately leads to improved investment decisions. The technology roadmapping process consists of three phases and is outlined in the Table 2.6 below.

**Table 2.6:** Technology Roadmapping Process [4]

<b>Phase I: Preliminary Activity</b> <ol style="list-style-type: none"><li>1. Satisfy essential conditions</li><li>2. Provide leadership/sponsorship</li><li>3. Define the scope and boundaries for technology roadmap</li></ol>
<b>Phase II: Development of the Technology Roadmap</b> <ol style="list-style-type: none"><li>1. Identify the "product" that will be the focus of the roadmap</li><li>2. Identify the critical system requirements and their targets</li><li>3. Specify the major technology areas</li><li>4. Specify the technology drivers and their targets</li><li>5. Identify technology alternatives and their time lines</li><li>6. Recommend the technology alternatives that should be pursued</li><li>7. Create the technology roadmap report</li></ol>
<b>Phase III: Follow-Up Activity</b> <ol style="list-style-type: none"><li>1. Critique and validate the roadmap</li><li>2. Develop an implementation plan</li></ol>

### **2.5.5 Technology Insertion**

Technology insertion is a very important concept to consider when dealing with rapid technological advancement and shrinking product life cycles. Developers and designers should take this into consideration at the conceptual planning phases to accommodate insertion of newer parts with ease of implementation. Thus, when a replacement part with different technologies is required, its implementation is quicker, cheaper, and more efficiently accomplished. Later in this chapter a discussion on modular designs that embeds flexibility into the design architecture and thereby increasing the options value of the product will be discussed.

### **2.5.6 Planned System Upgrades**

Planned systems upgrades is a task that should be performed to determining system time horizons for upgrades. It can be effectively combined with obsolescence prediction to coincide with a system upgrade at the phase-out stages of key products. This allows for an intelligent upgrade by working in the newer technologies for a competitive edge in the marketplace.

### **2.5.7 Life Cycle Analysis and DMSMS Monitoring**

Life cycle analysis and Diminishing Manufacturing Sources and Material Shortages (DMSMS) monitoring involves prediction and forecasting demand of components and monitoring suppliers, vendors, and manufacturers for product availability. There are companies that address product change notification (PCN's) for a nominal fee. TACtech and PCN.com are two such companies that provide services which include email notifications to the subscriber as well as online searching for product change notifications

at the bill of materials level. Suppliers and manufacturers also send out discontinuance notices with dates of when the product will be discontinued to allow companies to plan for discontinuance. However, discontinuance notices are also sent out late and there are many instances where they are not sent at all, thus the obsolete part is only discovered when the part is required, which is reactive. Therefore it is important for companies to keep an updated BOM and predict and monitor obsolescence to be more proactive in keeping a system or platform operational.

### **2.5.8 Part Selection Guidelines**

Part selection guidelines should involve selections of new parts to be made with reasonable data where available that forecast usage of the part. Certainly when developing a new platform designers and management want to minimize the risks of obsolescence in the systems during every phase of the life cycle of the system.

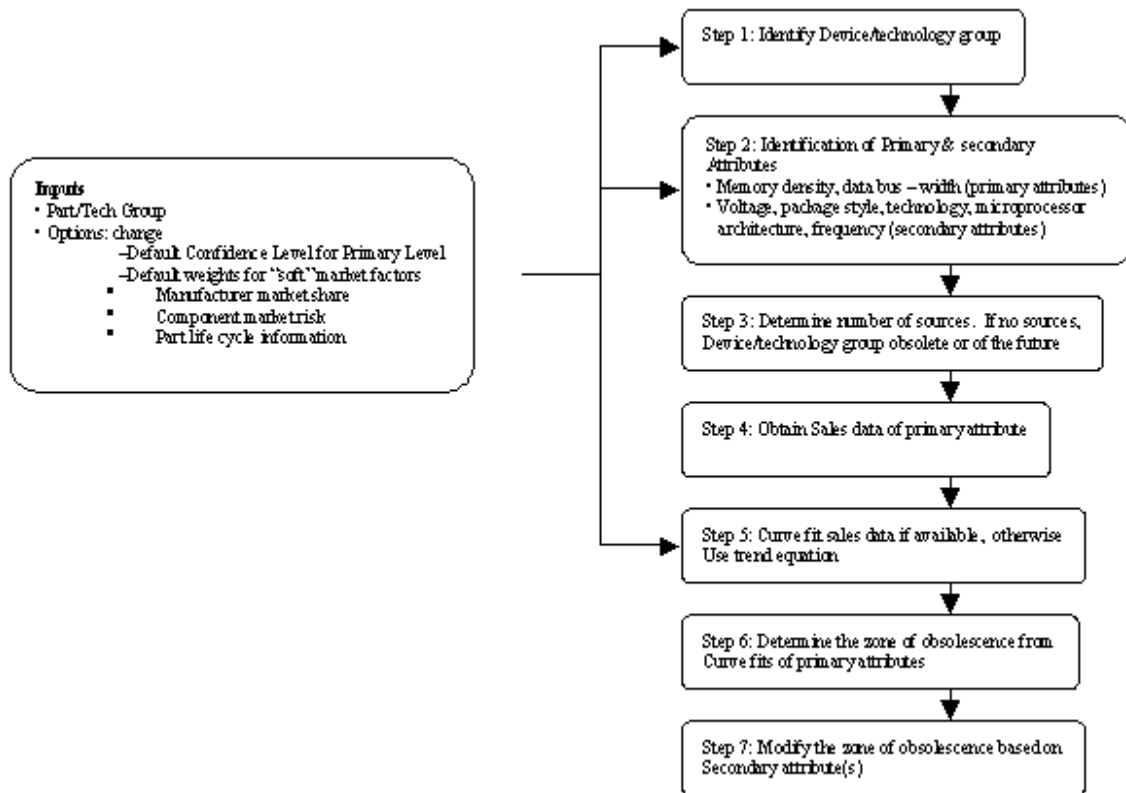
### **2.5.9 Part Documentation**

Part documentation involves compiling a repository database for easily accessing information about the part. The accessibility of this data is extremely useful in managing and dealing with issues of obsolescence. Parts documentation should be taken seriously and not relied on by a few individuals in the company who have it stored in their memories.

## **2.6 Forecasting**

Obsolescence forecasting is a proactive management approach that aids systems developers and manufacturers in identifying component obsolescence and discontinuances before they occur. Systems developers and manufacturers can better

plan, design, and sustain their products and systems by understanding the life cycles of the products they utilize. Figure 2.3 below depicts the approach developed by Sandborn and Petch, et al. [6]



**Figure 2.3:** The life-cycle forecasting methodology [6].

The above process is a 7-step approach to forecasting obsolescence. These steps are summarized as follow:

### 2.6.1 Step 1: Identify part/technology group

The primary purpose of this step is to identify the technology group of the part.

Pecht, et al., [6] considers the part technology group to be a family of parts with the same

technology and functional characteristics, irrespective of the company that produces the part. For example the size, number of transistors, and speed of the computer processors for (AMD, Intel, Micron, etc.) are considered to be the same.

### 2.6.2 Step 2: Identify part primary and secondary attributes

The primary attribute and secondary attributes are characteristics of the technology. These attributes are tracked by companies in the market research field to provide and sell the data they collect to manufacturers who use it in their forecasts to determine entry and exits from certain markets. Table 2.7 depicts an example of primary and secondary attributes.

**Table 2.7:** Primary and secondary attributes for IC part classes [6].

Part class	Primary attribute	Secondary attribute(s)
DRAM	Memory Size	DRAM type (e.g. EDO, FPM, Synchronous, Rambus) Package style (e.g. DIP, SOP, CC, PGA, QFP, MCM, other styles) Voltage (e.g. 5V, 3-5V, 3-3.5V, <3V)
SRAM	Memory Size	SRAM type (e.g. no-cache, synchronous, asynchronous, sync-burst) Package style (e.g. DIP, SOP, CC, PGA, QFP, MCM, other styles) Voltage (e.g. 5V, 3-5V, 3-3.5V, <3V)
Flash	Memory Size	Package style (e.g. DIP, SOP, CC, PGA, QFP, MCM, other styles) Voltage (e.g. 5V, 3-5V, 3-3.5V, <3V)
Logic Parts	Logic family (e.g. HC, HCT, TTL, LSTTL, FAST/FASTr)	Package style (e.g. DIP, SOP, CC, PGA, QFP, MCM, other styles) Voltage (e.g. 5V, 3-5V, 3-3.5V, <3V)

### **2.6.3 Step 3: Determine number of sources**

In this step the number of manufacturers and suppliers are determined for the part. If the part is already obsolete, no sources will be found. Also, if the part is new and not introduced into the market yet, no sources will be found.

### **2.6.4 Step 4: Obtain sales data of primary attribute**

This step calls for data mining of sales data, which is used to identify life-cycle curves. Market research companies readily compile sales data. Life cycle curves are computed with sales in number of units shipped, but if this data is not available, sales dollars or market share could be used.

### **2.6.5 Step 5: Construct profile and determine parameters**

Pecht and Sandborn, et al., [6] use the sales data to construct the life cycle curves of the part. A Gaussian distribution is used to fit a curve to the data which has the following distribution:

$$f(x) = ke^{-\frac{(x-u)^2}{2\sigma^2}}$$

The obsolescence zone is defined by Sandborn using the ordered pair as follows:

$$(u + 2.5\sigma - p, u + 3.5\sigma - p)$$

where  $\mu$  is the mean,  $\sigma$  the standard deviation and  $p$ , the date of assessment.

### 2.6.6 Step 6: Determine the zone of obsolescence

The zone of obsolescence is a time-interval estimation in which parts become obsolete. Sandborn, et al., split the life cycle out into ordered pairs as depicted in Table 2.8 below.

**Table 2.8:** Life Cycle Calculations

<b>Life Cycle Stage</b>	<b>Ordered pair (zones)</b>
Introduction	$(\mu - 3\sigma, \mu - 2\sigma)$
Growth	$(\mu - 2\sigma, \mu - \sigma)$
Maturity	$(\mu - \sigma, \mu + \sigma)$
Decline	$(\mu + \sigma, \mu + 2\sigma)$
Phase-out	$(\mu + 2\sigma, \mu + 3\sigma)$

### 2.6.7 Step 7: Modify the zone of obsolescence

In this phase Sandborn, et al., [6] determine the modifications to the life cycle intervals based on the secondary attributes. He postulates that, *“if the years to obsolescence for any of the secondary attributes falls within the life span (+/- 3σ years) of the main attribute, the years to obsolescence for the generic part will be modified”* [6].

We know that for the life cycle of a typical electronics part, it usually advances through six stages, namely; introduction, growth, maturity, decline, phase-out, and discontinuance. There are however certain parts that do not conform to this life-cycle as a result of market dynamics. For example, a product may have a false start and be phased

out during the introduction phase. Likewise, a product being phased out may have resurgence thereby not following the normal product life-cycle progression.

## **2.7 Regression Analysis**

The main objective of regression analysis is to develop relationships between 2 or more variables in order to gain insight of one of them through knowing the relationships of the others. There are several types of regression models, which include; simple linear regression, multiple regression, and non-linear regression. The variables in a regression model are considered to be random which is good as the factors driving obsolescence are highly variable. The simple regression model consists of one independent variable, related to a dependent variable. The multiple regression models consist of two or more independent variables, which are related to a dependent/response variable. As there are multiple factors driving obsolescence decisions and component discontinuances, multiple regression analysis is a good starting point in determining the response/dependent variable or Y as a function of several independent variables related to Y. Determining the independent or regressor variables requires a multidimensional approach, which integrates market intelligence, understanding the process, and identifying and researching leading indicators. Thus, predicting obsolescence using regression models combines hypothesis testing and leading indicators to develop the model, validate the model, verify the model, and draw statistical inferences about the model. A summary of these methods can combine to predict obsolescence.

Leading indicators are also good techniques that this research will use to gather information for the regression model as it is good in identifying turning points. Leading indicators will not be used as a stand-alone for predicting obsolescence because of the

high level of uncertainty of component obsolescence and the fast pace at which it occurs. Leading indicators as a stand alone technique usually requires a significant amount of data and as causal relationships are usually not established, the accuracy of leading indicators is not good. As obsolescence occurs at a quick rate, leading indicators usually are not great for short term forecasting and are very poor for long term forecasting. Regression models on the other hand are great for short term forecasting and fair for long term forecasting (2 years and up). Thus, if predicting obsolescence in the  $\pm 2$  year range, regression modeling will be used where necessary, provided there is the historic data needed by the model.

When the models are required for long-term obsolescence prediction, econometric models are preferred. Econometric models are a combination of interdependent regression models that describe certain sectors of the economy. Econometric models are very good predictors of turning points. It is also very good with short-term forecasts (0-3 months), excellent with medium range forecast (3 months – 2 years), and good with long term forecasts (2+ years). Econometric models predict the causal relationships better than regression models, however they are larger, more time consuming, and more expensive to construct. Thus econometric models can be used in obsolescence prediction when we consider different sectors of the economy, which we could model as a combination of regression models.

A hypothesis test is a statistical procedure to confirm or refute that there are differences among groups. In obsolescence prediction, hypothesis testing will be used in order to validate the belief that the factors in the model influence the outcome of a dependent variable. This research will investigate whether the data supports the

hypothesis to refute or confirm the belief, i.e., can hypothesis testing be used to determine whether the data provides statistical evidence to support the notion that the explanatory variable ( $x_n$ ) is related to the dependent variable (Y). One way of using hypothesis testing is when an explanatory variable has no impact on Y, we say that  $\beta_t = 0$ . With this knowledge a hypothesis test can be setup to test the null hypothesis that:

$$H_0: \beta_t = 0$$

versus the alternate hypothesis

$$H_1: \beta_t \neq 0$$

In order to conduct the hypothesis test we will compute the value of the t statistic as follows:

$$t = \frac{b_n - \beta_n}{\sqrt{\text{var}(b_n)}} = \frac{b_n - \beta_n}{se(b_n)}$$

The assumption is that  $H_0: \beta_t = 0$  is true. If the value of t is greater than the critical value ( $t_c$ ), or less than  $-t_c$  we reject  $H_0: \beta_t = 0$  in favor of the alternate hypothesis  $H_1: \beta_t \neq 0$  and conclude that there is evidence to suggest that Y depends on the explanatory variable tested. Thus the explanatory variable is a predictor of Y and should be in the model. Additional information pertinent in determining the validity and power of the model are the coefficient of determination ( $R^2$ ), the fitted values and the residuals.

Predicting the rate of change of computer processors, for example are important in estimating its obsolescence interval in order to develop proactive management decisions regarding systems designs and configuration. There are many systems in aerospace, military, medical, computer, and automotive applications that are highly dependent on computer processors and redesign and reverse engineering are usually tremendously expensive when not planning for obsolescence. A regression model will be explained in Chapter 6 that demonstrates how it can be used in obsolescence prediction.

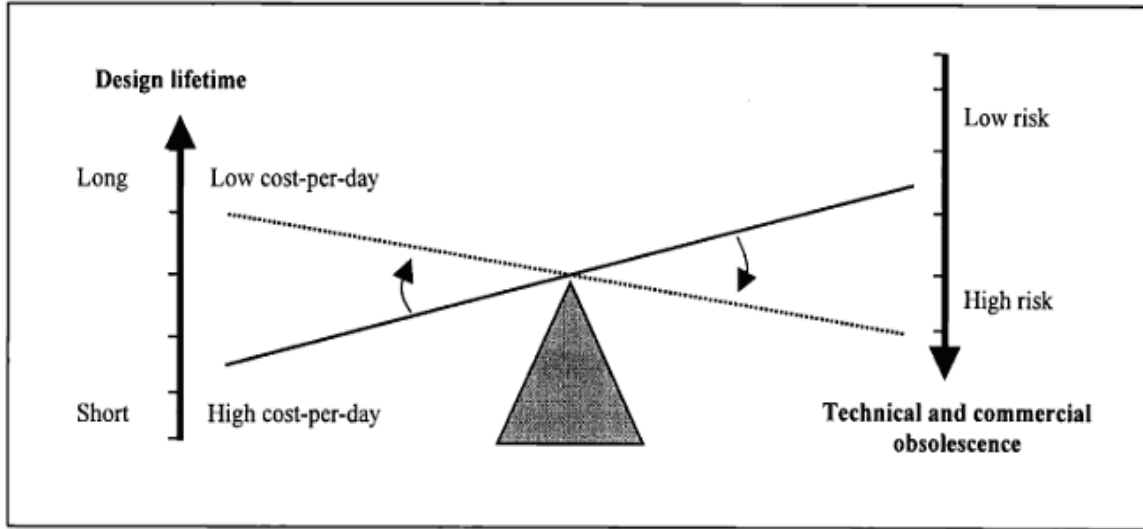
## **2.8 Design Flexibility**

Saleh [29], Lamassoure & Hastings [33] developed a framework for addressing characteristics of flexibility in systems design. A question posed by Saleh (1989) alludes to the fact that flexibility could mean many different things to different people, “*Is flexibility unambiguous – can it be separated from other concepts*”? What drives flexibility and when should it be used? How should it be used and what are the trade offs from using a flexible design from a cost, risks, and performance point of view. After the system has been fielded what are the conditions under which changes/upgrades can be made? Saleh suggests that flexibility should be built into system design. By building in flexibility it reduces the risk associated with the design and provides a mechanism for dealing with the risks of obsolescence. In the case of a spacecraft it is estimated that cost penalty of 30-40% are incurred when designing a spacecraft for 15years as opposed to 3 years [29]. Cost per operational day decreases monotonically with spacecraft design lifetime. Decision tree analysis and real options models capture the value of flexibility and a valuation process that has a focus on the customer [29].

Saleh(2002) groups the questions that managers, designers and customers should be asking about design lifetime of complex engineering systems into 3 categories namely [29]:

- 1) *What limits the design lifetime? How far can designers push the system's design lifetime? What is the design lifetime "boundary" and why can't it be extended?*
- 2) *How do the different subsystems scale with the design lifetime requirement, and what is the total system cost profile as a function of this requirement?*
- 3) *What does (or should) the customer ask the contractor to provide for a design lifetime, and why?*

The fundamental question is how does the product lifecycle requirements get decided and how are risks/tradeoffs balanced? This is certainly not an easy question to answer. On the one hand products with short lifecycles may pose more environmental concerns. On the other-hand, long lifecycles could also be problematic for the investor as the system may become technically and commercially obsolete before its end of life. Thus, risks and uncertainty based on market volatility are indeed complex issues. Saleh (2002) strongly asserts that relating component obsolescence to system's obsolescence is a huge challenge. In the case of a satellite for example, Figure 2.4 depicts the trade offs of the design lifetime scenario as a function of risk [29].



**Figure 2.4:** The design lifetime trade-offs

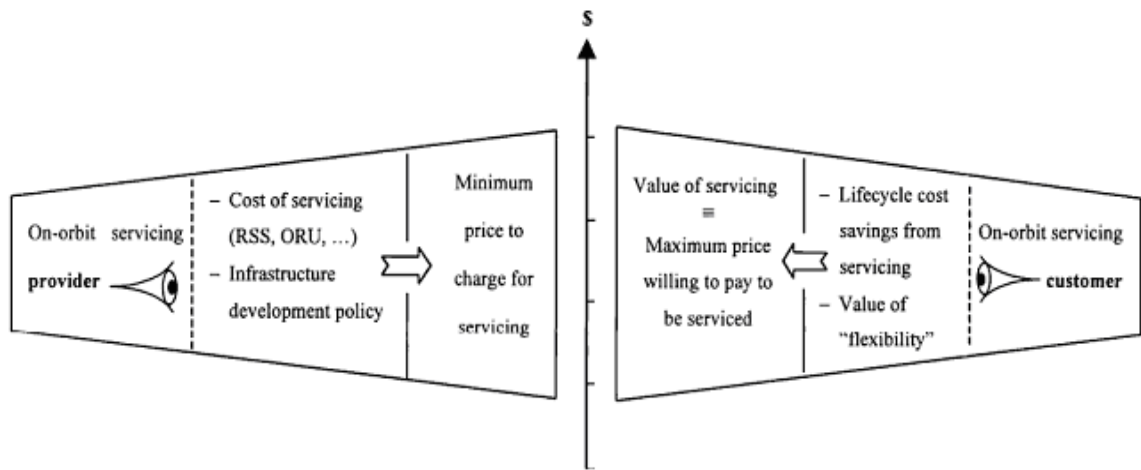
As can be seen, if the system is designed for a long lifetime, the cost-per-day to operate it is lower than if designed for a short lifetime, however the risk that the product becomes technically and commercially obsolete is high. There are countless examples of this happening throughout history and therein lies the challenge – what level of flexibility to embed to minimize the loss and increase competitive advantage in the marketplace.

## **2.9 Cost Models (The pitfalls of the traditional approaches)**

Saleh(2002) and Lamassoure(2001) assert that the traditional valuation tools such as approaches using net present value (NPV) calculations, underestimate certain key characteristics. For example, building in flexibility is a significant advantage to servicing which NPV calculations do not capture [33]. Decision Tree Analysis and Real Options calculations are better suited to more accurately capture the value of flexibility in servicing [29]. In addition the traditional approach has the providers' perspective in mind. However, more and more emphasis is going to be given to the customers'

perspective. Recently, providers are becoming more cognizant of product sustainability as contractual agreements between customers and providers are moving in the direction that favors the customer by making the provider responsible life-cycle sustainment.

Figure 2.5 demonstrates the differences in the provider versus the customers' perspective.



**Figure 2.5:** On-orbit servicing provider's perspective vs customer's perspective

The traditional approaches of standard discounted cash flows such as (NPV or IRR) do not capture the value of flexibility [33],[29], Faulkner(1996), Trigeorgis(1996). In addition, the traditional NPV approaches, "...*separate value of servicing from costs (shift from provider to customer...)*". An example of the shortcomings of the traditional NPV approach is adapted from Saleh as follow [29]:

*Assume a project has a current value  $S = \$200m$  and its value after one year is discrete but uncertain: it can either increase to  $S^+ = \$400m$  with a subjective probability  $p$ , or decrease to  $S^+ = \$100m$ . The owner of the project gives a potential buyer the option, but not the obligation, to acquire the project after one year for a price  $E = \$280m$ . What is the value of the option? In other words what price for the option will the owner and potential buyer agree upon?*

Let  $C_n$  be the discrete cash inflow and  $I_n$  be the discrete cash outflow over  $N$  periods of time, and a risk adjusted discount-rate  $k$ , the standard NPV calculation is written as follow:

$$NPV = \sum_{n=1}^N \left\{ \frac{C_n}{(1+k)^n} - \frac{I_n}{(1+k)^n} \right\}$$

In the above example the NPV of buying the project is as follows:

$$NPV = p \frac{S^+ - E}{1+k} + (1-p) \frac{S^- - E}{1+k}$$

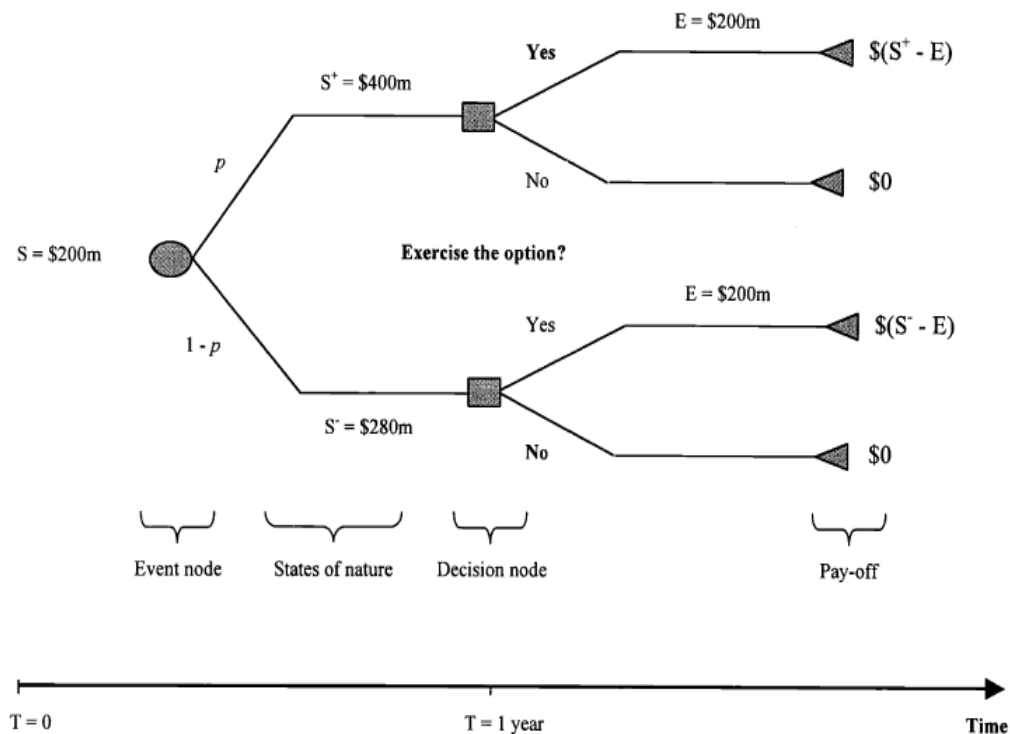
We assume  $p = 0.5$ , which means that the probability of the project value going up or down is equal. In addition, taking a risk-adjusted discount rate  $k = 20\%$ , we get:

$$NPV = -\$25m$$

From the perspective of the NPV, the project does not appear to be interesting and thus the option to acquire it is discarded. What the calculation fails to take into consideration is the flexibility of having the right, and not the obligation, of acquiring the project after one year. Next, how the decision-tree analysis differs from the NPV approach is considered.

The Decision-Tree Analysis is a more robust approach than the NPV approach as it does account for flexibility and is, “*good for dealing with complex sequential decisions, and good for dealing with uncertainty at distinct/discrete points in time*” [29].

Saleh(2001) cites Trigeorgis(1996) as asserting that the NPV approach is often misused by managers whose main focus is on the initial decision to accept or reject a project detrimental to subsequent decisions. Thus Saleh(2002) stipulates that the Decision-Tree Analysis (DTA) approach forces management to take the initial decision and interdependencies of subsequent decisions into consideration, by laying out an operational strategy. DTA starts at the end node of the tree and works backwards. The expected risk-adjusted discount NPV of this dynamic approach is calculated at each stage by multiplying the NPV in subsequent stages. Flexibility is accounted for, “...by considering only optimal decisions made at each evolution of the value of the project” [29]. The following investment example is taken from Saleh(2002) and depicted in Figure 2.6.



**Figure 2.6:** Decision Tree Example

The buyer or potential investor exercises the option, thereby acquiring the project, if the option value increases with a payoff of  $(S - E^+)$ . However, on the otherhand, if the project value decreases, the potential investor has the option of not acquiring the project and thus avoiding the loss.

Under the conditions listed above Saleh(2002) states that the value of the option is as follows:

$$V_{DTA} = p \frac{\max(S^+ - E; 0)}{1 - k} + (1 - p) \frac{\max(S^- - E; 0)}{1 + k}$$

Similar to the previous NPV calculation, we assume that the probability of the project to go up or down is equal ( $p = 0.5$ ), and lets assume the risk-adjusted discount rate to be 20% (i.e.  $k = 20\%$ ). The result is:

$$V_{DTA} = \$50m$$

This result is certainly different from the result of using the NPV approach and implies that acquiring the project is now \$50m and a lot more attractive to the potential investor. The NPV approach led to a decision to abandon the project and the DTA approach on the otherhand now says the investor should acquire the project. The main difference in the two approaches is the flexibility factor ( $V_{flexibility}$ ), where the investor has the right, but not the obligation, to acquire the project after 1 year. The value of  $V_{flexibility}$  in the two approaches outlined above is as follow:

$$V_{\text{flexibility}} = V_{\text{DTA}} - \text{NPV}$$

$$V_{\text{flexibility}} = \$50\text{m} - (-\$50\text{m}) = \$100\text{m}$$

Thus flexibility in the decision making process is significant and should not be underestimated as in the traditional NPV valuation method. In as much as the DTA is superior to the NPV in the valuation of an investors' decision, it also has its limitations.

The limitations of the DTA approach are stated by Saleh(2002) as follows [29]:

*First, it can often become an unmanageable “decision-bush analysis when actually applied in realistic settings, as the number of different paths through the tree (or bush!) expands geometrically with the number of decisions, or states considered for each variable.*

*Second, it can only account for a finite number of decision nodes, occurring at discrete decision times, following discrete variations of the unknown parameter(s). In other words, DTA cannot account for uncertain variables that are continuous.*

*Third is the problem of determining the appropriate discount rate. Using a constant discount rate presumes the risk borne per period is constant; this is obviously not the case when options are available. Flexibility (availability of options) decreases a project's exposure to uncertainty, thus alter the project's risk*

As stated above the DTA approach is an improvement upon the traditional NPV approach but falls short on the manageability, uncertainty, and discount rate. Options-Pricing Theory and Real Options Theory on the other-hand do account for flexibility and the discount rate.

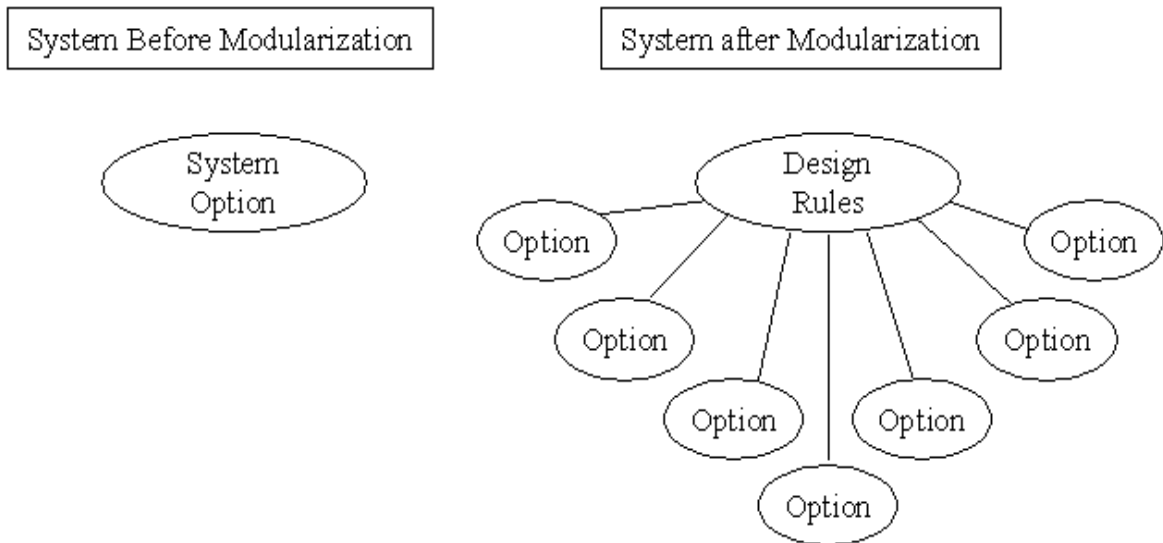
## **2.10 Real Options**

Based on the groundbreaking work published by Fischer Black and Myron Scholes in 1973, options valuations have become entrenched in the field of finance and financial engineering. An option is defined as, “...the right but not the obligation to purchase or

sell something in the future.” The product to be bought or sold can be a, “security, a contract, or even a design” [48]. The bearer of an option has the right to wait and see what the outcome will be before exercising their right. Thus if the option is favorable, the bearer gains and if the option is unfavorable the bearer has the right to walk away and thus avoids the loss. Options are mostly used in financial trading. Real options are an, “extension of financial option theory to options on real (i.e., non-financial) assets” [49] Real options have been used in a variety of engineering analysis and applications as real options are, “embedded in designs, technologies, and production processes” [49]. As an example a company may use real options to evaluate a flexible modular product design which allows the company the flexibility of changing the inputs or outputs. Thus real options are a valuable tool for the companies in valuation of design alternatives.

As technology innovation and competitive intensity are increasing rapidly in the marketplace, companies have to be able to respond to the changes quickly. Embedding flexibility into the design architecture allows companies a level of flexibility to respond to market dynamics quickly. Flexibility in the design of products can be a design that is modular where the modules operate independently of each other. A design that is interdependent and that is not modular, “*delivers one option – to take the output of the process or leave it*” [49]. On the other hand the options on a modular design have a multiplying effect. Upgrading the system in a modular approach could be changing one of the modules as opposed to an interdependent design that is vertical where the entire system needs to be redesigned. Thus modularization in system design is an opportunity to embed flexibility into a design, which could be used as a strategic advantage where risk and uncertainty abounds.

Figure 2.7 is a representation of the differences in options in a system design that is modular as well as a system that is interdependent or non-modular. It clearly depicts that a system that is non-modular only has one option as opposed to a modular design with many options dependant on the level of modularization. In a non-modular design where risk and uncertainty in the electronics industry is high, system failure could lead to catastrophic results for the company. It is like “putting all your eggs in one basket”. The modular design on the other hand is a method of hedging against future uncertainty as the models functions independently and distributes the risk across the modules. If for example, one of the modules fails or needs to be updated it can be worked on independently.



**Figure 2.7:** Options on a system before and after modularization (adopted from Baldwin and Clarke) [48].

As designs evolve, there has been “a shift from interdependency to modularity, because it changes the number, value, and location of design options, has the power to accelerate dramatically the rate of change of the system as a whole” [48]. Baldwin stipulates that the value of a design option goes up significantly with modularization when there is uncertainty associated with a design outcome. Thus companies today are strongly motivated by market dynamics and uncertainty to experiment with new modular designs. The modular design dates back to the 1960s when IBM introduced the System/360 which, “...was without question the most successful line of computers ever introduced by a single company” [48]. Computers today still use the same principles introduced by IBM in its System/360 design, but include many more modules. Embedding flexibility into a design can involve adding additional modules in a design. Adding more modules in the design increases the level of complexity and cost in the short run for the company that is uncertain of its initial benefits.

## CHAPTER 3

### OPTIONS PRICING FRAMEWORK

#### 3.1 Real Options Overview

Dealing intelligently with flexibility and uncertainty is characteristic of the real options approach. Financial investors reward companies who deal with risk and uncertainty intelligently, thus positively affecting the stock price of the company. Current management uses one of 3 tools to manage risk and uncertainty, which is depicted in Table 3.1 [82].

**Table 3.1:** Three approaches to risk

<b>Method</b>	<b>Approach to Risk</b>	<b>Instrument</b>
Capital Budgeting	Indirect	Discount Rate
Portfolio Analysis	Relative	Benchmark
Options Pricing	Direct	Probability

The first approach will discount the future potential cash flows to the present and base their decision on the outcome. Risk is dealt with indirectly and is based on the cash flows and value of the current asset and discount rate. Portfolio analysis on the other hand adds diversification to risk and allows only the projects with positive cash flows to be incorporated thereby assuming to minimize risk. Real options incorporates risk and uncertainty directly as well as flexibility into the decision making process. Volatility is not necessarily seen as an obstacle but an opportunity and thus the real options methods assign a value to volatility. Real options allow a company to hedge their risk and mitigate loses. Real option allows you to not only determine the benefits of investing in a project/new technology today, but to wait until a future point in time when it may be more lucrative. Brach states that real options, “...entail a cross-organizational exercise

*designed to lay out the options, discover the risks, and determine the range and reach of managerial flexibilities” [82].*

A financial option is a contractual agreement to execute a transaction either to buy or sell shares of stock at a specified date in the future. This obligation is neither an equity nor a debt but a contractual agreement that gives you the right to execute depending on market dynamics, without the obligation. If the stock is “*in the money*”, you execute your right and gain. If the stock is “*out of the money*” you do nothing and the option expires and thus you are no worse off minus the premium you paid for the contract. Financial options differ from real options as financial options deal with stock and real options deal with assets that are fixed and permanent. Real options consist of calls and puts, which give the firm the right, but not the obligation, to acquire and use the assets to the strategic benefit of the firm. The value of real options is that it allows a firm to, “*...integrate managerial flexibility into the valuation process and thereby assist in making the best decisions*” (Brach, 2003) [82].

Brach (2003) categorizes the option available to the firm into 6 types as depicted in table 3.2 below [82].

**Table 3.2:** The Basic Real Options

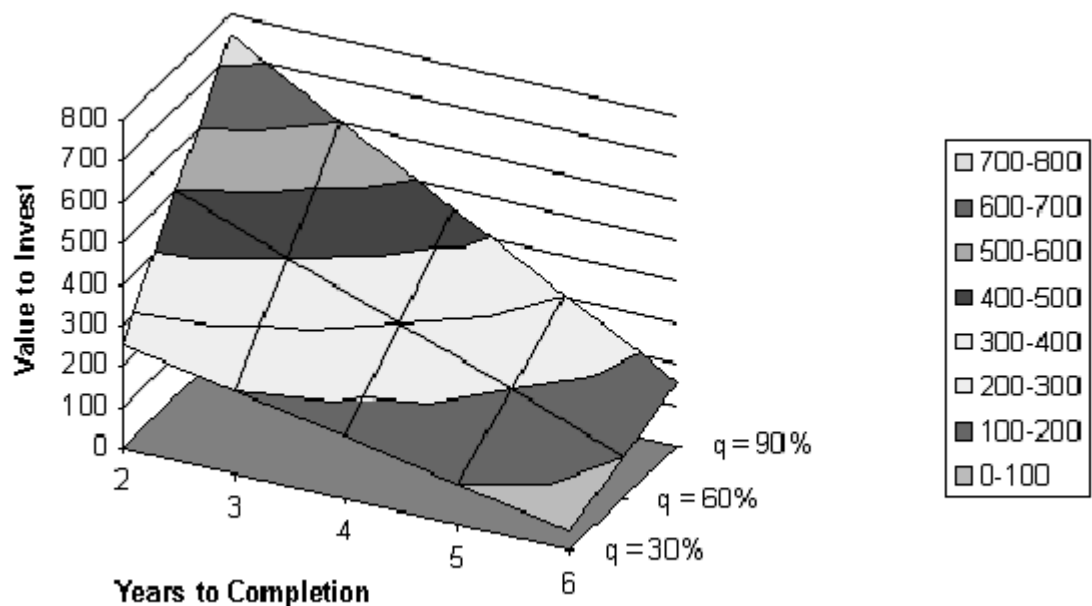
<b>The Option to Defer</b>	Wait until further information reduces market uncertainty.
<b>The Option to Abandon</b>	Dispose of an unprofitable project.
<b>The Option to Switch</b>	Change input/output parameters or <i>modus operandi</i> .
<b>The Option to Expand/Contract</b>	Alter capacity depending on market conditions
<b>The Option to Grow</b>	Entertain future-related opportunities
<b>The Option to Stage</b>	Break up investment into incremental, conditional steps.

According to Brach, the concept of real options is attractive to management, however management is often stified with how to use real options in practice and which model to incorporate as they often find it ambiguous. Management decisions often have goals and objectives to reach a financial position in the future. Achieving future goals can have many different paths. Real options allow management the flexibility of taking different paths and changing paths based on future information that becomes available. As stated before risk and uncertainty is an ever-present factor in corporations today, which is spurred by market dynamics, competitive behavior, political changes, and new discoveries. New technological discoveries often do not happen at a specified date chosen by a company, rather it occurs randomly. Thus the use of real option in the valuation process, allow the company the added flexibility of dealing intelligently with future uncertainties.

Uncertainty in the market place is a known factor that is difficult to predict. In the twentieth century we have seen many companies make colossal mistakes by not investing in the correct technology when it mattered causing their market share to decline significantly and also leading to companies going out of business completely. For example when the telephone was invented, the companies who owned a monopoly on the predecessor technology, the telegraph, predicted incorrectly that the telephone would replace their product; subsequently driving them out of business. Christensen [34] calls this phenomenon, disruptive technologies, which he attributes to the cause of the failure of great firms. Another example closer in time is that of the decision for IBM in the early 1980's to outsource its operating system and processor to Microsoft and Intel respectively. Had IBM known then what effect it would have, they most likely would

have renegotiated their contractual agreements with Microsoft and Intel and maintained ownership. As history has it Microsoft and Intel emerged as a dominant force increasing their market capitalization significantly over the past two decades. IBM on the other-hand has never reached the same level of profitability it enjoyed in the decades prior. An even more recent example is that of the digital photography industry. Polaroid who enjoyed a significant market share in the analog industry, waited much too long to adopt the digital technology, subsequently eroding a significant portion of their market share.

As an example, management of Company ABC decides that it will invest in developing a new product. Management of Company ABC decides to use real options to value the decision and determine their path of action. Let's assume that there are 3 alternative cash flows where it is estimated from market intelligence that the probability to completion of the project is 30%, 60%, and 90% respectively. Additionally, it is estimated that the future cash flows of \$1 billion will be generated from the investment decision. Figure 3.1 depicts a 3-dimensional investment decision.



**Figure 3.1:** Investment Decision

The y-axis represents the value management is willing to invest today, given the years to completion of the project (x-axis) and the probability that the project will be completed (z-axis). For example management will invest up to \$800 million today if they knew that there is a 90% probability of completing the project in 2 years. On the contrary, management may be willing to invest approximately \$250 million today if the probability of the project finishing in 2 years drops to 30%. The worse case scenario is a significant reduction in the budget to approximately \$50 million if the completion time of the project is stretched out to 6 years with a 30% chance of completion.

As the probability of completion decreases management will reduce its initial expenditure of the option to invest today. Likewise as the uncertainty in the years to completion increases the initial investment value decreases. In this way Real Options does have significant value as it accounts for flexibility and uncertainty. The project in Boston MA, known as the “big dig”, may have found significant value in the real options analysis. The real options model may have revealed some of the potential upsides and downsides before the initial implementation of the project. It is now known that the project was excessively over-budgeted and the probability to completion within the timeframe stipulated was extremely low. In the figure above it shows that if the worse case scenario is assumed, that is the project is highly risky with a maximum time to completion of 6 years, management would only be willing to invest \$50 million in the project at present.

A significant difference between financial options and real options is that financial options uses past history of stock volatility to determine the future value. Real options on

the other hand may be valuing an investment decision of a new product or asset that has no historic information. Thus new methods and hypothesis need to be developed to creatively determine future cash flow scenarios. Monte Carlo simulation can also be used to create a distribution of future prices/payoffs opportunities. The expected value computed from the simulation results increases the riskless hedge will also be explored.

### **3.2 Black-Scholes Model**

Any discussion on financial options pricing models cannot be complete without an introduction of the Black-Scholes model. Based on the groundbreaking work published by Fischer Black and Myron Scholes in 1973, options valuation has become entrenched in the field of finance and financial engineering [82]. The Black-Scholes model is the framework of options valuation as we know it today. The Black-Scholes model is built on models previously developed by Markov, Wiener, and Ito regarding stochastic processes. A stochastic process is used to describe variables whose values changes over time in uncertain ways. A Markov property is a specific type of stochastic process where predicting the future depend only on the present value of a variable. It is irrelevant how the present has emerged from the past history of the variable. With regard to stock prices, it is usually expressed as a Wiener process, which is a particular type of Markov stochastic process [83]. A Wiener process has been used in physics to describe the motion of a particle known as the Brownian motion. In a stochastic process with variable  $z(t)$ , where  $t \geq 0$ , the  $\Delta z$  is related to  $\Delta t$  by the following equation:

$$\Delta z = \varepsilon \sqrt{\Delta t} \quad \text{or} \quad dz = \varepsilon \sqrt{dt}$$

where,  $\varepsilon$  is a random normal distribution  $N(0,1)$  with mean zero and standard deviation of 1, and  $\Delta z$  is independent for any two intervals.

A generalized Wiener process for variable  $x$  can be written as follows:

$$dx = a dt + b\varepsilon_t \sqrt{dt}$$

where,  $a$  and  $b$  are constants. The above Wiener equation has an expected drift rate of  $a$  per unit time and variability  $b$ .

The Wiener process was further developed by Ito and known as the Ito process as written below:

$$dx = a(x, t)dt + b(x, t) dW_t$$

where  $x$  is stochastic and  $dW_t = \varepsilon_t \sqrt{dt}$ . The expectation  $a(x, t)$  and variance  $b(x, t)$  are functions of  $x$ , with time  $t$ .

The Black-Scholes model built on the Wiener and Ito process and was derived as follows:

$$dS_t = \mu S_t dt + \sigma S_t dW_t$$

where  $W_t$  is a Wiener process and the price  $S$ , the option is written on is assumed to follow a geometric Brownian motion with constant drift  $\mu$  and volatility  $\sigma$ .

The following characteristics are also true for the Black-Scholes model indicated in the equation above [81],

- i. *It is possible to short sell the underlying stock*
- ii. *There are no arbitrage opportunities*
- iii. *Trading in the stock is continuous*
- iv. *All securities are perfectly divisible*
- v. *It is possible to borrow and lend cash at a constant risk-free interest rate*
- vi. *The stock does not pay dividends*

Furthermore, based on the Black-Scholes formula above, the value of the European call option was derived as follow:

$$C(S,T) = SN(d_1) - Xe^{-rT}N(d_2)$$

where,

$$d_1 = \frac{\ln\left(\frac{S}{X}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}}$$

and,

$$d_2 = d_1 - \sigma\sqrt{T}$$

where,

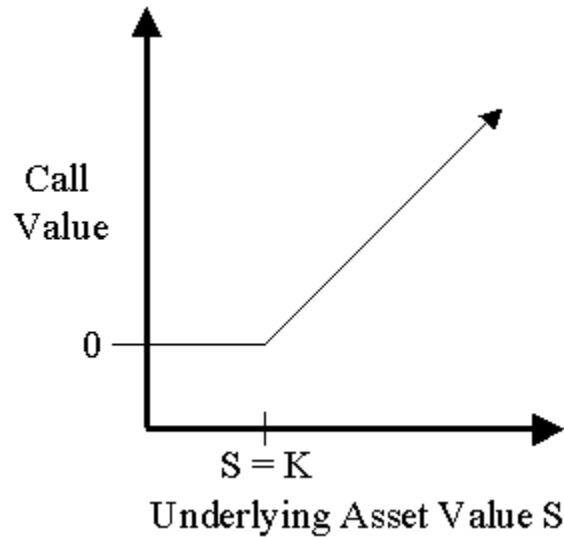
- S = current stock price
- X = strike or exercise price of the option
- T = the expected life of the option in years
- r = current continuously compounding risk-free rate
- $\sigma^2$  = the variance of the underlying security
- ln = natural logarithm
- e = the exponential function
- N(x) = standard normal cumulative distribution

The Black-Scholes model demonstrated above works well for the European style exercise, as it allows the bearer to execute their decision only at the time of maturity. In addition there are other underlying assumptions in the Black-Scholes model. Namely, that (1) returns are log-normally distributed, (2) trading of the securities are continuous, (3) unlimited number of markets to trade with (4) volatility remains static over time. The returns on Real options, however, tend to be exponential. In addition, upward or downward jumps between transactions are encountered at certain instances in time. Thus, the Black-Scholes model is not the best valuation method when it comes to valuing real options on real assets.

We will thus consider the extension of the Black-Scholes model, including the binomial and trinomial model as it captures the American style exercise more accurately. Real options are of significant importance to the valuation of the alternative designs as it allows the decision maker/investor a more robust understanding of the value of the options embedded in the design. The binomial, trinomial, and sensitivities (Greeks) methods will be explored in this dissertation to determine its effectiveness.

### **3.3 Call Options**

Options can either be a call option or a put option. A call option gives the bearer the right, but not the obligation, to buy an underlying asset in the future at a predetermined price. The European call option can only be executed on the day that was specified and not before then. The American call option can be executed on or before the day specified. Figure 3.2 shows the payoff for the call option where the y-axis is the value of the call and the x-axis is the value of the asset.



**Figure 3.2:** Payoff from a Call Option

The payoff for the call option can be written in mathematical terms as follows:

$$C = \text{Max} [0, S-K]$$

where S is the stock value and K is the strike price. The strike price K is the price at which the bearer can buy the call option. As the asset price increases, the value of the call increases and the transaction is “in the money”. As the strike price approaches the asset value the value of the call decreases and if the strike price is equal to the call price, the value of the call remain zero and said to be “at the money.” When the asset value decreases to below the strike price, the bearer walks away and the value remains zero.

A simple example of valuing a Black-Scholes’s European Call Option with the following values shown in Table 3.3 is calculated.

**Table 3.3:** Example of Call Option Valuation

Variable	Real Option	Value
S	Present Value of Asset	1000
X	Cost of acquiring asset	800
r	Risk-free rate	0.05
T	Length of time option available	5
$\sigma$	Asset risk	0.3

In order to compute the cumulative normal distribution, the approximation is used as follows:

$$d_1 = \frac{\ln\left(\frac{1000}{800}\right) + \left(0.05 + \frac{0.3^2}{2}\right)5}{0.3\sqrt{5}} = \frac{\ln(1.25) + 0.4750}{0.6708} = \frac{0.2231 + 0.4750}{0.6708} = 1.0407$$

$$d_2 = d_1 - \sigma\sqrt{T} = 1.0407 - 0.3\sqrt{5} = 1.0407 - 0.6708 = 0.3699$$

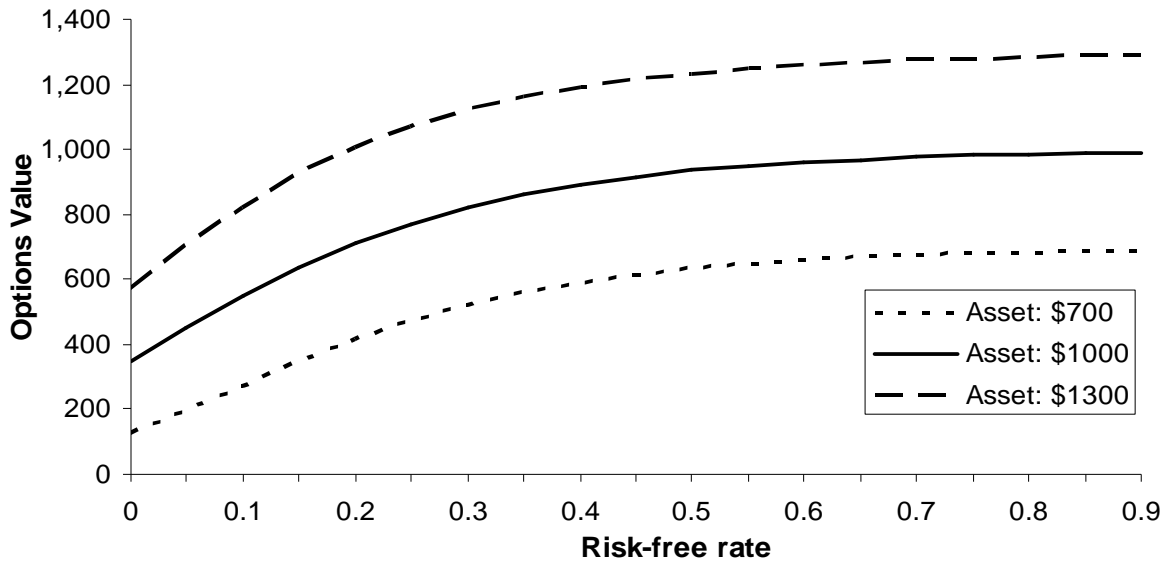
$$N(d_1) = N(1.0407) = 0.8510$$

$$N(d_2) = N(0.3699) = 0.6443$$

$$\text{Value of the Call Option} = 1000(0.8510) - 800e^{-0.05(5)}(0.6443) = \underline{\underline{\$449.59}}$$

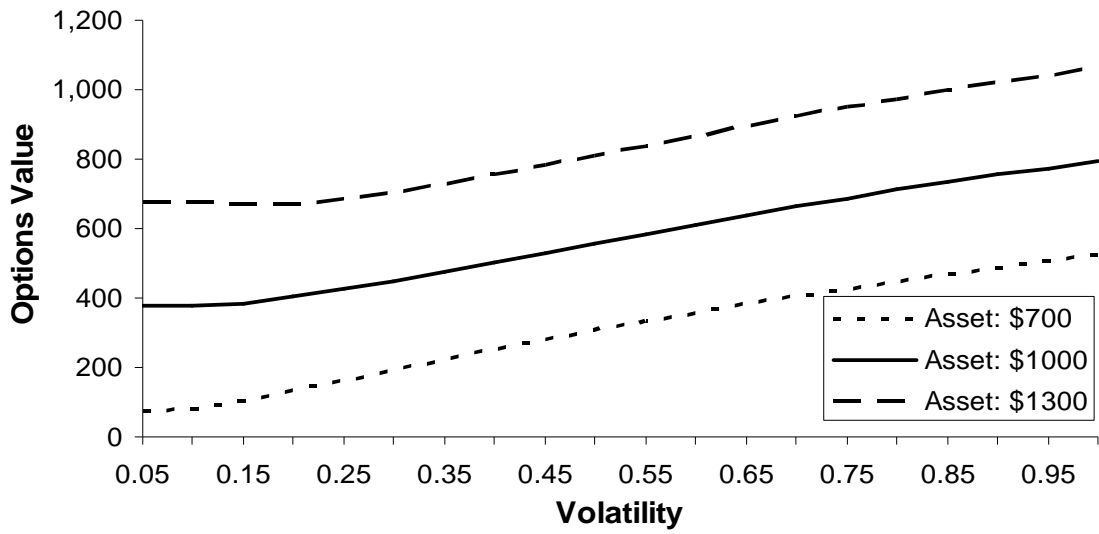
The holder of the option can immediately exercise it for a gain of \$200, by paying \$800 to exercise it and receive a share worth \$1000. The option in this case will trade in the marketplace for \$449.59. The option may be worth more than \$1000 before it expires in 5 years. The call option is sensitive to the risk-free rate and volatility, thus a simulation was performed in excel to show the sensitivity of the options value as a function of the risk-free rate. Figure 3.3 depicts the changes in the options value as a function of the

risk-free rate. As can be seen the simulation was performed for three values of the asset and shows that the options value increases steadily until the risk-free rate approaches 30% and then levels off and remains constant.



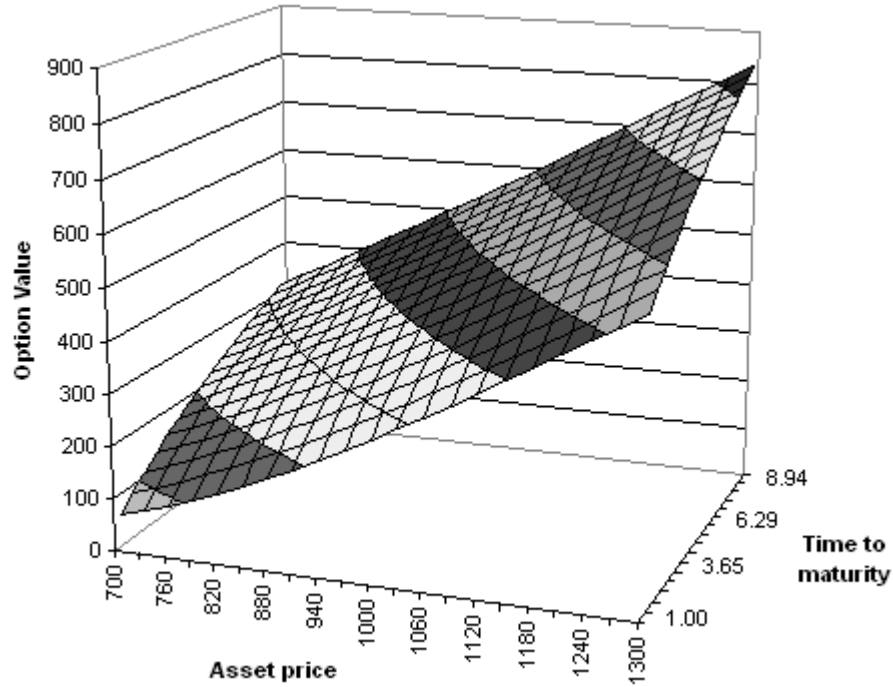
**Figure 3.3:** Call Option Value as a function of the Risk-free rate

Volatility also affects the value of the option. Figure 3.4 depicts the options value as a function of volatility.



**Figure 3.4:** Call Option Value as a function of Volatility

Notice that the options value increases with higher volatility. In addition to the interest rate and volatility, the price of the asset is in constant flux. It moves up and down over time as determined by the market. Thus Figure 3.5 depicts the changes for the above example over time.



**Figure 3.5:** Change in Asset Price over time

It is also important to have an idea of the sensitivities or (Greeks) as it is known to determine the impact of small changes of a parameter on the options value. The options sensitivities are found by taking the partial derivatives of the Black-Scholes model which then allows one to see the impact that small changes of a parameter under study have on the value of the option. The sensitivities to be explored in this dissertation are the delta, gamma, and theta sensitivities.

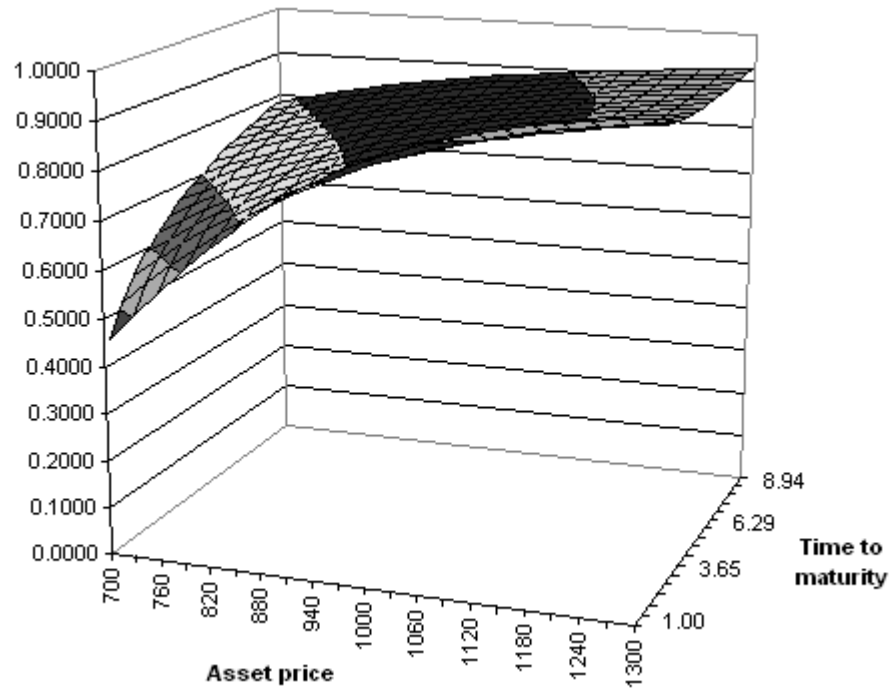
Delta is defined as, “*the option’s sensitivity to small changes in the underlying asset price*” [85]. The formula for the delta Call option is written as follows:

Delta Call Option:

$$\Delta_{call} = \frac{\partial c}{\partial S} = e^{(b-r)T} N(d_1) > 0$$

$$\Delta_{call} = e^0(0.851) = 0.851$$

Thus the value of delta is 0.851 or 85.1%. This means that the call value will increase or decrease with every 0.851 dollars increase in the asset value. Figure 3.6 shows the delta sensitivity for the above example. As  $N(d_1)$  approaches 1 it means that the call option is getting deeper in-the-money, thus favorable.



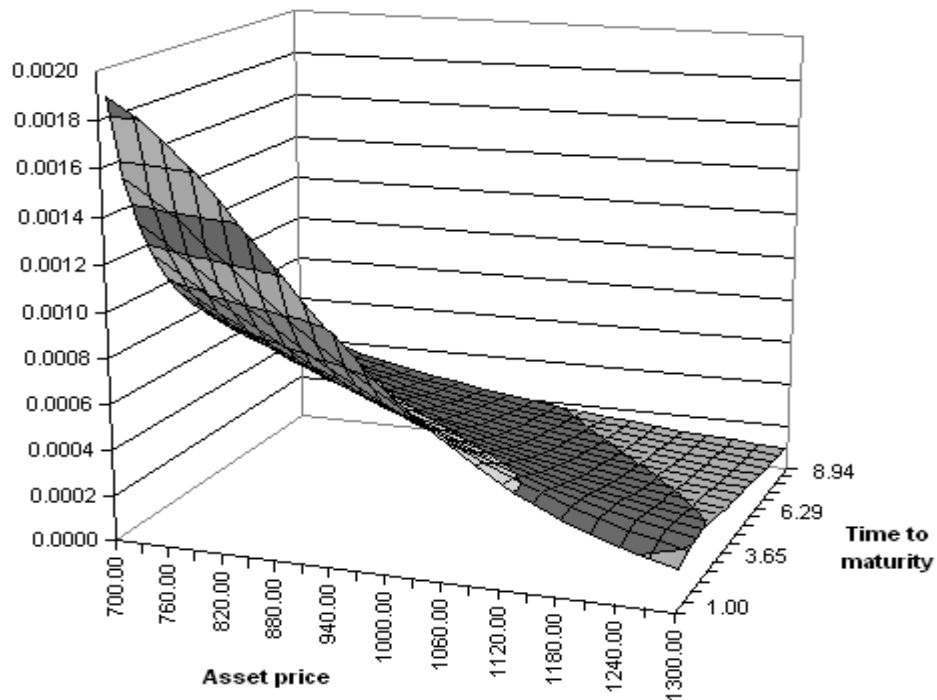
**Figure 3.6:** Sensitivity of Delta

The Gamma sensitivity is defined as, “...the delta’s sensitivity to small changes in the underlying asset price” [85]. The gamma sensitivity formula for the call option is written as follows:

Gamma Call Option:

$$\Gamma_{call} = \frac{\partial^2 c}{\partial S^2} = \frac{\partial^2 p}{\partial S^2} = \frac{n(d_1)e^{(b-r)T}}{S\sigma\sqrt{T}} > 0$$

Figure 3.7 shows the values of gamma for different times to maturity and various asset prices. This gives an indication of the risk and what the investor is willing to allow.



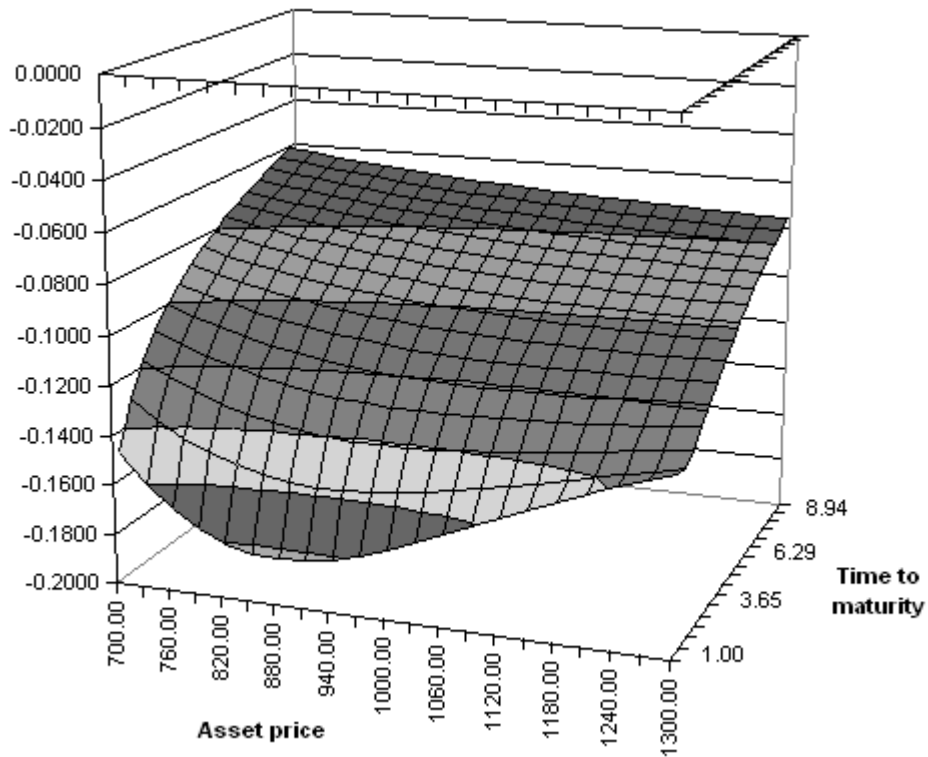
**Figure 3.7:** Sensitivity of Gamma

In addition to the above sensitivities we would also like to explore the Theta sensitivity for purposes of the decision making process. Theta is, “...the option’s sensitivity to small changes in time to maturity” [85]. The mathematical formula of the Theta Call option is as follow:

Theta Call Option:

$$\Theta_{call} = -\frac{\partial c}{\partial T} = -\frac{Se^{(b-r)T} n(d_1)\sigma}{2\sqrt{T}} - (b-r)Se^{(b-r)T} N(d_1) - rXe^{-rT} N(d_2) \leq 0$$

Figure 3.8 shows the Theta sensitivity for the above example.

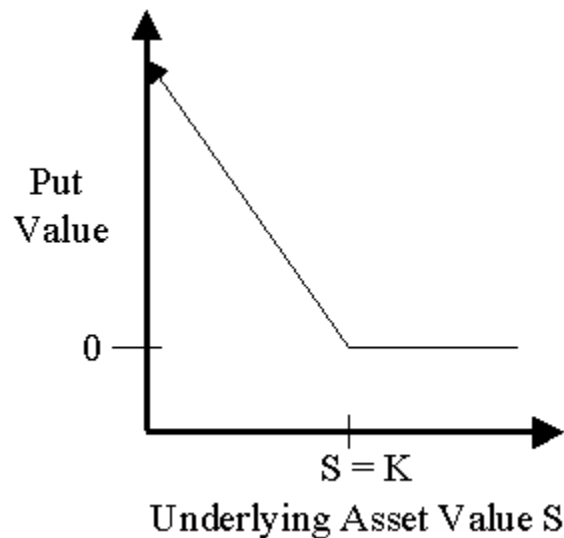


**Figure 3.8:** Sensitivity of Theta

Based on the calculations and sensitivities, the investor is in a better position to make an informed decision about the direction of their investment.

### 3.4 Put Options

As previously mentioned, the option can be a call option or a put option. The put option gives the bearer the right, but not the obligation, to sell the underlying asset in the future at a predetermined price. The combination of the 2 allows the investor to create a hedging opportunity. Similar to the European call, the bearer can only execute it on the day that was specified and not before then. In this case it is to sell not buy. On the contrary, the American put option can be executed on or before the day specified. Figure 3.9 shows the payoff for the put option.



**Figure 3.9:** Payoff from a Put Option

The payoff for the put option can be written in mathematical terms as follows:

$$P = \text{Max} [0, K-S]$$

As can be seen from the diagram, a drop in the asset value increases the payoff for the put bearer. Similar to that of the call, if the asset value and the strike price are equal

at or before exercise, the value of the put is zero. If the asset value drops to below the value of the strike price, the bearer allows the option to expire and the value remains zero. The cost associated with purchasing the call or put option, the premium, has not been factored into the calculation.

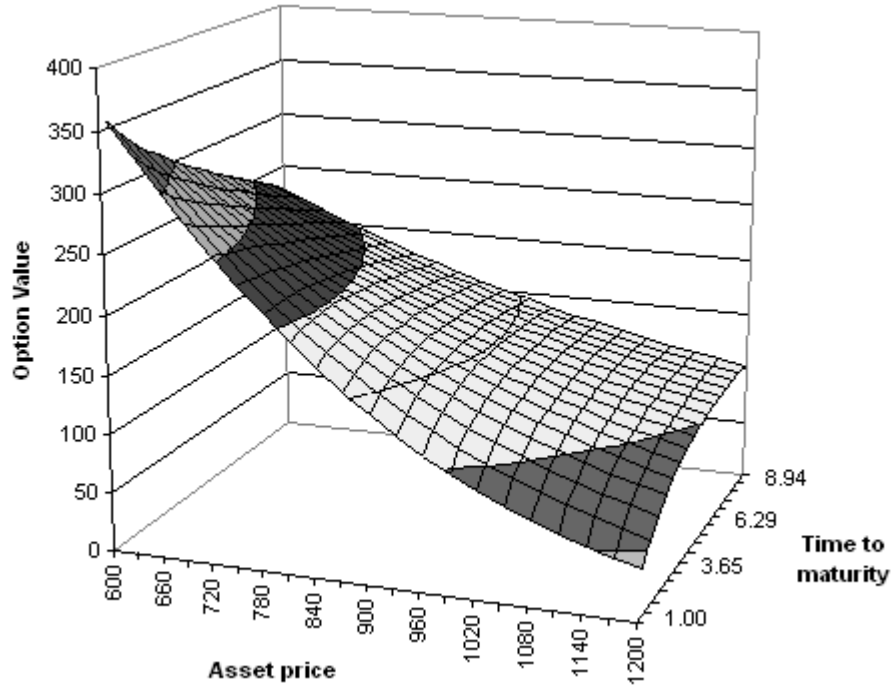
An example of valuing a Black-Scholes's European Put Option with the following values depicted in Table 3.4 is calculated.

**Table 3.4:** Example of Put Option Valuation

<b>Variable</b>	<b>Real Option</b>	<b>Value</b>
S	Present Value of Asset	800
X	Exercise Price	1000
r	Risk-free rate	0.05
T	Length of time option available	5
□	Asset risk	0.3

The value of the Put Option = **\$196.92**

Figure 3.10 depicts the value of the option as a function of asset price and time to maturity. As can be seen from the figure the value of the option decreases as the asset price increases.



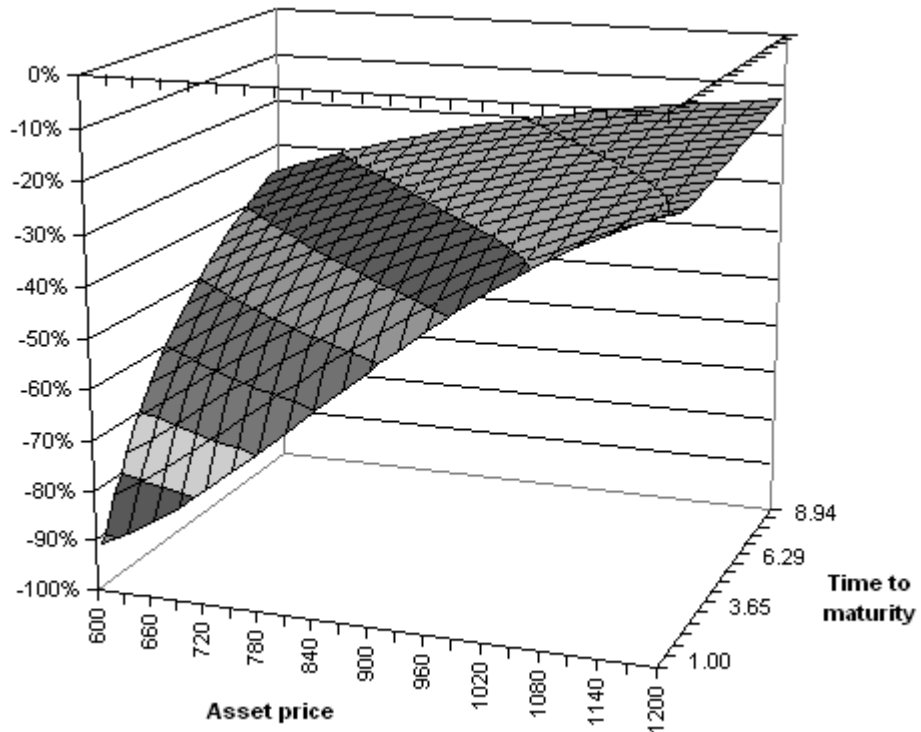
**Figure 3.10:** Change in Asset Price over time

The sensitivities on delta, gamma, and theta are also shown for the put option as defined in the section above.

Delta Put Option:

$$\Delta_{put} = \frac{\partial p}{\partial S} = e^{(b-r)T} [N(d_1) - 1] < 0$$

The delta sensitivity is depicted in Figure 3.11.

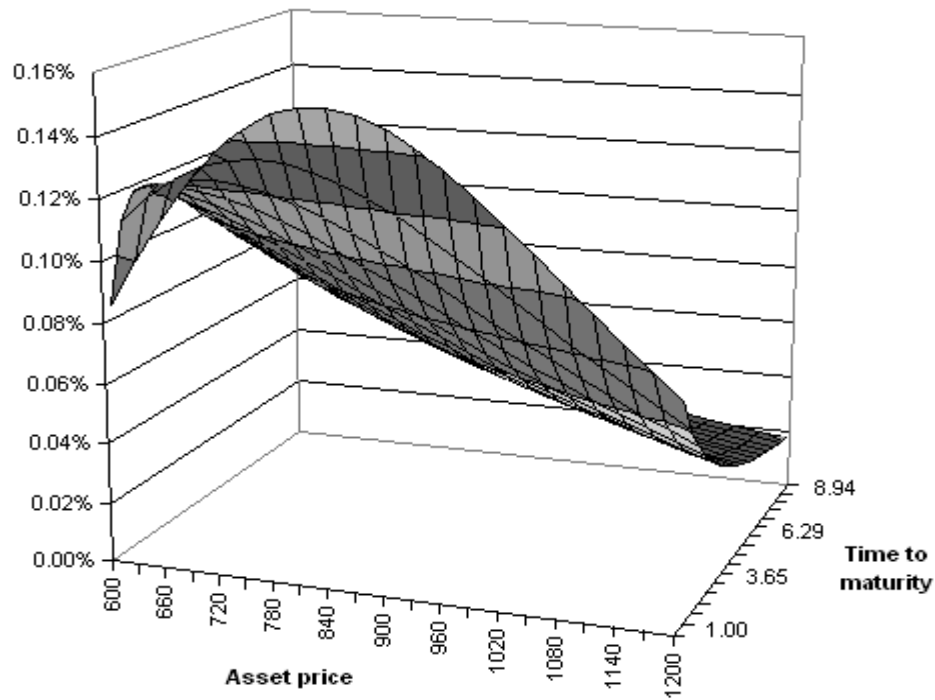


**Figure 3.11:** Delta Sensitivity

The calculation of Gamma is the same is in the case of the call option and written as follows:

$$\Gamma_{put} = \frac{\partial^2 c}{\partial S^2} = \frac{\partial^2 p}{\partial S^2} = \frac{n(d_1)e^{(b-r)T}}{S\sigma\sqrt{T}} > 0$$

Gamma sensitivities are depicted in figure 3.12 below.

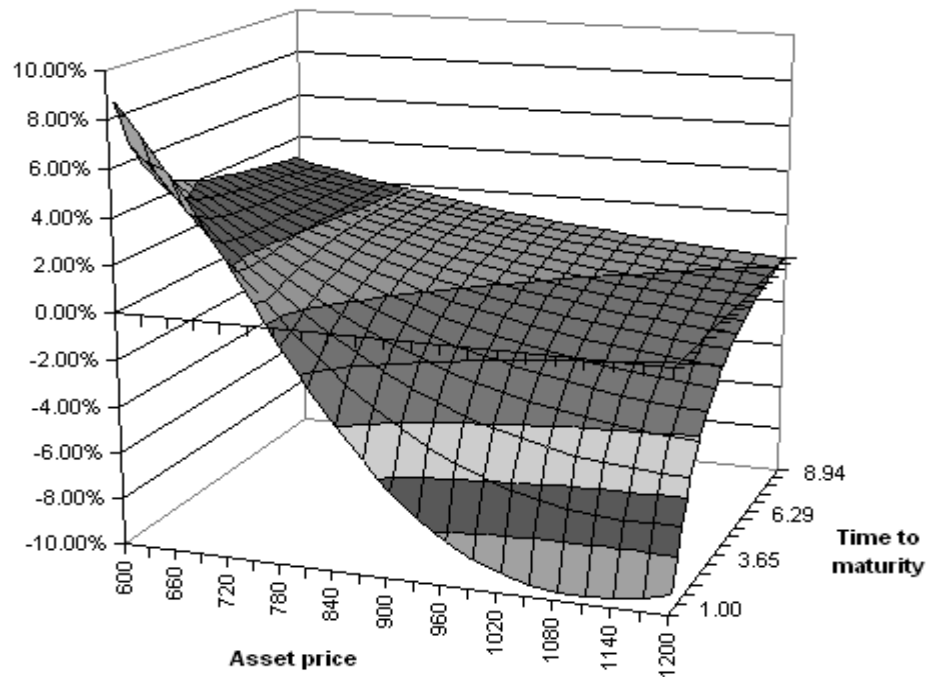


**Figure 3.12:** Gamma Sensitivity

Theta for a call option is expressed mathematically as follow:

$$\Theta_{call} = -\frac{\partial c}{\partial T} = -\frac{Se^{(b-r)T} n(d_1)\sigma}{2\sqrt{T}} + (b-r)Se^{(b-r)T} N(-d_1) + rXe^{-rT} N(-d_2) \leq 0$$

The range of values of theta is shown in Figure 3.13 below.



**Figure 3.13:** Theta Sensitivity

The investor's decision on the direction of the project will be a well informed decision, based on the stream of cash flows and sensitivities.

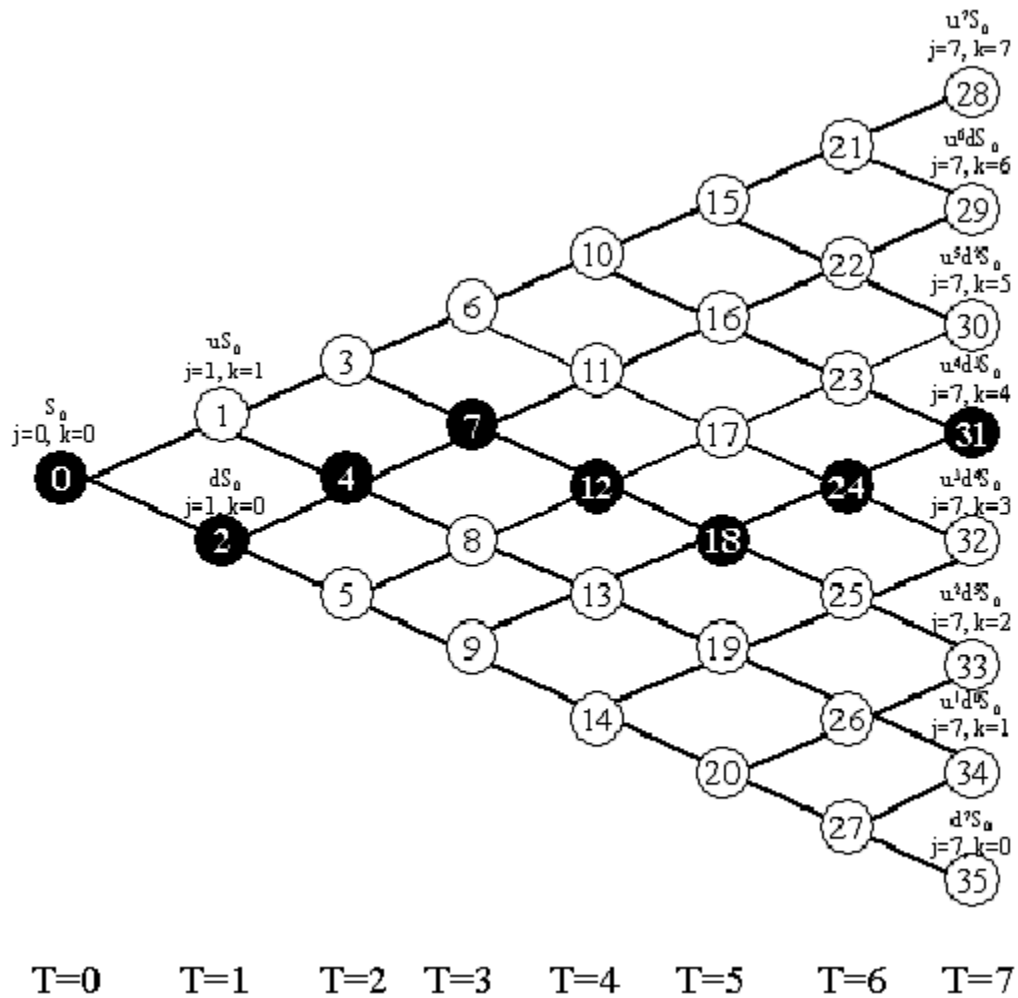
### 3.5 Binomial Model

The **binomial model** developed by Cox-Ross and Rubinstein in 1979 is a method that allows the option to be exercised at different points in time before the option expires or on the expiration day. Thus the binomial model has multiple decision points and has the advantage of allowing the volatility to change over time. The binomial options pricing model allows an investor or company to make strategic decisions which include that of adopting a new technology today or to defer until a later date in anticipation of a newer technology being released. Thus many decision points in a binomial model is

possible. One advantage of the binomial model is that it has many paths and can change direction when future information becomes available.

Let's assume that a company can take one of the two actions. The first option is that the company can adopt the newer technology today; however they would have to forgo the option of any revisions for the next three years. Secondly, it can defer its adoption today of the new technology until the release of a more advanced technology in the future. Their decision may lead to an upside (in-the-money) or a downside (out-of-the-money) situation if an incorrect decision is made. Additionally, a viable option for the company may be to invest in research and learning today. The company thus gains an additional option, "...*that of making the discovery itself.*" [82].

Figure 3.14 depicts a 7 period binomial lattice where T represents the time steps. As can be seen, there are many different paths from ending node to starting node that can be traversed. From any node the movement can only be one of two options, upward or downward.



**Figure 3.14:** The Binomial Lattice

For example at  $T = 0$ , node 0, the movement of  $S_0$  can be upward or downward. The upward movement happens with probability  $p$  to node 1 taking on a value  $uS_0$  or downward to node 2 with value  $dS_0$ . If the one time step is denoted by  $\Delta T$ , it follows that

$$u = e^{\sigma\sqrt{\Delta T}}$$

and,

$$d = \frac{1}{u} = e^{-\sigma\sqrt{\Delta T}}$$

Furthermore, it follows that the risk-free probability

$$p = \frac{er\Delta T - d}{u - d}$$

where  $r$  is the risk-free interest rate

The value of the future stock is dependent on the path that is traversed. The price of the stock is calculated at each node. The asset value at each node in the lattice can be denoted as follows

$$S_j = u^k d^{j-k}(S_0)$$

where  $(k = 0, 1, 2, \dots, j)$

For example the asset price at node 31 in the figure below is  $S_7 = u^7 d^3(S_0)$

The probability that the stock will move upward or downward is generally calculated from historic information for financial options valuation where past history is available. In the case of the real option, the probability of an upward or downward movement may combine estimation and market intelligence. The nodes are discrete intervals. One possible path is highlighted in the figure. From node 0 the movement is downward to node 2 then upward to nodes 4 and 7 respectively until node 31 is reached. At any of the nodes there are only 2 possible movements, upward or downwards. For example, if you

are at node 4, only nodes 7 or 8 are attainable. Nodes 6 and 9 in the time period cannot be reached and thus this mimics the Markov property that the jump to the current node is dependent only on the previous state and nothing before.

The number of nodes in a binomial tree where the first time step is 0, is  $\frac{(n+1)(n+2)}{2}$

In the lattice depicted above the number of nodes is  $\frac{(7+1)(7+2)}{2} = 36$

The number of possible paths leading to node (j, k) is given by  $\frac{j!}{k!(j-k)!}$

In the figure depicted node 31 will have  $\frac{7!}{4!(7-4)!} = \frac{5040}{144} = 35$  possible paths

On the other hand node 28 will have  $\frac{7!}{7!(7-7)!} = \frac{5040}{5040} = 1$  possible path

It follows that with a 7-time step model there are  $2^7 = 128$  possible terminal stock price paths in the model to evaluate. As the time steps are increased the number of possible paths increases exponentially. Consider for example a 20 and 30 time step model. The number of possible paths will be  $2^{20}$  about 1 million and  $2^{30}$  about 1 billion respectively.

The probability of reaching a node (j, k) is as follows

$$\frac{j!}{k!(j-k)!} p^k (1-p)^{j-k}$$

Thus the probability of reaching node 31 and 28 respectively if p is 0.5 is as follows

$$\text{Node 31: } \frac{j!}{k!(j-k)!} p^k (1-p)^{j-k} = 35(0.5^4) * 0.5^3 = (35)(0.0625)(0.125) = 0.2734$$

$$\text{Node 28: } \frac{j!}{k!(j-k)!} p^k (1-p)^{j-k} = 35(0.5^7) * 0.5^0 = (1)(0.0078)(1) = 0.0078$$

The options value can be computed for all the nodes in a binomial lattice, with reasonable assumptions. Management can thus use the options available to make strategic decisions that value risk and uncertainty. A numeric example is described in the next chapter.

## CHAPTER 4

### BINOMIAL MODEL NUMERICAL EXAMPLE AND RESULTS

#### 4.1 Introduction

This chapter presents a numerical example and results of an American Call Option utilizing the binomial model. Let's assume that there are 5 lattice steps in this example, which represents 1 year increments. The lattice steps indicate the various nodes or stages the project is in. As an example node one may represent the conceptual design phase and node 5 the production phase. The binomial approach allows for 2 possible outcomes at the end of each stage, an upward jump to a higher option value or a downward jump to a lower option value. The benefit of using the binomial approach is that the company doesn't need to exercise all their options at once and can wait until a future point when more information is available. In addition the company also has the option to abandon the project or change direction depending on future requirements and technological advancements. Thus, as information becomes available the company is in a better position to make decisions on the direction that the project will take.

#### 4.2 Numerical Example

As an example, we present a numeric example of an options pricing model. Table 4.1 below depicts the parameters and values of the baseline model.

**Table 4.1:** Values of Baseline Model

<b>Variable</b>	<b>Value</b>
Asset Value (\$)	\$100 million
Implementation Cost (\$)	\$80 million
Maturity (Years)	5
Risk-free Rate (%)	5%
Dividends (%)	0
Volatility (%)	20%
Lattice Steps	5
Stepping-Time (dt)	1
Up Step-Size (up)	1.2214
Down Step-Size (down)	0.8187
Risk-neutral Probability (prob)	57.75%

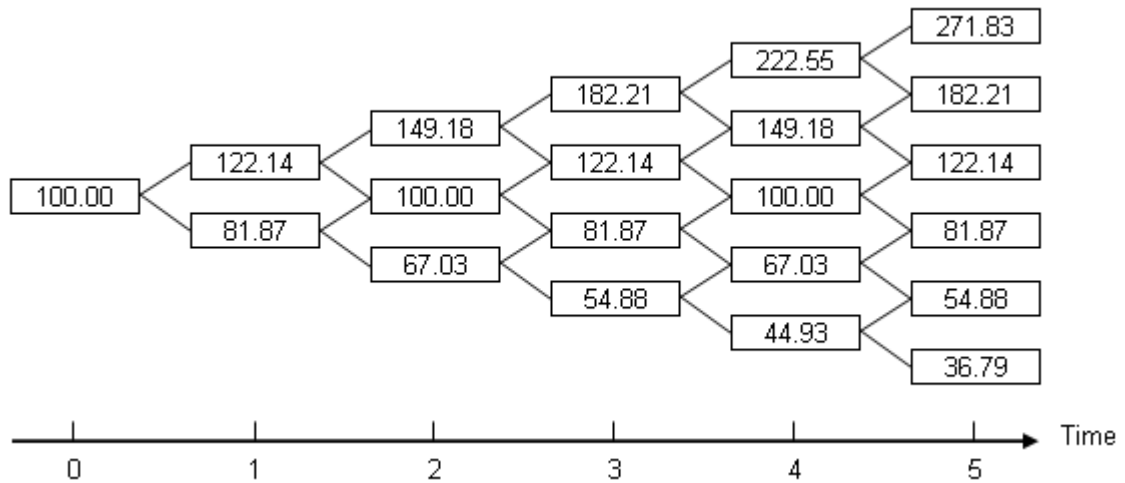
As shown in Table 4.1, we assume that the value of the asset is \$100 million. We also assume that it costs the company \$80 million in implementation cost. The implementation cost includes labor and conversion, raw material costs, overhead, inventory, and variable costs. Let's assume that the risk-free rate is 5% and that volatility is 20% in the baseline model. The upward step-size is calculated based on the formula in the previous chapter where  $u = e^{\sigma\sqrt{\Delta T}} = 1.2214$ . In the same way the downward step-size is calculated as follows

$$d = \frac{1}{u} = e^{-\sigma\sqrt{\Delta T}} = 0.8187$$

Furthermore, it follows that the risk-free probability is then

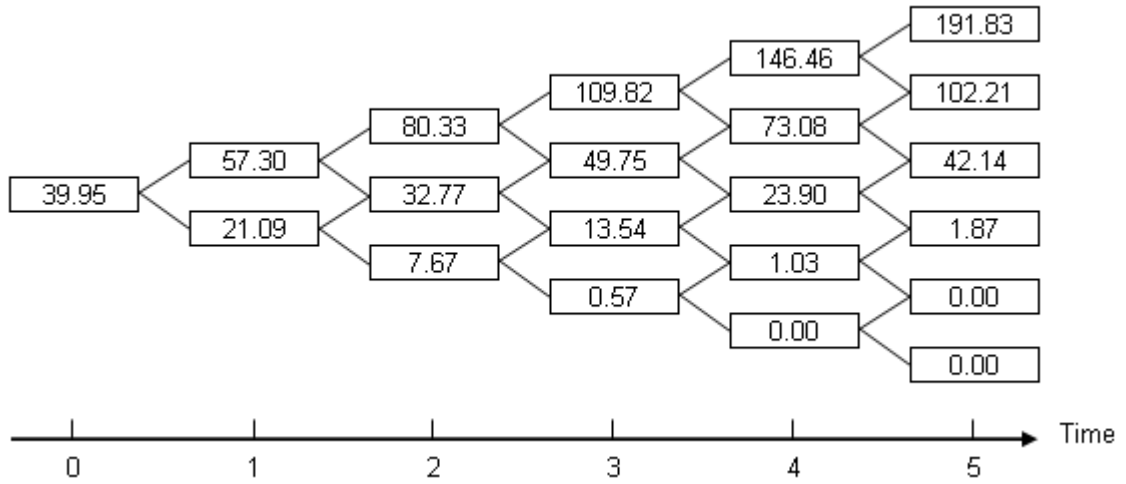
$$p = \frac{er\Delta T - d}{u - d} = 0.5775, \text{ where } r = 5\%$$

The results of the underlying asset lattice is then computed and depicted in Figure 4.1 below where the horizontal axis are the lattice steps in years and every node has an upward and downward jump until year 5.



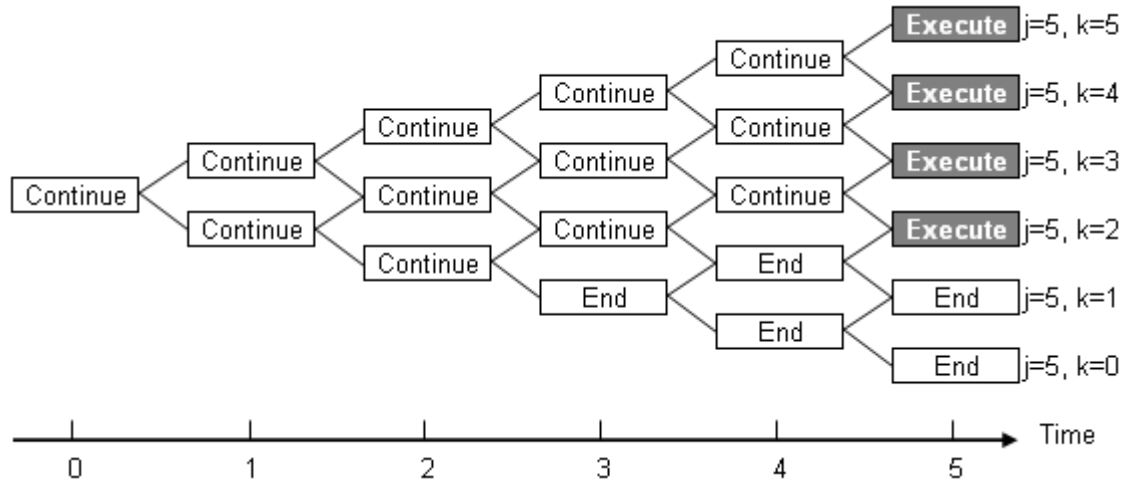
**Figure 4.1:** Underlying Asset Lattice

We now determine the value of the option in order to determine whether it is a good investment and the path to follow. We start at the end of the tree and work backwards. As an example let's examine the end node with value of 36.79 in time period 5. Since we are using an America Call Option to value this investment, recall that the call option is represented by the formula;  $\max [0, X-S]$ , where  $X$  is the asset value and  $S$  the implementation cost in this case. Thus  $\$36.79 \text{ mil} - \$80 \text{ million} = -\$43.21 \text{ million}$ . Hence,  $\max[0, -\$43.21 \text{ million}] = 0$  and the option is non-optimal and not considered. Likewise, node with value  $\$271.83$  in time period 5 is calculated at  $\$191.83 \text{ million}$ . In this way the option value lattice is completed and depicted in Figure 4.2 below.



**Figure 4.2:** Option Value Lattice

The call option value of this project is positive and valued at \$39.95 million and thus viewed favorably by the investors. The decision lattice is represented in Figure 4.3.



**Figure 4.3:** Decision Lattice

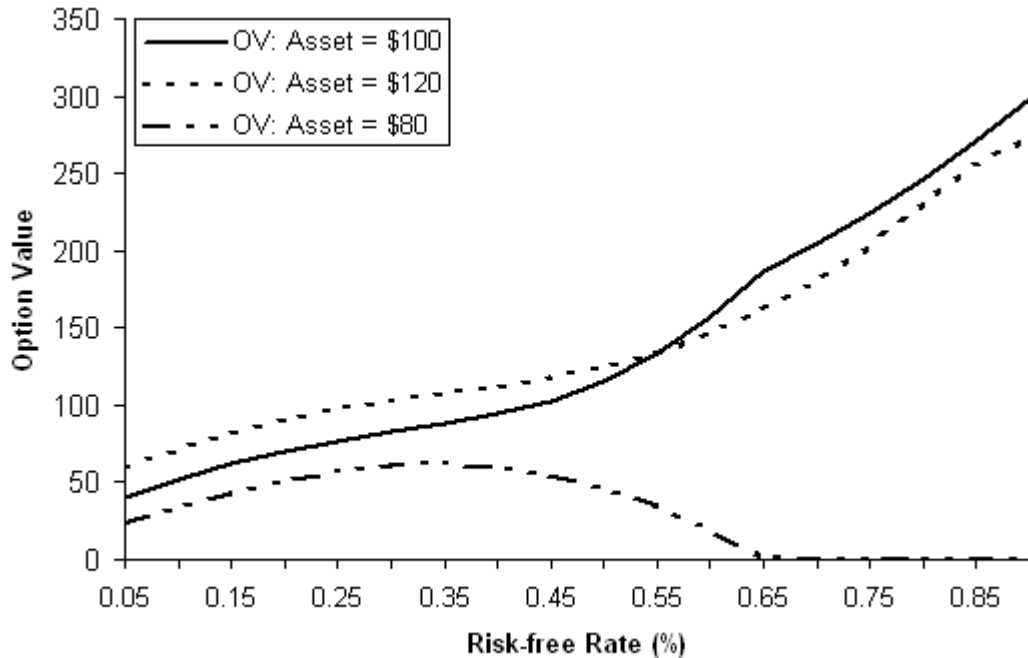
As can be seen there are several paths that are favorable and a few that are not favorable. The final decision shows that paths with terminal nodes  $j=5$  and  $k=2,3,4$ , and  $5$  is in-the-

money and thus favorable. The number of possible paths that can be traversed is calculated as follow:

$$\frac{5!}{5!(5-5)!} + \frac{5!}{4!(5-4)!} + \frac{5!}{3!(5-3)!} + \frac{5!}{2!(5-2)!} = 26 \text{ paths}$$

There are 19 paths that can be traversed with a positive outcome. Thus the investor now has several options available to her.

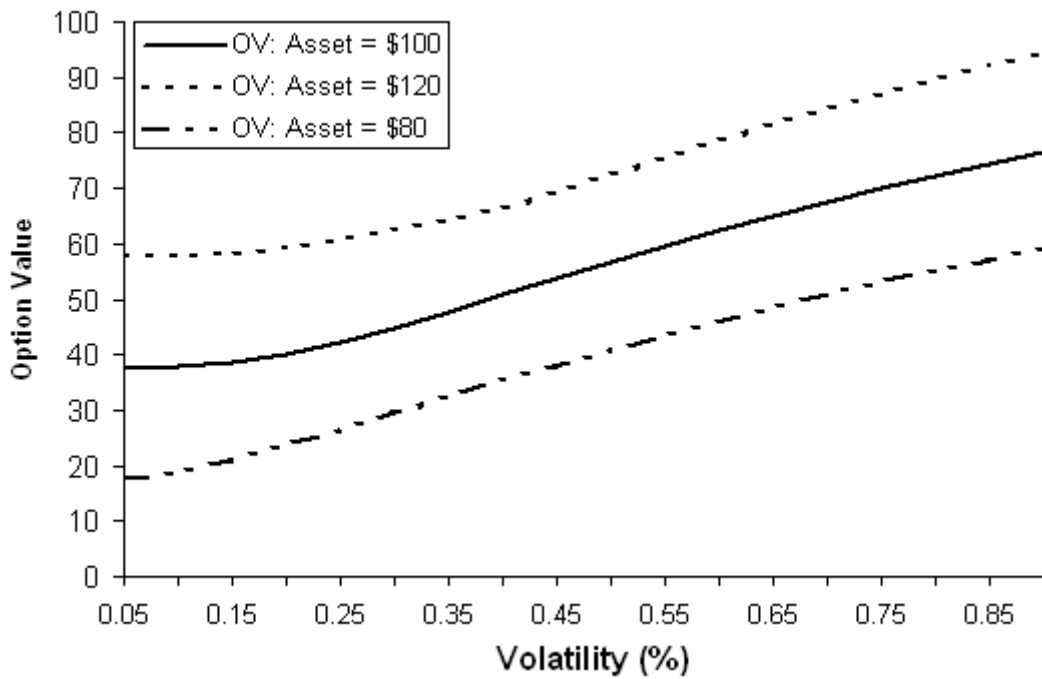
At this point the baseline calculation consisted of a static risk-free interest rate and market volatility. Since the options value is sensitive to the interest rate and volatility we perform simulations to compute the impact of small changes in those rates. Figure 4.4 represents the options value as a function of the risk-free rate for 3 asset values, where \$100 million is represented in the base model.



**Figure 4.4:** Option Value as a function of the Risk-free Rate for 3 Assets

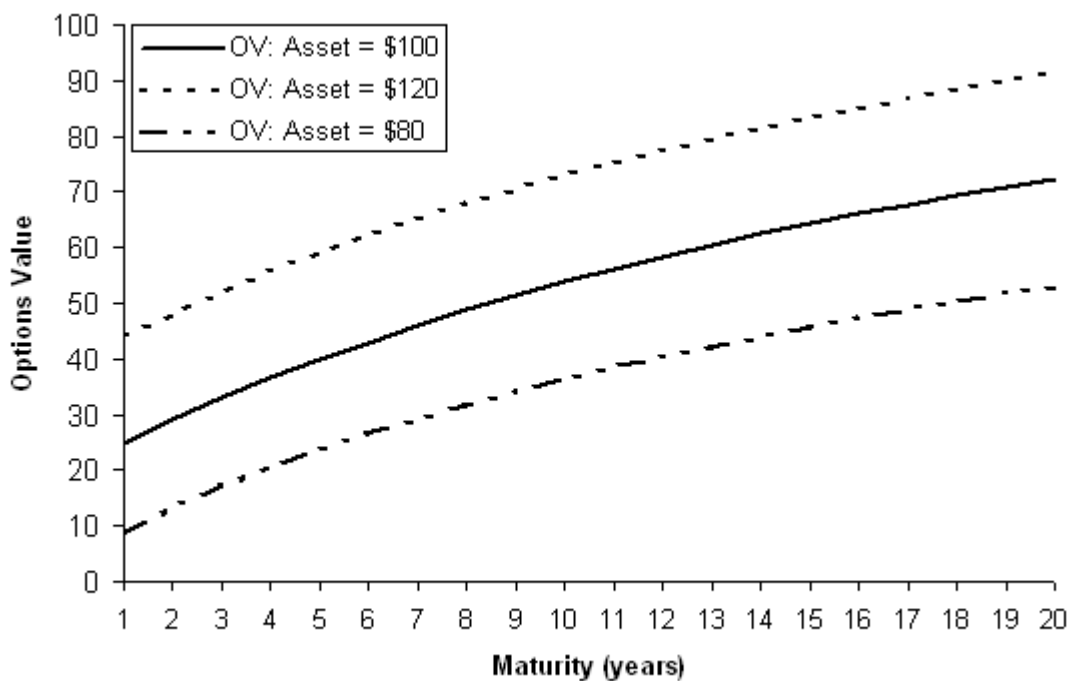
As can be seen the value of the option increased as the risk-free rate increases for the baseline asset (\$100 million). For a higher asset value (\$120 million) the value of the option increases as the risk-free rate increases. It is an interesting observation to note however, that the options value for a higher asset (\$120 million) is lower than that of the (\$100 million) asset as the risk-free rate approaches 60%. On the other hand, as the value of the asset decreases to \$80 million, the option value firstly increases as the risk-free rate increases until approximately 35%. It starts declining after 35% and continues to decline and approaches zero at 65% risk-free rate.

The options value is also sensitive to volatility. As can be seen in Figure 4.5, the options value increases for higher degrees of volatility in all 3 cases. Thus, higher volatility is favorable.



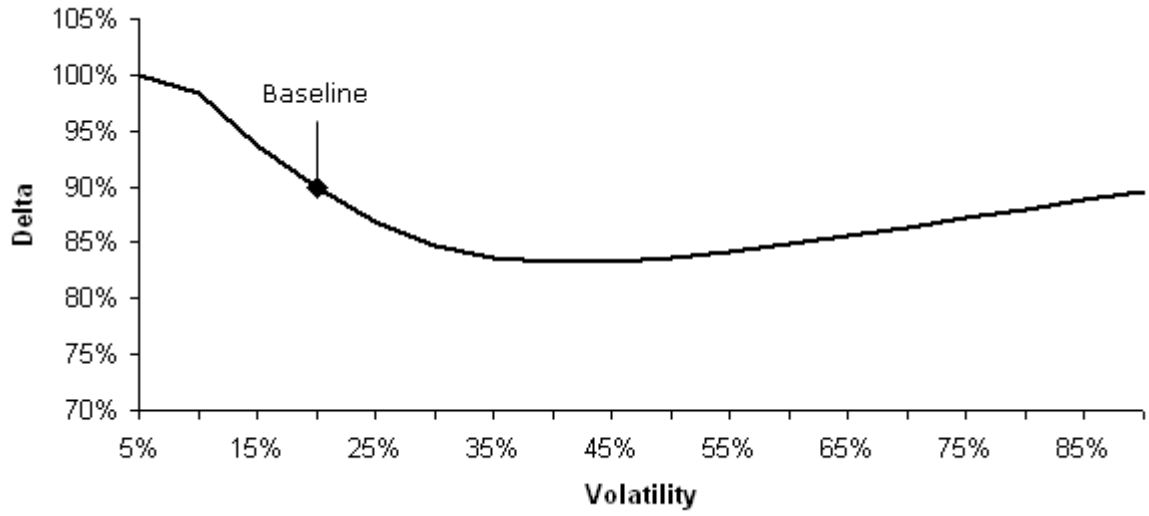
**Figure 4.5:** Option Value as a function of Volatility for 3 Assets

In addition to the risk-free rate and volatility, the time interval to implementation of the project also has a bearing on the options value. Figure 4.6 below depicts the options value for 3 assets when varying the time to maturity.

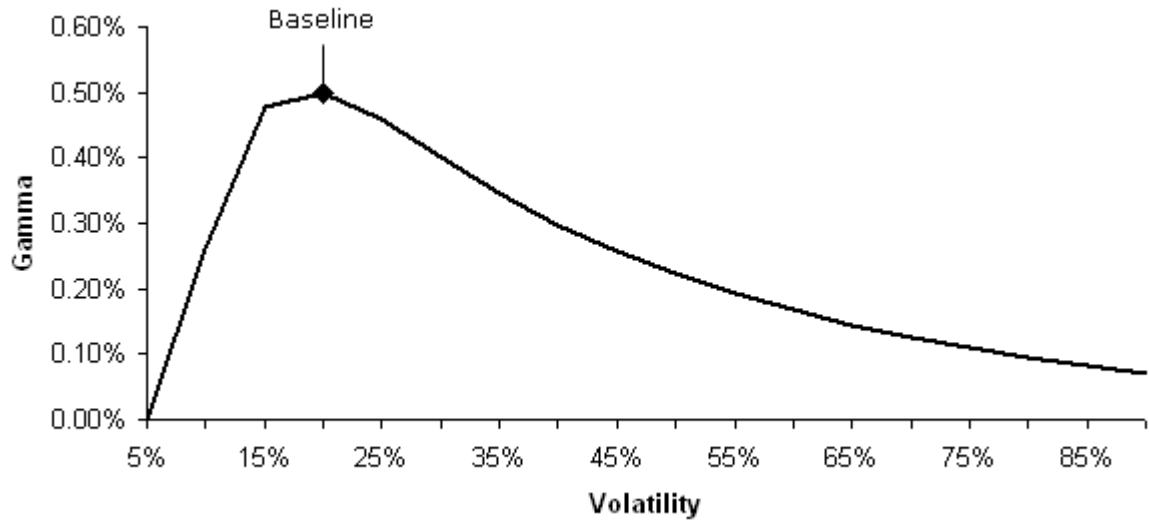


**Figure 4.6:** Option Value as a function of Maturity for 3 Assets

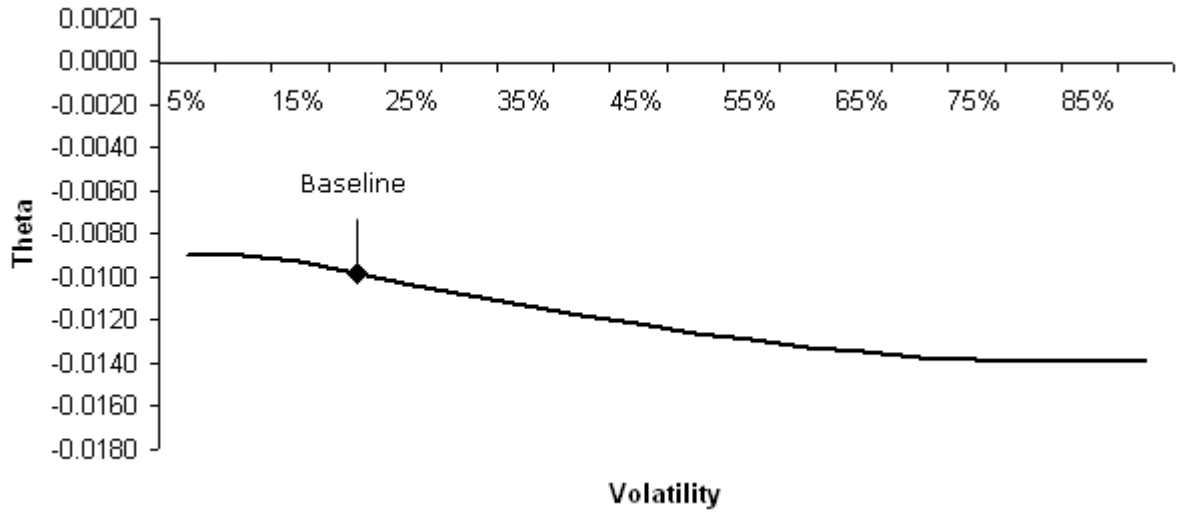
In addition the following numerical calculations were performed to see the sensitivities of delta, gamma, and theta as a function of change in volatility. These calculations are represented in Figures 4.7, 4.8, and 4.9 below.



**Figure 4.7:** Delta: Change in Option price for one unit change in Asset price

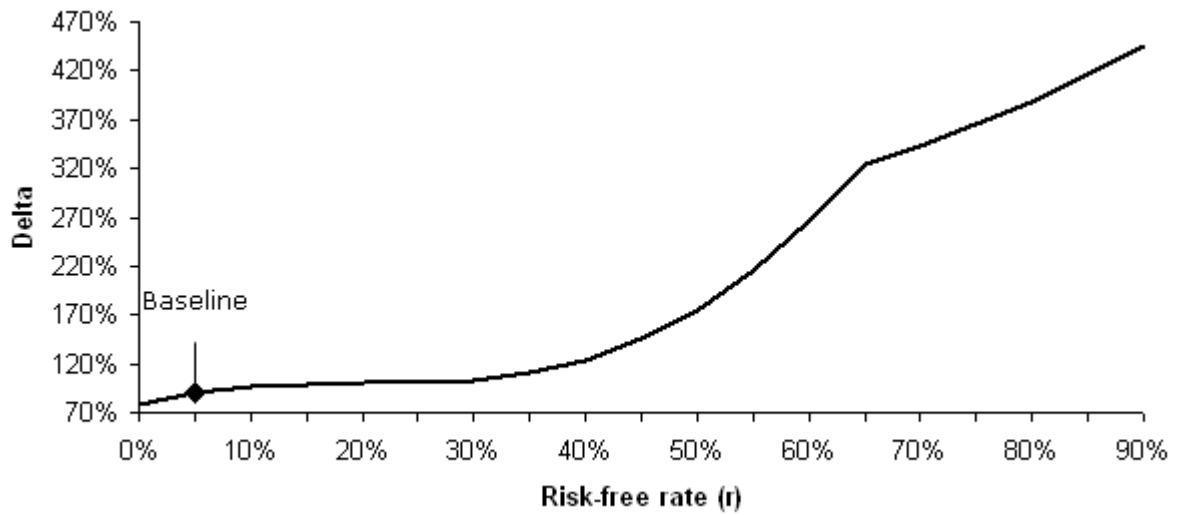


**Figure 4.8:** Gamma: Change in Delta for one unit change in Asset price

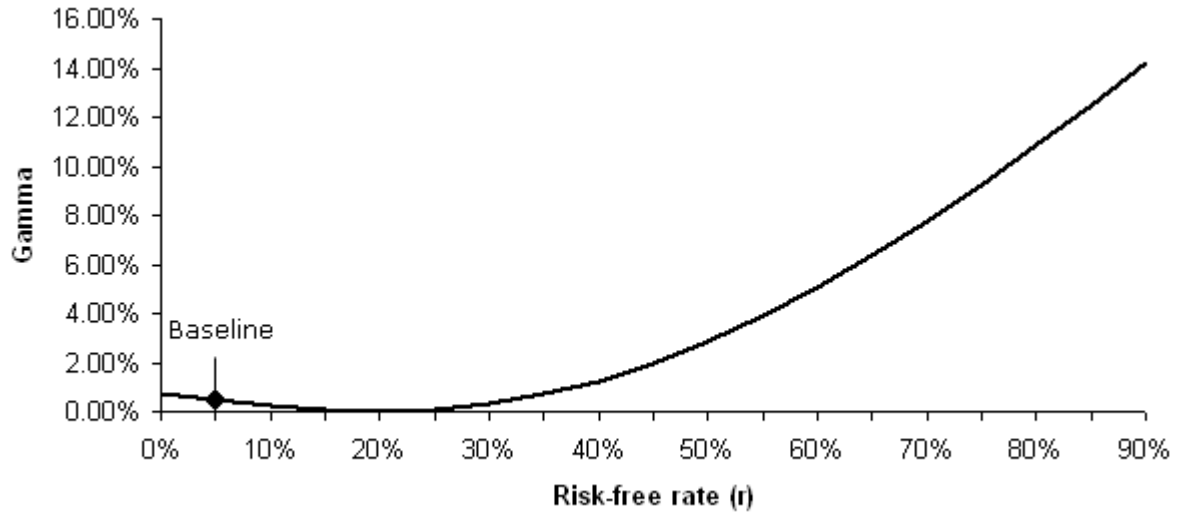


**Figure 4.9:** Theta: Change in Option Value for a one day closer to maturity

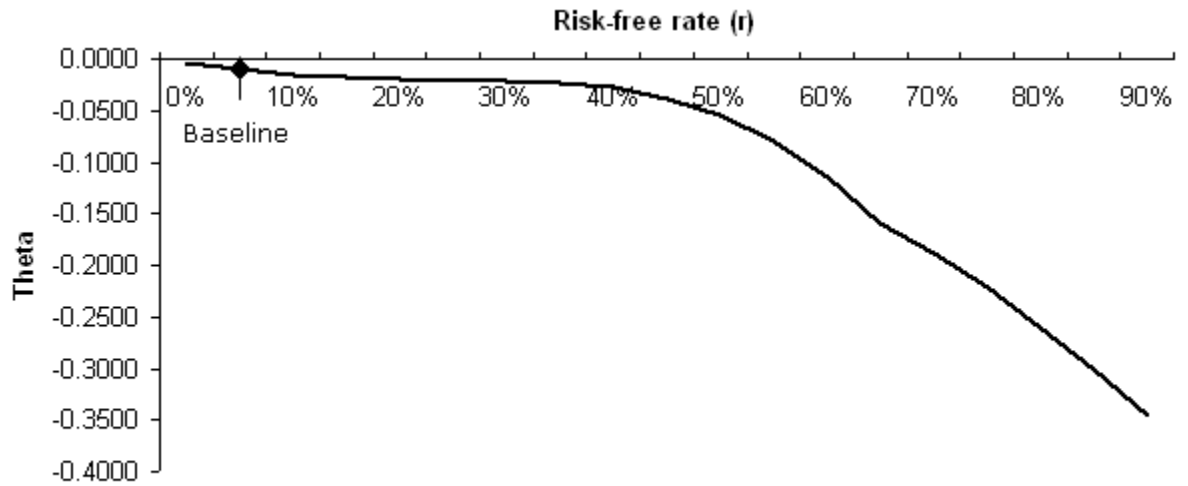
Sensitivities of delta, gamma, and theta were also performed on the options value as a function of the risk-free rate and represented in Figures 4.10, 4.11, and 4.12.



**Figure 4.10:** Delta: Change in Option price for one unit change in Asset price



**Figure 4.11:** Gamma: Change in Delta for one unit change in Asset price



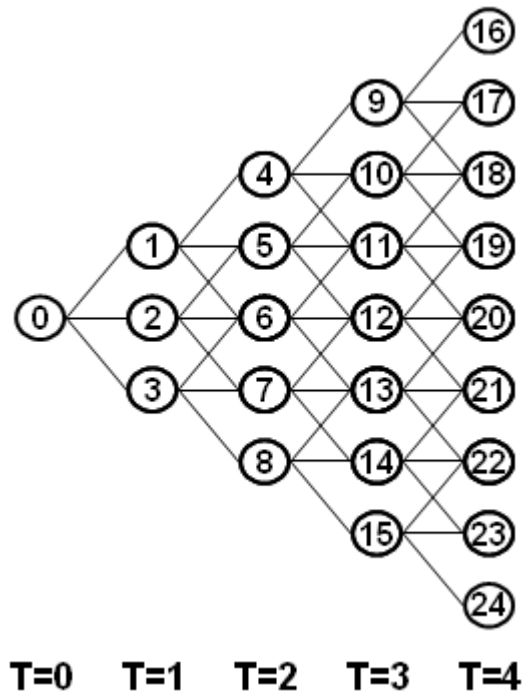
**Figure 4.12:** Theta: Change in Option Value for a one day closer to maturity

Thus in conclusion, the binomial model allows the decision maker to explore many different paths. It allows for future information to be considered as it becomes available and the approach itself is not too complex and time consuming. Additionally sensitivities on interest rate, volatility, asset valuation, and implementation cost are easily performed.

**CHAPTER 5**  
**TRINOMIAL MODEL**

**5.1 Introduction**

Boyle introduced the trinomial trees in 1986 [85]. Figure 5.1 below depicts a typical trinomial lattice.



**Figure 5.1:** The Trinomial Lattice

As can be seen the trinomial trees are similar in appearance to the binomial trees, upward and downward jumps, however it contains an additional node at each step, that of doing nothing. Thus the movement can be upward, downward or stay the same. Haug states that the trinomial model offers more flexibility than the binomial method [85]. In an upward movement, the size of the jump is calculated as follows:

$$u = e^{\sigma\sqrt{2\Delta T}}$$

and the downward movement size is

$$d = \frac{1}{u} = e^{-\sigma\sqrt{2\Delta T}}$$

Furthermore, it follows that the upward probability is

$$p_u = \left( \frac{e^{\frac{b\Delta T}{2}} - e^{-\sigma\sqrt{\frac{\Delta T}{2}}}}{e^{\sigma\sqrt{\frac{\Delta T}{2}}} - e^{-\sigma\sqrt{\frac{\Delta T}{2}}}} \right)^2$$

and the lower probability is

$$p_d = \left( \frac{e^{\sigma\sqrt{\frac{\Delta T}{2}}} - e^{-\frac{b\Delta T}{2}}}{e^{\sigma\sqrt{\frac{\Delta T}{2}}} - e^{-\sigma\sqrt{\frac{\Delta T}{2}}}} \right)^2$$

The probability that the asset price remains unchanged is given by Haug as

$$p_m = 1 - p_u - p_d$$

where

T = the time to maturity  
b = cost of carry  
n = number of steps  
σ = volatility

## 5.2 Numerical Example

Let's apply the same numerical example from the previous chapter to the trinomial case. Let's assume that we are valuing the option as an American Call option. The baseline case is given in Table 5.1 as follows:

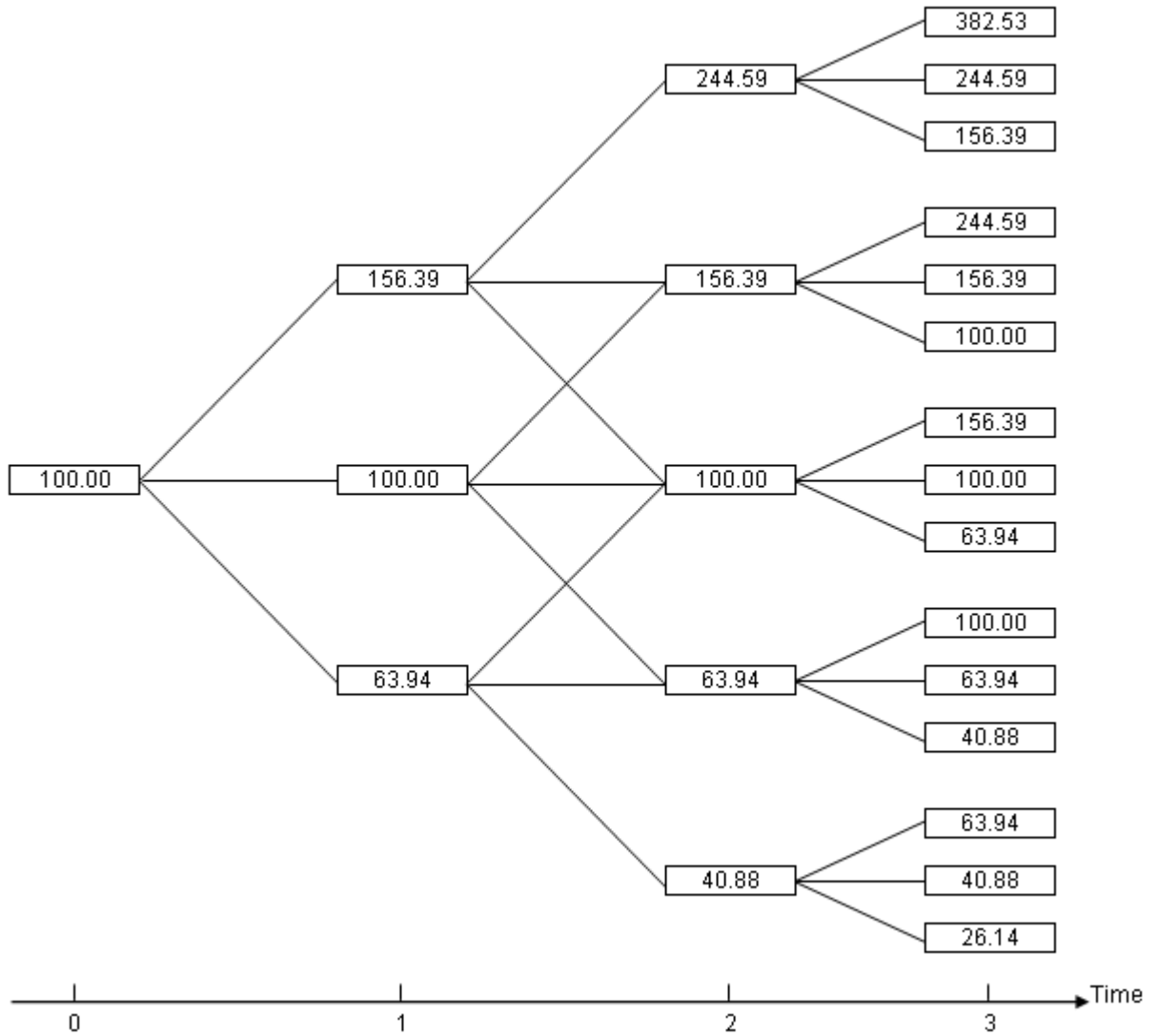
**Table 5.1:** Baseline Model of Trinomial numeric example

<b>Variable</b>	<b>Value</b>
Asset Value (\$)	100
Implementation Cost (\$)	80
Maturity (Years)	5
Risk-free Rate (%)	0.05
Dividends (%)	0
Volatility (%)	0.2
Lattice Steps	3

Based on the above formulas the following parameters are calculated and displayed in Table 5.2 below and Figure 5.2 depicts the values of the underlying asset lattice for a 3-step lattice.

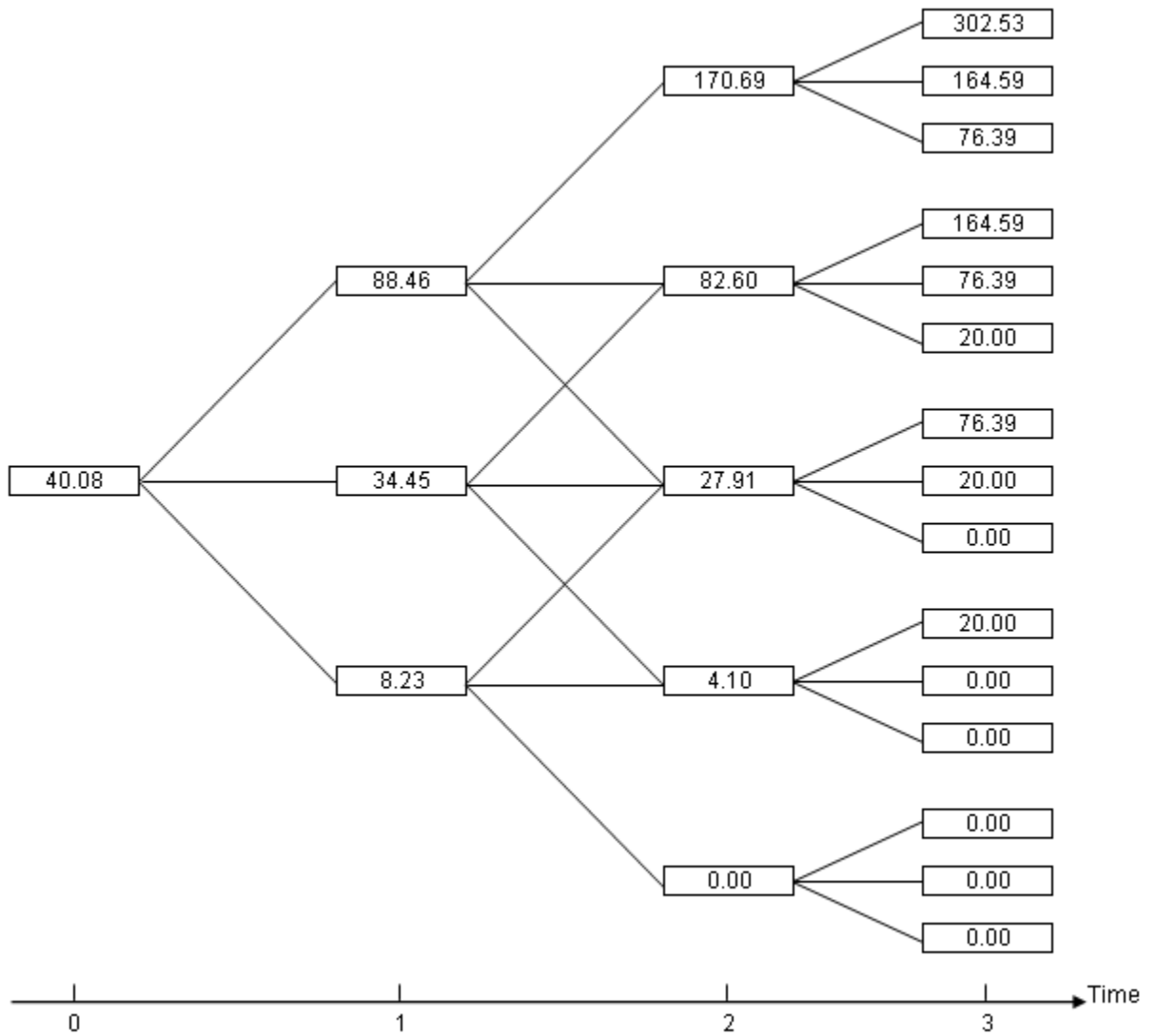
**Table 5.2:** Parameter Calculation of Trinomial example

<b>Parameter</b>	<b>Value</b>
Stepping-Time (dt)	1.6667
Up Step-Size (up)	1.5639
Down Step-Size (down)	0.6394
High Branch Probability ( $P_H$ )	0.2226
Middle Branch Probability ( $P_M$ )	0.6667
Low Branch Probability ( $P_L$ )	0.1108



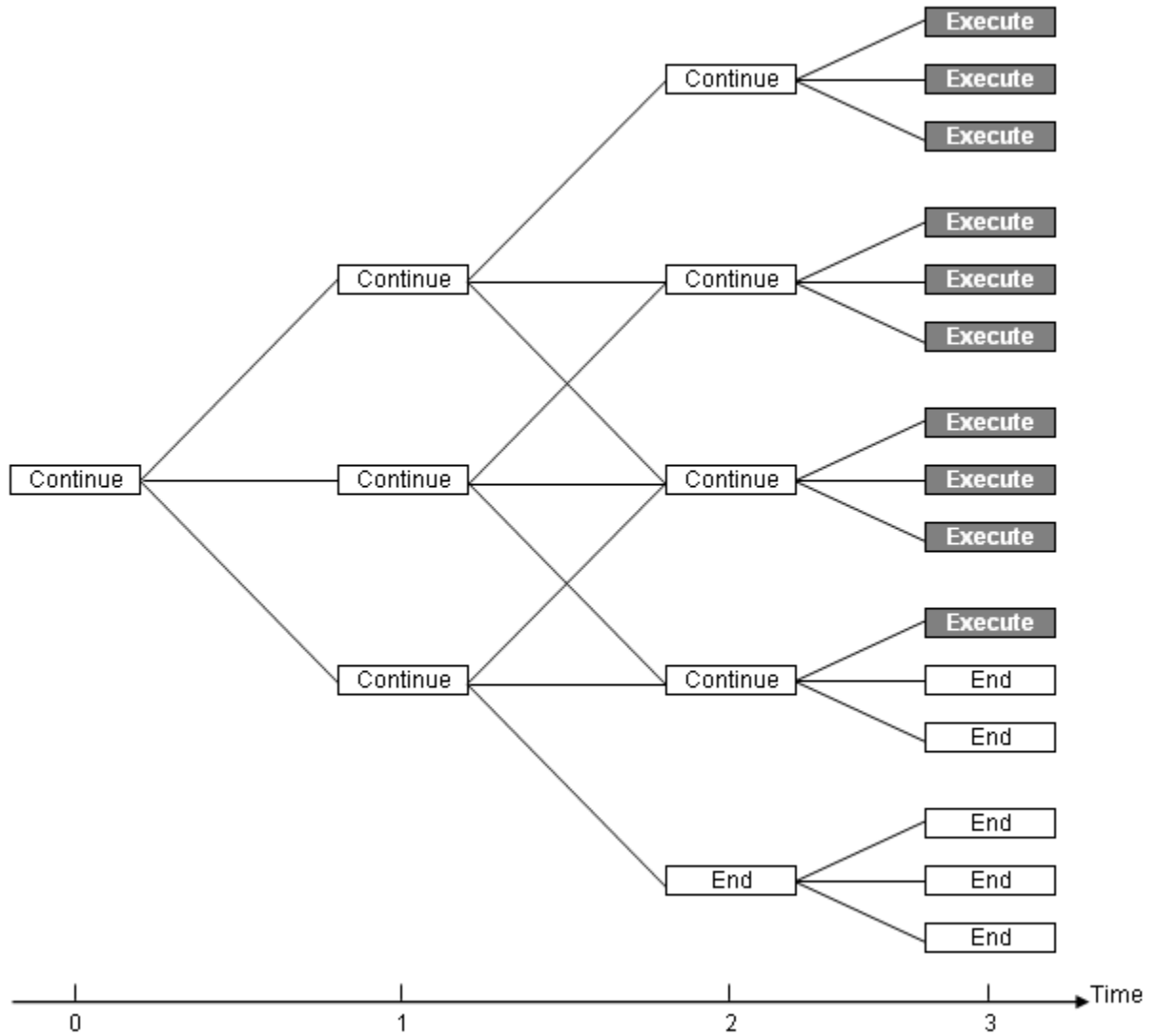
**Figure 5.2:** Underlying Trinomial Asset Lattice

Similar to the binomial calculation above, we start at the end of the tree and work backward when calculating the trinomial options value displayed in Figure 5.3. The value of the option for this example is \$40.08 million.



**Figure 5.3:** Trinomial Option Value Lattice

The decision lattice follows which indicated the viable paths to an in-the-money outcome and is shown in Figure 5.4.



**Figure 5.4:** Trinomial Decision Lattice

Similar to that of the binomial model the sensitivities of the trinomial model can be performed to see the impact on the options value to small changes in the asset value, implementation cost, interest rate, volatility, and time to maturity. Thus, a well informed decision can be made with the available information.

## **CHAPTER 6**

### **SEMICONDUCTOR INDUSTRY**

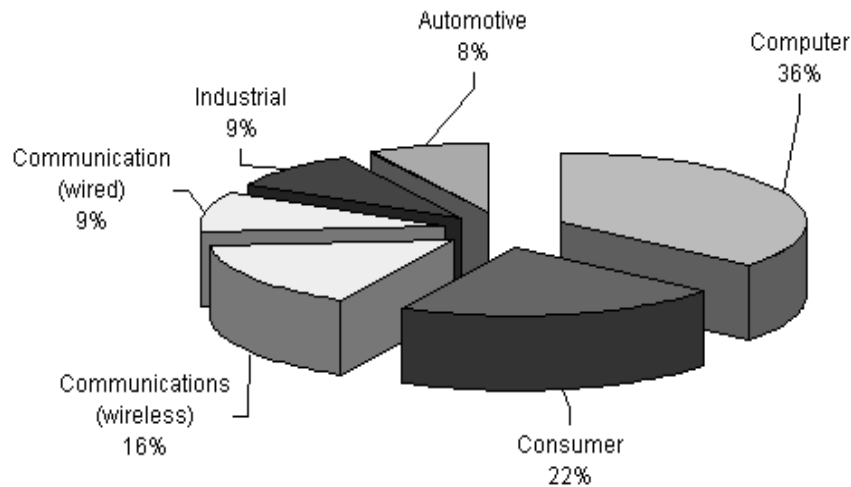
#### **6.1 Introduction**

In 1947 the transistor was invented which has led to the consumer electronics and computer revolution. A transistor functions as a solid-state electronic switch. The transistors in use today are mostly the Metal Oxide Semiconductor Field Effect Transistors (MOSFETs). MOSFETs have layers of material deposited on silicon substrates. Impurities are then added to some of the silicon layers through a process called “doping or ion bombardment”. Other layers contain silicon dioxide (an insulator) as well as polysilicon (which act as an electrode). Metal is also added to act as the wires connect the transistor to other components. This assembly allows the silicon to act as an insulator and a conductor of electricity. Thus the term semiconductor is used to refer to the material silicon. MOSFETs consist of 3 connections; the source, gate, and drain. When more than one transistor is combined on the same base without wires, a circuit is formed. This circuit is referred to as an Integrated Circuit (IC), which is a chip with etched electronic switches. In 1959, the first IC was invented by Texas Instruments and contained 6 transistors, certainly a far way to today’s microprocessors that contains upward of several hundred million transistors.

#### **6.2 Semiconductor Industry**

The semiconductor industry has grown significantly over the past few decades. It is estimated that the Compound Annual Growth Rate (CAGR) from 1961 to present is 15% [98]. Semiconductors are used in many products including computer, consumer,

automotive, industrial, communications, military, and avionics. Semiconductor sales reached \$250B in 2006, which is estimated at 20% of the electronic industry sales [98]. Figure 6.1 below depicts 2006 sales to the various market segments for semiconductor products.



**Figure 6.1:** 2006 Semiconductor Market Segment [98]

As can be seen from the figure above, computer and consumer electronics (e.g. mobile phones, laptops, game consoles) make up a significant part of the semiconductor market. Customers in consumer electronic and computer markets are constantly expecting enhancement in features of the products they buy and thus speed, power consumption, cache, architecture, and size are all vital considerations in future generations of microprocessors. It is thus these high volume markets that dictate market requirements regarding the next generation of microprocessor. The fast pace of newer product introductions often mean that the predecessors are discontinued as a result of economies of scale and thus semiconductor manufacturers' focus is on the high volume market

segments. To give an indication of the cost of operating a production facility or “Fab” as it is commonly referred to. Today’s high-quality fabs cost anywhere from \$2-5 billion. The 5 top semiconductor companies current in operation are Intel (USA), Samsung (S. Korea), Toshiba (Japan), Texas Instruments (USA), and STMicroelectronics (Italy/France). Despite the enormous capital intensive process, there is a wave of companies entering the market, which includes “Fabless” companies. A “fabless” company is one that owns its own intellectual property and outsources its wafer/chip production and thus do not have to invest in huge capital outlays in Fab production facilities. It is therefore without question that competition in the semiconductor industry is intense as companies compete for market share.

### **6.3 Microprocessors**

Microprocessors are the “heart and brains” of a system they are embedded in. In 2007, the biggest semiconductor company, Intel, posted revenue of \$38.3 billion [92]. Microprocessor sales within its Digital Enterprise and Mobility groups were \$10.7B and \$15.2B respectively accounting for 68% of its total sales [92]. Similarly, microprocessor sales within other semiconductor companies are the biggest part of their revenue. Thus it is without mention that new microprocessors with enhanced features are being introduced at a rapid pace. These new and improved microprocessors continue to enable new products that they are embedded in. Thus an understanding of the microprocessor evolution is important.

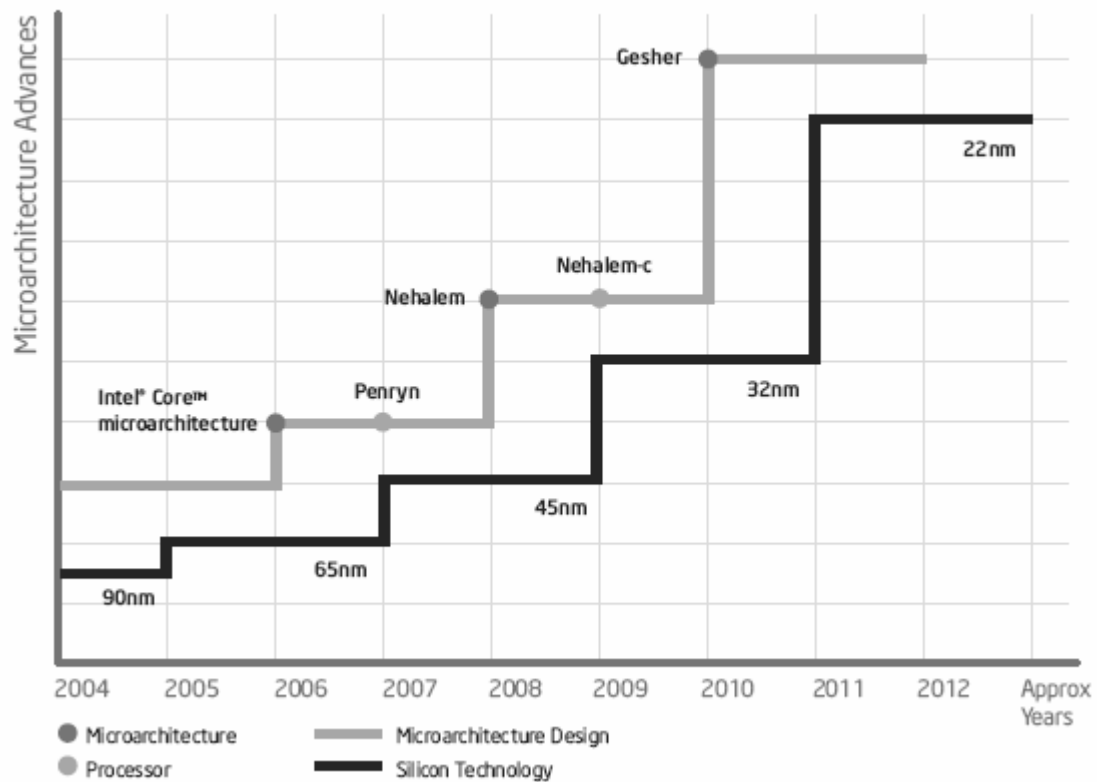
Table 6.1 depicts the advancements of the microprocessor from 1971 to present.

**Table 6.1:** Evolution of the microprocessor [3]

Processor Name	Date Introduced	Transistors	Microns	Clock speed	Data width
4040	1971	2300	10	400KHz	4 bit
8080	1974	6,000	6	2 MHz	8 bits
8088	1979	29,000	3	5 MHz	16 bits
80286	1982	134,000	1.5	6 MHz	16 bits
80386	1985	275,000	1.5	16 MHz	32 bits
80486	1989	1,200,000	1	25 MHz	32 bits
Pentium	1993	3,100,000	0.8	60 MHz	64-bit bus
Pentium II	1997	7,500,000	0.35	233 MHz	64-bit bus
Pentium III	1999	9,500,000	0.25	450 MHz	64-bit bus
Pentium 4	2000	42,000,000	0.18	1.5 GHz	64-bit bus
Pentium 4 "Prescott"	2004	125,000,000	0.09	3.6 GHz	32 bits
Pentium D "Presler"	2005	376,000,000	0.07	3.6 GHz	64-bit bus
Core 2 Duo (Conroe)	2006	291,000,000	0.065	3.0 GHz	64-bit bus
Core 2 Quad (Kentsfield)	2007	582,000,000	0.065	2.66 GHz	64-bit bus
Core 2 Quad (Yorkfield)	2008	820,000,000	0.045	3.0 GHz	64-bit bus

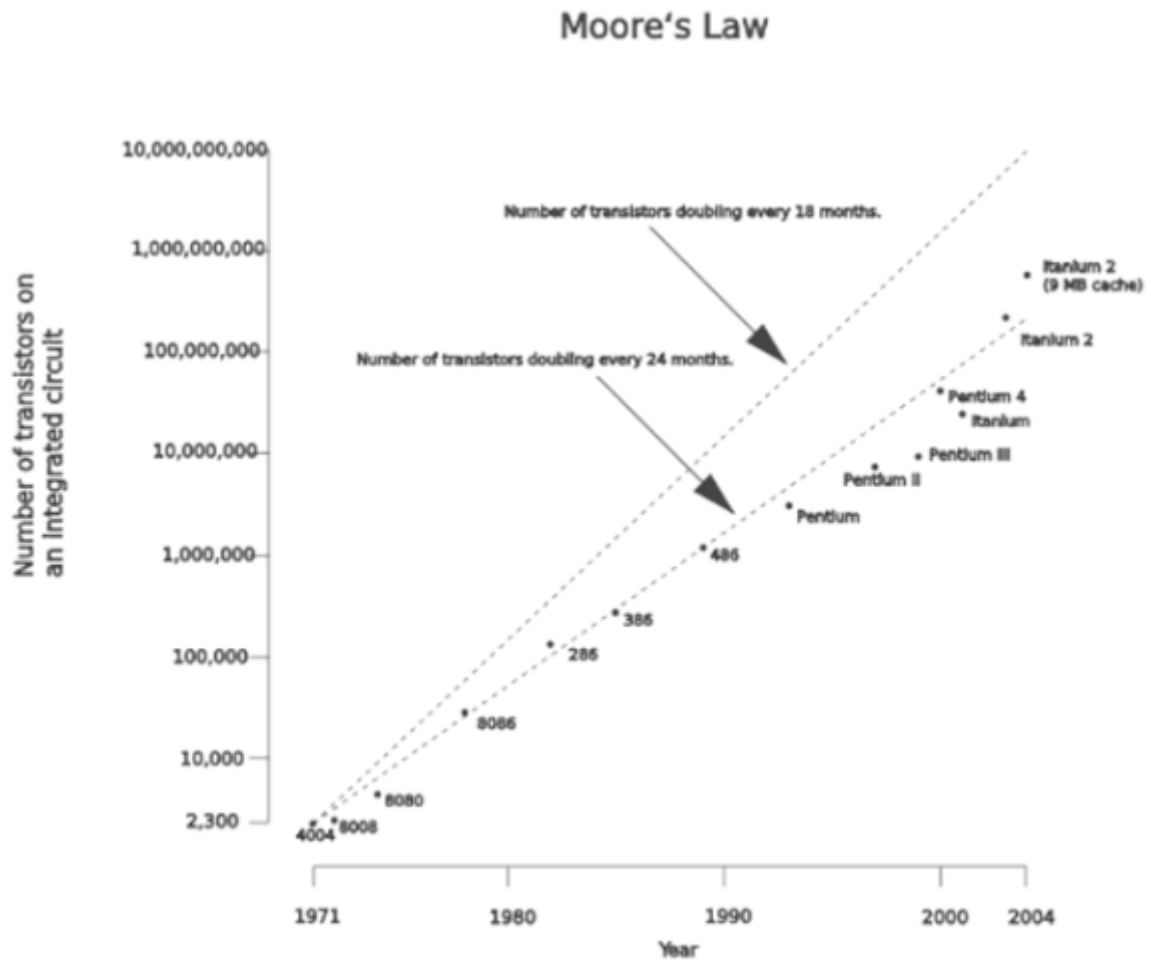
The table above lists some of the key characteristics of the microprocessor by date of introduction. As can be seen from the table above, the number of transistors has risen progressively over the years. The 4-bit 4040 processor introduced in 1971 had 2,300 transistors, 10 microns wide and clocked at 400 KHz. Significant advances have been made since and today depicted in Intel's latest release in 2008 of the Core 2 Quad. The Core 2 Quad is a 64-bit processor running of four cores and has 820 million transistors, 0.045 microns wide and clocks at 3.0 GHz. The width of the wires measured in microns is usually referred to as the manufacturing process. Smaller manufacturing processes means that transistor density can be increased. Today's manufacturing process is 222 times smaller than that of the 4004-processor released in 1971. Microprocessor technology continues to improve and thus the manufacturing process nodes will also continue to improve. Figure 6.2 below released by Intel, depicts the past, present, and future micro-architecture advances in silicon manufacturing process technology.

## Intel Architecture and Silicon Cadence Model



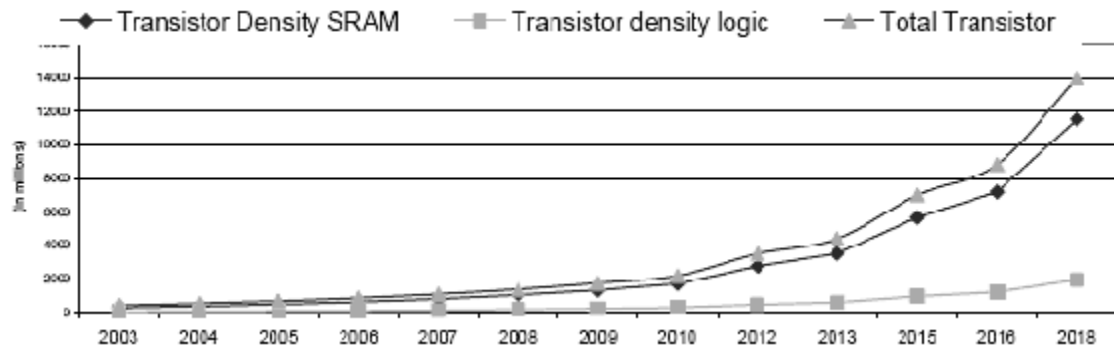
**Figure 6.2:** Intel Current and Predicted Manufacturing Process nodes [93]

As can be seen from the Intel example in the figure above, the next scheduled improvement in silicon technology is on schedule for 2009 to 2011. The 32 nm or 0.032 microns is a 30% improvement in the current 0.045 micron node. This has led to improvements in computer density. On average the density has doubled every 18-24 months as predicted by Moore in his paper published in 1965. Figure 6.3 below depicts the actual transistor density against the prediction by Moore in 1965.



**Figure 6.3:** Actual Transistor density vs. Moore's Prediction [94]

As can be seen from the figure above, transistor density has improved significantly and Moore's Law has mostly held steady for almost 4 decades. Silicon technology will continue to improve and so will transistor density. Figure 6.4 depicts the future trend of transistor density.



**Figure 6.4:** Transistor Densities Trend [91]

It is thus without question that the 2 microprocessor attributes discussed above in terms of the size and transistor count will continue to improve significantly and usher in a constant stream of new microprocessors with advanced technologies. The two attributes discussed above are not the only improvements made in microprocessor technology. There has been significant improvement made to other attributes as well including power consumption, cache, micro-architecture design, and bus width. Power consumption has mainly seen significant improvements over the past decade. Voltage did not improve at the same rate as transistor density. Voltage started out at 5 volts and remained at 5 volts for a long time eventually decreasing to 3.3 volts in the early 1990s. In the last 5 years the voltage in the newer processor has hovered around +- 1 volt. This is a very important attribute of the processor as energy efficiency and prolonged battery life has become an ever important characteristic of processor design, especially since processors are running much faster and hotter today. This is well received by manufacturers of embedded

products as it helps with energy efficiency and allows them to offer advancements in their new product offerings.

#### **6.4 Microprocessor Dilemma**

It is without question that the microprocessors in use today outperform its predecessors in most of its attributes as the manufacturing process and silicon technology improves. The complex micro-architectures are superior today allowing the processors to process more and more instruction per second than its predecessors. Transistor density and processor speeds are far ahead today as depicted in the tables and plots above. In addition, today's microprocessors have been able to reduce the size, weight, and power consumption of the products that they are embedded in. These are all great advances; however manufacturers of products with long service life-cycles especially those in the military and avionics industries are adversely affected which will be explained in later sections.

Semiconductor companies cannot manufacture all microprocessor product variants as a result of economies of scale, thus they constantly discontinue the older versions to give way to the newer model. In addition, the processors are getting more and more complex thus the hardware that is needed to support the complexity of the new designs are also getting more and more complex. Furthermore, there are many safety concerns in using the commercial processors in avionics and military products. In a report by the FAA in 2006, it is stated that processor specifications are usually available from the semiconductor OEM. However information about the design, production, testing, and validation is considered proprietary and not made available, thus it is a challenging task for product designers and developers to decide which processors to include in their

designs [91]. Additional challenges are brought to bear in determine fault tolerances and safety critical temperatures, especially in avionics and military products.

Avionics and military manufacturers are thus left with determining mitigation strategies for dealing with issues of obsolescence. Current mitigation strategies include; bridge buys, system redesign to accommodate the new processor, buying from an aftermarket source, and re-engineering. These are all very expensive alternatives. It is said that manufacturers currently spend millions of dollars on near obsolete inventories, which in many cases doesn't even get used in the product that it was originally designated for. Changing to a new processor or a similar processor from a competitor has major implication on qualifying, testing, programming logic, and delayed schedules. Thus, processor obsolescence has become a significant and costly challenge for those in the avionics and military industries. To deal with this and develop proactive strategies for dealing with microprocessor obsolescence, we develop prediction models to estimate the time to discontinuance as a first step. Using the real options approach will thus follow to determine the best financial option for the manufacturing.

#### **6.4.1 Microprocessor Prediction**

Proactive management strategies include predicting discontinuance dates of microprocessors and integrating the predictions into the strategic decision making process. Predictions are never perfect; however it is a proactive approach to dealing with issues of obsolescence. Doing nothing is not an option as it is known to have very costly results often leading to delayed schedules, unbudgeted fixes, and ultimately shutting down a program. For manufacturers of sustainment-dominated products (products that typically have long life-cycles), the question to answer is; “what makes best economic

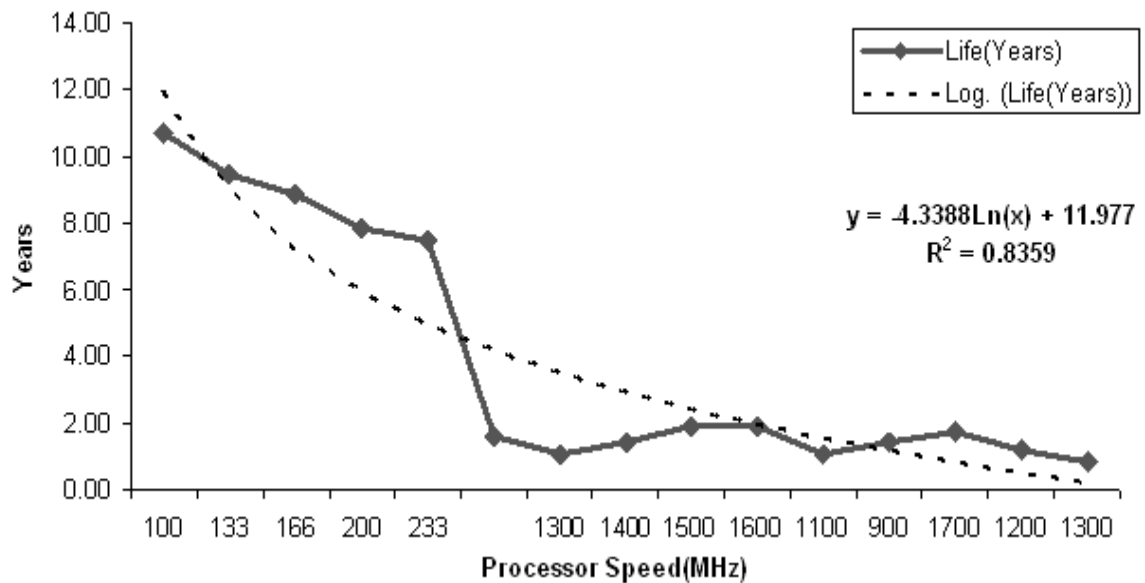
sense that will sustain the product”. This question will be answered using the real options approaches in the next section. However, as a starting point a prediction of processor obsolescence is necessary.

Microprocessor has been divided into processor families. A family typically consists of a specific micro-architecture. Intermittent improvements are made over time within the specific processor families that allows the processor to operate faster. As an example, Table 6.2 depicts the release dates and discontinuance dates of several processor models within the Pentium product family. The Pentium (100MHz) released in 1994 had a service life of 10 years before being discontinued in 2004. The service life of the Pentium processors continued to decline over time to 7.46 years for the Pentium 233 processor. The Pentium mobile processor was released in 1998 and initially had a service life of 1.10 years which is significantly less than its desktop counterpart. As can be seen from table 6.2 below, the service life for desktop Pentium processors and mobile Pentium processors are significantly different. The range is from 10 years in the earliest models to approximately 10 months in the later models as indicated below.

**Table 6.2:** Pentium Processor discontinuance rate [91]

Processor	Speed	Start Date	Discontinue Date	Life(days)	Life(Years)
Pentium	100	3/7/94	11/24/2004	3,915	10.70
Pentium	133	6/1/95	11/24/2004	3,464	9.46
Pentium	166	1/4/96	11/24/2004	3,247	8.87
Pentium with MMX	200	1/8/97	11/24/2004	2,877	7.86
Pentium with MMX	233	6/2/97	11/24/2004	2,732	7.46
Pentium Mobile		1/12/98	8/17/1999	582	1.59
Pentium M	1300	3/12/03	4/16/2004	401	1.10
Pentium M	1400	3/12/03	8/9/2004	516	1.41
Pentium M	1500	3/12/03	2/18/2005	709	1.94
Pentium M	1600	3/12/03	2/18/2005	709	1.94
Pentium M Low Voltage	1100	3/12/03	4/16/2004	401	1.10
Pentium M Ultra Low Voltage	900	3/12/03	8/9/2004	516	1.41
Pentium M	1700	6/2/03	2/18/2005	627	1.71
Pentium M Low Voltage	1200	6/2/03	8/9/2004	434	1.19
Pentium M Low Voltage	1300	4/7/04	2/18/2005	317	0.87

Figure 6.5 below shows the service life of the Pentium processor from earliest release date. Fitting a trend curve to the data yield an R-square of 84%, indicating that the prediction in the curve is very good at estimating discontinuance in future releases.



**Figure 6.5:** Years to Discontinuance (Pentium Processor)

The prediction equation is as follows:

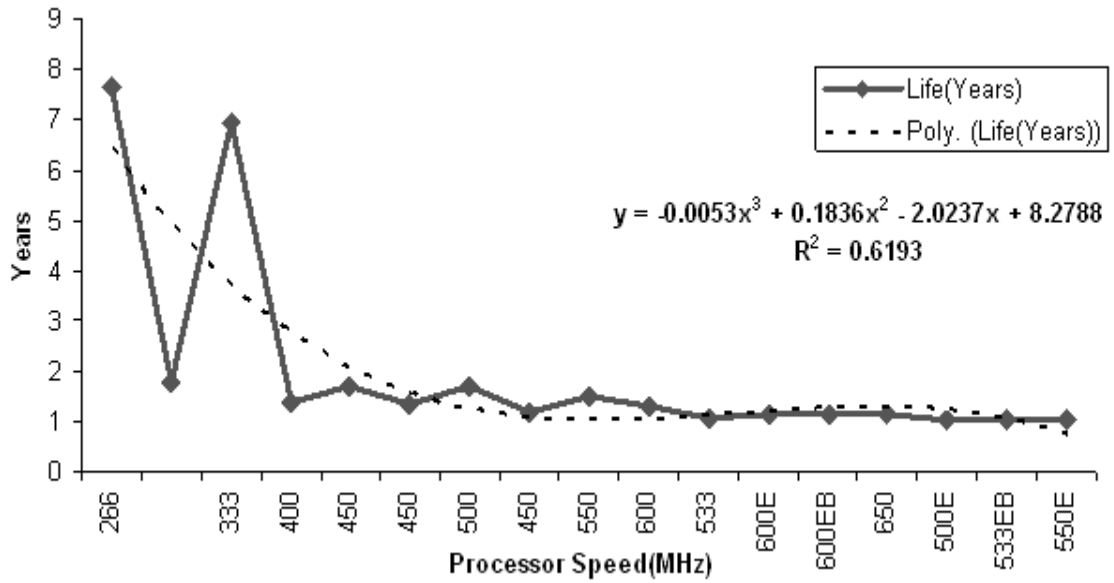
$$y = -4.338\text{Ln}(x) + 11.977$$

The y axis in this case indicates the years to obsolescence as a function of the order the processor was released. For example the Pentium processor, 100 MHz and 1600 MHz released in 1994 and 2003 respectively will calculate its service life as follows.

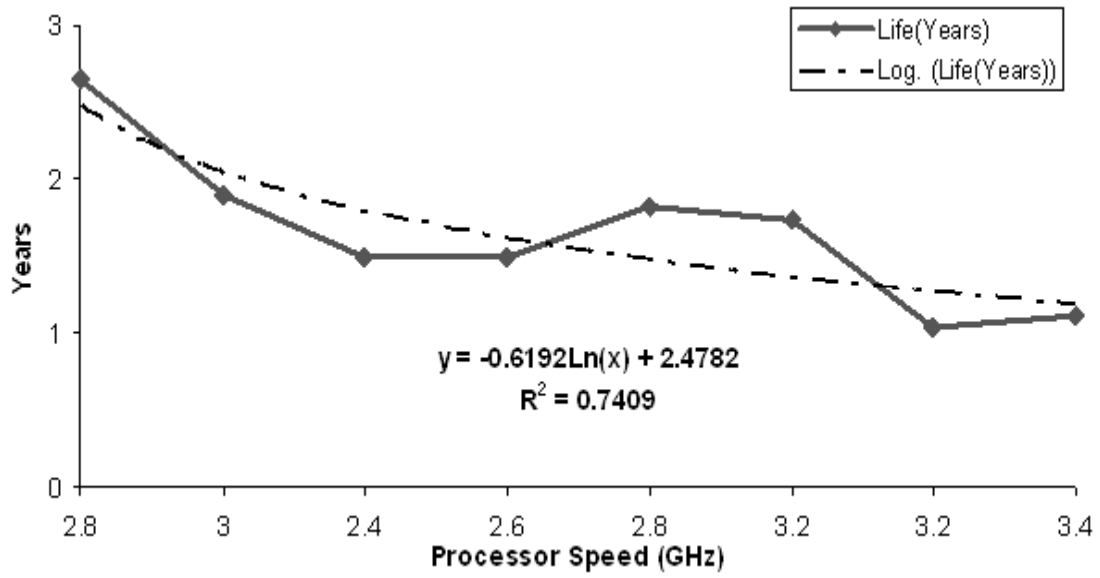
$$\text{Pentium 100: } y = -4.338\text{Ln}(x) + 11.977 = -4.338\text{Ln}(1) + 11.977 = \mathbf{11.99 \text{ Years}}$$

Pentium 1600:  $y = -4.338\ln(x) + 11.977 = -4.338\ln(10) + 11.977 = \mathbf{1.98 \text{ Years}}$

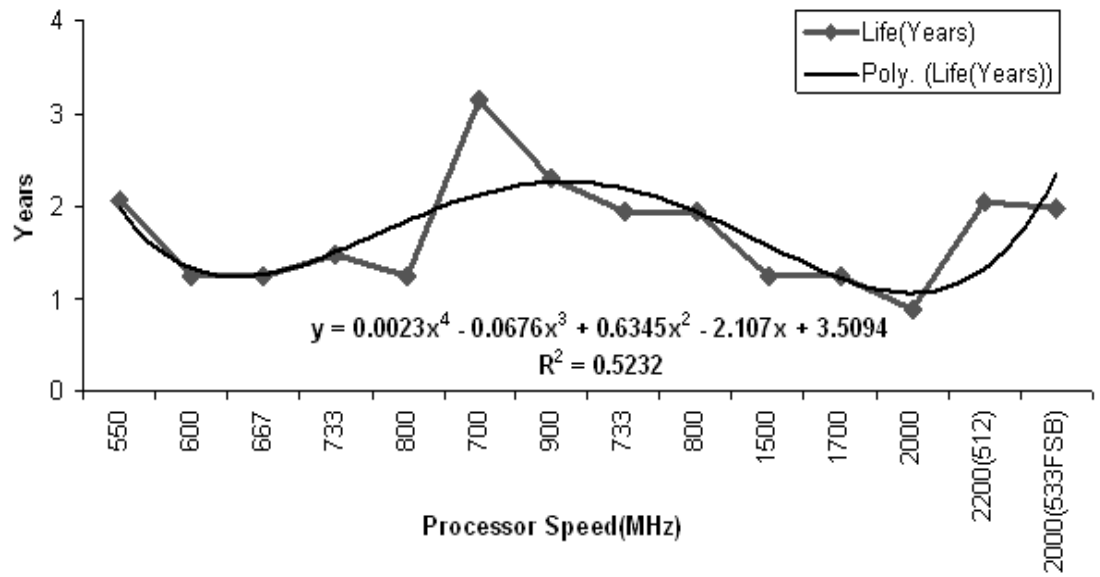
Likewise, Figures 6.6, 6.7, 6.8, 6.9 and 6.10 depicts the service life of the Pentium3, Pentium4, Xeon, Celeron, and Celeron Mobile processor families respectively.



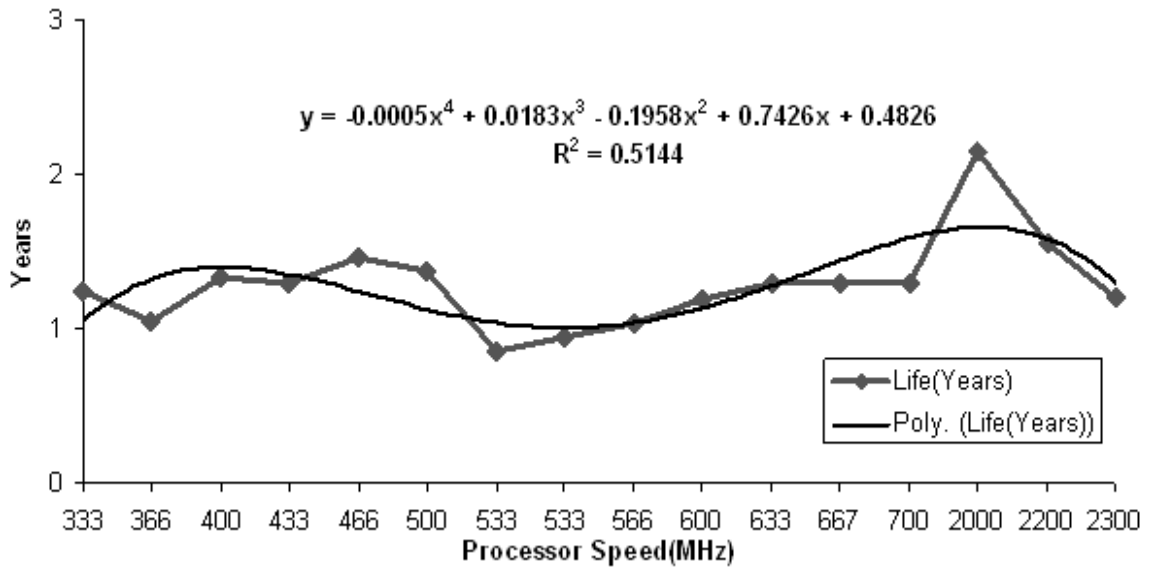
**Figure 6.6:** Years to Discontinuance (Pentium3 Processor)



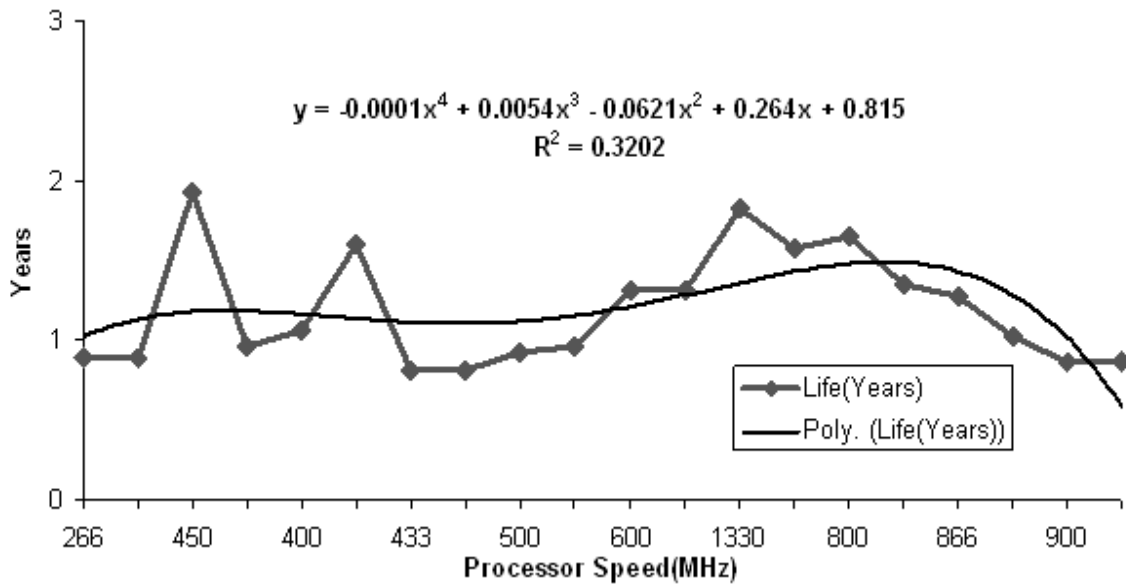
**Figure 6.7:** Years to Discontinuance (Pentium4 Processor)



**Figure 6.8:** Years to Discontinuance (Xeon Processor)



**Figure 6.9:** Years to Discontinuance (Celeron Processor)



**Figure 6.10:** Years to Discontinuance (Celeron Mobile Processor)

Given the prediction equations a confidence interval can be developed to determine within reasonable accuracy the life span of a new processor within the processor family.

## 6.4.2 Microprocessor Regression Model

The historic background of the processor leads us to consider 3 variables as a second step to modeling the process statistically and drawing inferences about the rate of change of the microprocessor based on the variables. We will now develop this model as a multiple regression with 2-way interactions where the key inputs are depicted in the Table 6.3 below:

**Table 6.3:** Regression Model Inputs

<b>Dependent Variables</b> Date of Introduction
<b>Independent Variables</b> Process (microns) Clock Speed (MHz) Number of Transistors
<b>Variable Interactions</b> Process * Clock Speed Process * Number of Transistors Clock Speed * Number of Transistors

Data on the manufacturing process, clock speed, and number of transistors were used from the earliest processors to processors in recent years. The regression equation to solve the model can be written as follows:

$$Y = \beta_1 + \beta_2(\text{Process}) + \beta_3\text{Clock Speed} + \beta_4\text{Number of Transistors} \\ + \beta_5\text{Size*Clock Speed} + \beta_6\text{Size * Number of Transistors} \\ + \beta_7\text{Clock Speed * Number of Transistors} + \varepsilon$$

Minitab was used to solve the model above and yielded the output in Table 6.4.

**Table 6.4:** Regression Output

<b>Predictor</b>	<b>Coef</b>	<b>StDev</b>	<b>T</b>	<b>P</b>
Constant	32772.9	528.3	62.04	0
Clock Speed	25.175	6.177	4.08	0
Process	-658.4	73.86	-8.91	0
Transistors	-41.154	9.535*10 <sup>-5</sup>	-3.9	0.001
Clock Speed*Size	-86.76	27.14	-3.2	0.004
Clock Speed*Transistors	-27	5.0*10 <sup>-8</sup>	-3.77	0.001
Size *Transistors	0.0024563	5.182*10 <sup>-4</sup>	4.74	0

S = 969.4

R-Sq = 93.9%

R-Sq(adj) = 92.5%

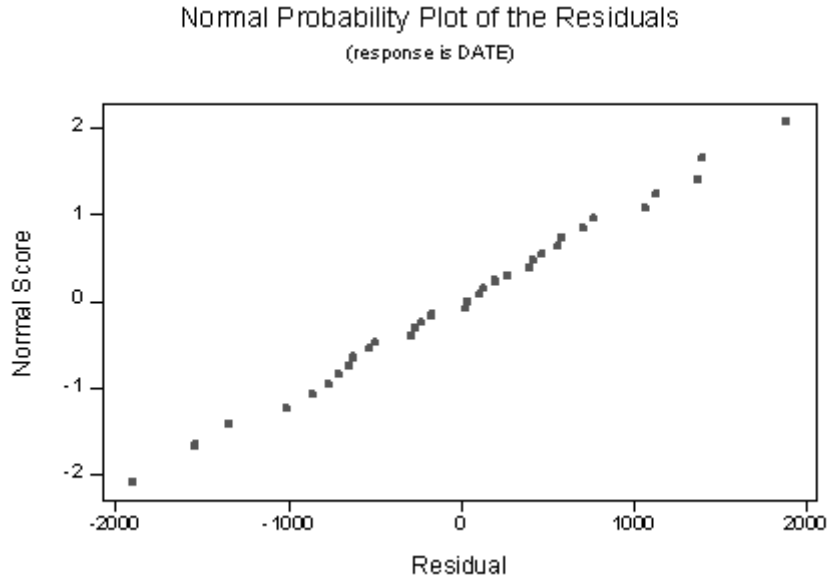
**Analysis of Variance**

<b>Source</b>	<b>DF</b>	<b>SS</b>	<b>MS</b>	<b>F</b>	<b>P</b>
Regression	6	3747825532	62454255	66.46	0
Residual Error	26	24432820	939724		
Total	32	399158352			

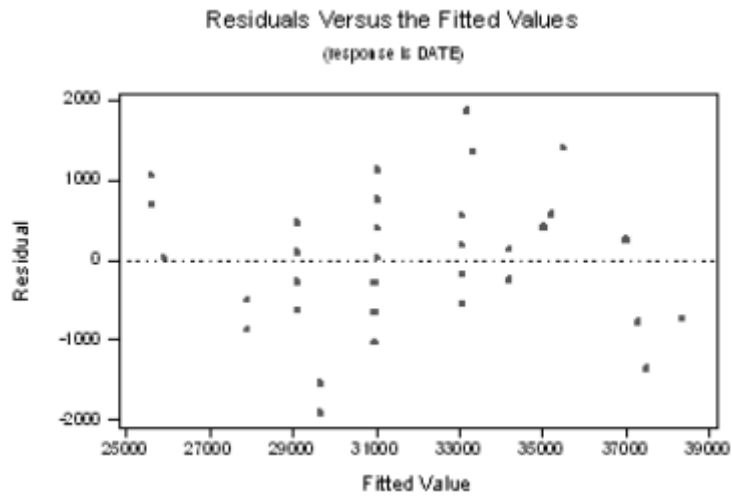
The p-values for all the variables are less than 0.05 and 0.01, thus at the  $\alpha = 0.05$  and 0.01 level we determine that all the variables are significant. Thus the model can now be expressed as follows:

$$Y = 32772.9 - 658.40 (\text{Size}) + 25.175\text{Clock Speed} - 3.7154 \times 10^{-4} \text{Number of Transistors} - 86.76\text{Size} \times \text{Clock Speed} + 0.0024563\text{Size} \times \text{Number of Transistors} - 2.0 \times 10^{-7} \text{Clock Speed} \times \text{Number of Transistors}$$

The model has an R. Square of 93.9% indicating that 93.9% of the variability is accounted for by the model. Additional analyses shown in Figures 6.11 and 6.12 indicate that the residuals are normally distributed, and the fitted values are fine, which suggests that the model is valid.



**Figure 6.11: Normal Probability Plot**



**Figure 6.12: Fitted Values Plot**

Thus, the model shown above can be used to estimate new processor introductions given the estimate of the 3-variables; process, transistors, speed. This preliminary work provides the foundation for the development of a generalized obsolescence prediction

tool, which is an important aspect in the development of models and tools that can help to predict, assess, actively manage, and mitigate obsolescence.

## CHAPTER 7

### COMPANY ABC - CASE STUDY

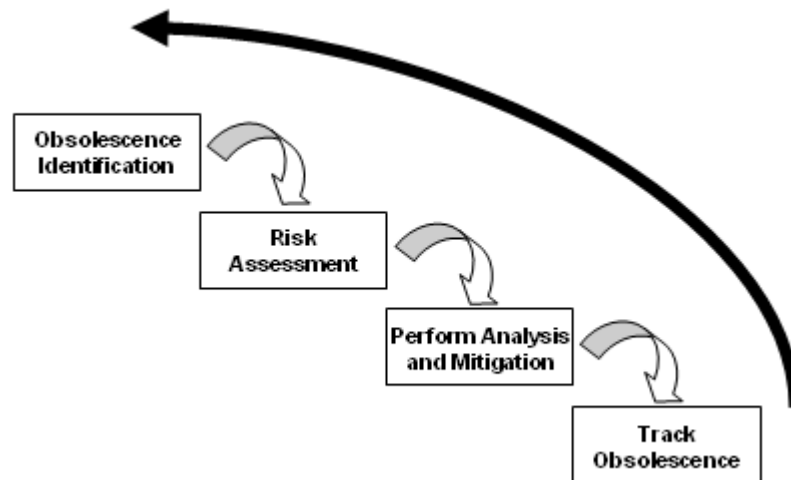
#### 7.1 Introduction

In this chapter we present a case study which involved the University of Massachusetts and an industry partner, company ABC, a U.S. manufacturer of motion detection systems. For confidentiality purposes the name of the company will remain anonymous. Company ABC manufactures custom low-volume products for the U.S. Navy that is typically in use for over 20 years. The acquisition phase is typically 4-5 years before the product is fielded. Component obsolescence has become a significant problem for ABC, impacting their budget with expensive mitigation solutions as a result of their reactive nature in dealing with it. Thus a collaborative effort between the University of Massachusetts and ABC was established to assist company ABC in determining strategies for effectively managing and mitigating component obsolescence issues. An obsolescence management plan, a proactive approach to dealing with issues of obsolescence should ensure that, *“obsolescence issues are anticipated, identified, analyzed, mitigated, and reported in the most economical and timely fashion and to provides guidance for obsolescence management for system life cycle support”*.

#### 7.2 ABC’s Obsolescence Management Plan

Figure 7.1 depicts the management plan for ABC where the first step is to identify obsolescence for the most vulnerable items. Obsolescence prediction is key in identifying the items most vulnerable. Once identified, an assessment of the risk is performed. This is followed by analysis to develop the best approach to mitigate the

obsolescence effect optimally. The process starts over and tracking obsolescence continues.



**Figure 7.1:** Company ABC’s Obsolescence Mitigation Strategy

### 7.3 Obsolescence Identification

Items are identified as candidates for obsolescence risk assessment based upon verified information and/or various existing conditions. The following attributes will be considered when identifying possible obsolescence risks:

- Life cycle stage assessment
- Industry trends
- Market forecasts
- Escalating costs
- Reliability issues
- Safety
- Complexity
- Commonality
- Changing performance requirements
- Mean time between failures
- Qualified supplier availability
- Special manufacturing processes

These attributes are narrowed down to 4 factors which includes; (1) market share, (2) number of manufacturers, (3) life cycle stage, and (4) ABC’s assessment of risk as described below.

#### 7.4 Assessment of Risk

ABC’s risk assessment index was developed based on two key attributes; criticality and likelihood of obsolescence occurring. Table 7.1 shows the characteristics for the criticality attribute.

**Table 7.1:** Criticality Attribute Ranking

<b>Criticality</b>	<b>Value(1-5)</b>
Safety	4
Functionality	3
Cost	5
Complexity	5
Commonality	3
<b>Average</b>	<b>4</b>

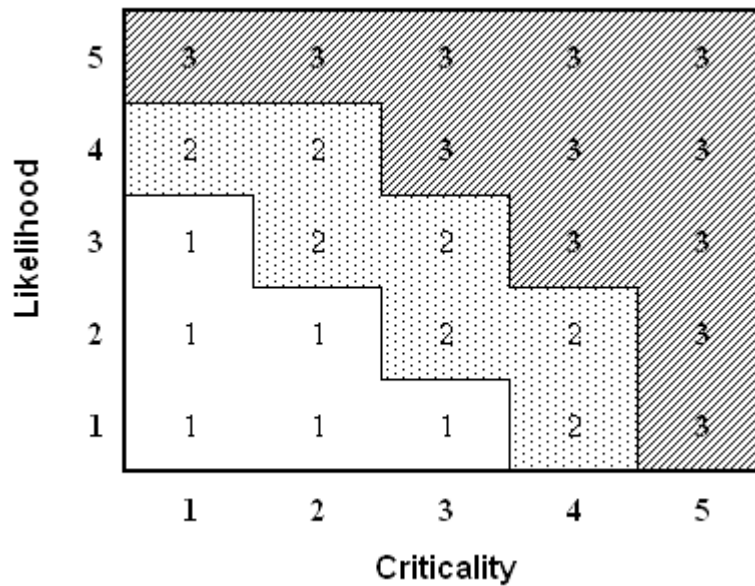
As can be seen safety, functionality, cost, complexity, and commonality are all identified by a cross-functional team as being part of the criticality characteristics. Values from 1-5 are assigned to each component by the cross-functional team comprised of engineering, finance, purchasing, and supply chain, where 1 is least critical and 5, most critical. In ranking a specific item in ABC’s bill of material the team asks, what are the implications on safety, functionality, cost, etc of the end product if the component is obsolete? In a similar way the characteristics of the likelihood characteristics are listed in Table 7.2.

**Table 7.2:** Likelihood Attribute Ranking

Likelihood	Value(1-5)
Low mean time between failures (MTBF)	3
In-Service Data received	4
Development Cycle	2
Special Mfg. Processes or Techniques	5
COTS, MIL-Spec. or Vendor item	2
<b>Average</b>	<b>3</b>

Low mean time between failures, in service data received, development cycle, special manufacturing process, and COTS items are ranked. The ranking for both the criticality and likelihood attributes are averaged and plotted on the rating scale depicted in Table 7.3 below.

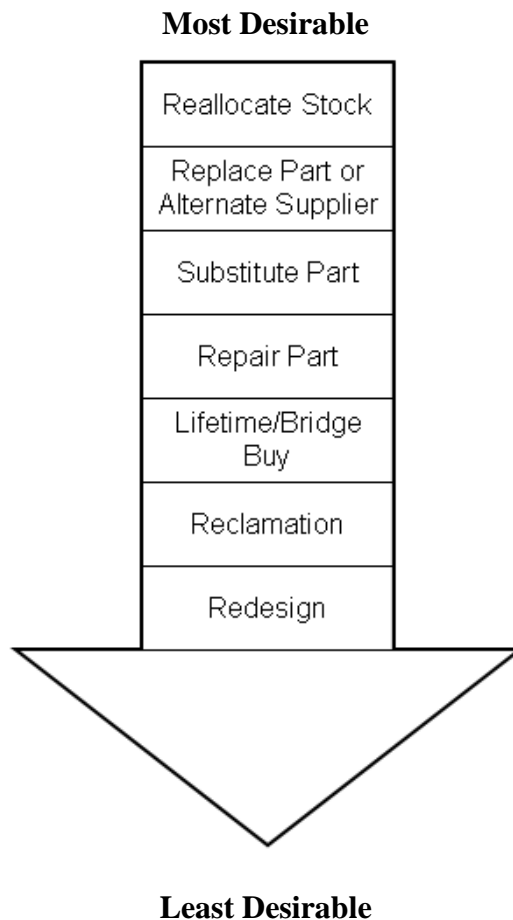
**Table 7.3:** Rating Table



If the ranking falls in the area labeled 1, the risk is deemed low and no immediate action is taken. The shaded area labeled 3 above indicates that the company places a high risk level on the component and shaded area 2 indicates a medium risk.

## 7.5 Mitigation

The obsolescence team initiates the appropriate actions necessary to generate alternatives for obsolescence resolution with a focus on maintaining current equipment capabilities and performance. The factors that are considered include impacts to cost, technical interoperability, schedule, logistics, and readiness. There are several approaches to obsolescence mitigation which consists of reallocating stock, replacing the part, substituting or repairing the part, executing a lifetime buy of the part, reclamation, or redesigning the part/system. Figure 7.2 depicts the approaches listed from most desirable to least desirable.



**Figure 7.2:** Most to Least Desirable Activities

The pros and cons to the approaches depicted above follows:

### **7.5.1 Reallocate Stock**

Residual stock is available in-house to satisfy the requirements of anticipated future use. This is the easiest solution, least costly, and a high degree of confidence that the stock to reallocate is compatible. The worst case scenario is that there is not enough stock available and that there may be a negative ramification on the program the stock was originally dedicated for. This option is seen as a temporary solution.

### **7.5.2 Replacement Part or Alternate Supplier**

A replacement part is available from the original manufacturer or the same part type is available from another manufacturer. A qualification process may be required to qualify this manufacturer. Form, fit, or function remains unchanged. The disadvantages are that a replacement part/alternate supplier may require detailed testing to determine compatibility and qualify the new manufacturer.

### **7.5.3 Substitute Part**

A different part is used to replace the original. Form, fit, or function may vary from the original part. Next higher testing or qualification testing may be required to verify the substitute part. The substitute part may be supplied from the same or different manufacturer. The baseline documentation is affected at certain levels.

#### **7.5.4 Repair Part**

Repair of component is possible. The repair of the component may be done with an alternate supplier or substitute part. Next higher testing is required to determine if this option is cost effective.

#### **7.5.5 Lifetime/Bridge Buy**

A one-time purchase of the quantity of the components needed to support the production and supportability for the life-cycle of the system. Lifetime buys can be very expensive. There are risks of under/over purchasing and shelf life and inventory holding costs need consideration. More advanced replacement parts may be available at a time in the future that may be more desirable.

#### **7.5.6 Reclamation**

Reclamation is the salvaging other items that haven't lost their functionality. The possibility of degradation of the item and its limited life has to be assessed.

#### **7.5.7 Redesign**

The next higher testing that contains the obsolete component must be modified to maintain the same level of functionality. There are costs, schedule, baseline documentation, and logistics to consider.

### **7.6 Analysis**

To assist company ABC in identification of high risk components we developed a tool depicted in Figure 7.3 below. The tool links company ABC's bill of materials as indicated below and performs a risk assessment.

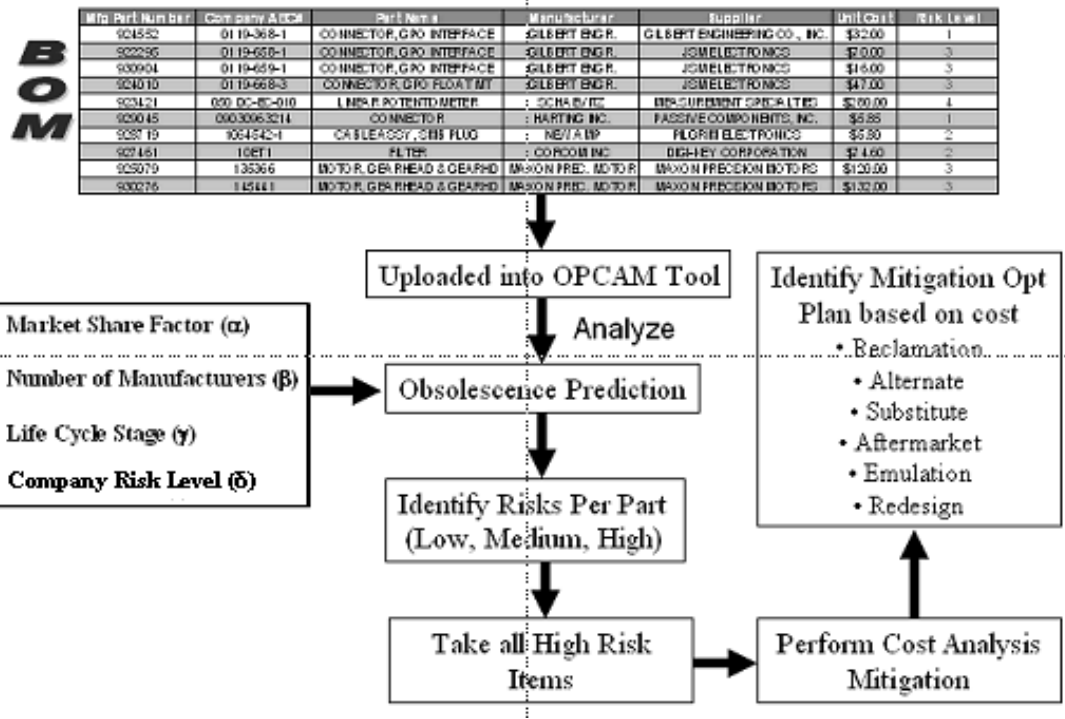


Figure 7.3: Company ABC's Obsolescence Mitigation Strategy

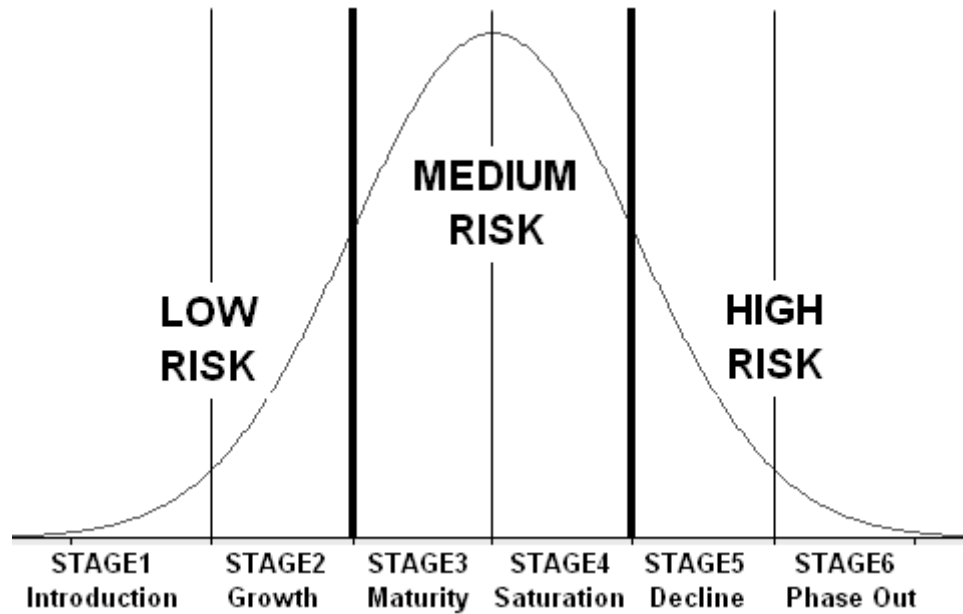
The four factors identified to be part of the risk assessment are listed in Table 7.4 below.

Table 7.4: Risk Assessment Factors

Factor	Parameter	Level
Market Share	$\alpha$	Low, Medium, High
Number of Manufacturers	$\beta$	Low, Medium, High
Life Cycle Stage	$\gamma$	Low, Medium, High
Company ABC' Risk Rating	$\delta$	Low, Medium, High

Information on component market share, number of manufacturers currently producing the components, as well as the life cycle stage is available through third party companies at a nominal cost. The component life cycle curve is depicted in Table 7.4 below. For

our risk assessment determination we assume that the introduction and growth stages are low risk, maturity and saturation stage are medium risk and the decline and phase out stages are high risk.



**Figure 7.4:** Product Life Cycle Stages

### 7.7 Algorithm

The algorithm utilized by the model as follows:

$$RISK\ INDEX = w_1\left(\frac{(\alpha - 1)}{2}\right) + w_2\left(\frac{(\beta - 1)}{2}\right) + w_3\left(\frac{(\gamma - 1)}{2}\right) + w_4\left(\frac{(\delta - 1)}{2}\right)$$

where:

- $w_i$  = weighted average of the  $\alpha, \beta, \gamma, \delta$  factors for  $i = 1, 2, 3, 4$
- $\alpha$  = Manufacturers' Market Share and (1=Low, 2=Medium, and 3=High)
- $\beta$  = Number of Manufacturers/Availability and (1=Low, 2=Medium, and 3=High)
- $\gamma$  = Life Cycle Stage and (1=Low, 2=Medium, and 3=High)
- $\delta$  = Company's Risk Level as defined by the management team and (1=Low, 2=Medium, and 3=High)

As an example, let's assume that the weight of each factor is the same (i.e.  $w_1 = w_2 = w_3 = w_4 = 0.25$ ). Let's also assume that all factors are high risk.

$$RISK\ INDEX = w_1 \left( \frac{(\alpha - 1)}{2} \right) + w_2 \left( \frac{(\beta - 1)}{2} \right) + w_3 \left( \frac{(\gamma - 1)}{2} \right) + w_4 \left( \frac{(\delta - 1)}{2} \right)$$

Thus,

$$RISK\ INDEX = 0.25 * \left( \frac{(3-1)}{2} \right) + 0.25 * \left( \frac{(3-1)}{2} \right) + 0.25 * \left( \frac{(3-1)}{2} \right) + 0.25 * \left( \frac{(3-1)}{2} \right) = 1$$

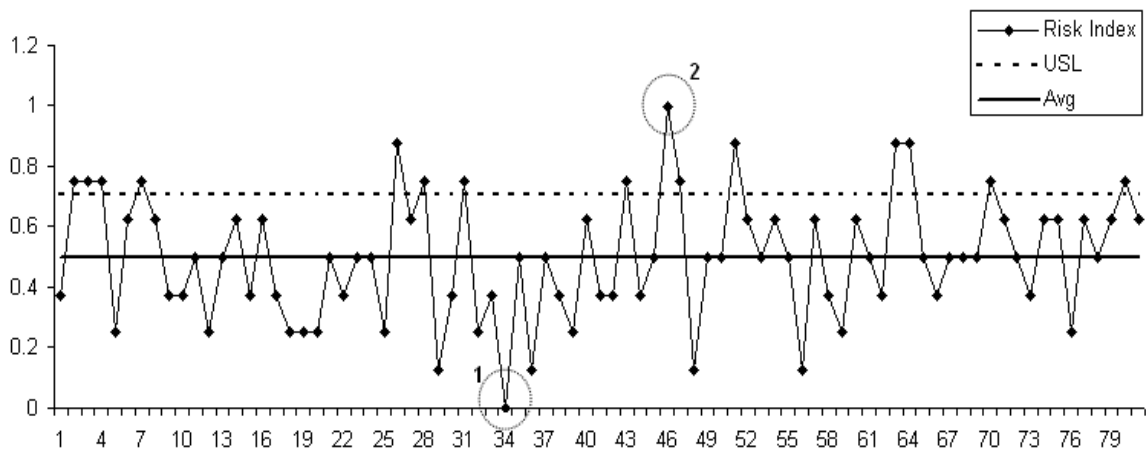
In this case immediate action is performed on the component to mitigate the risk. In this way the risk can be assessed for each component and mitigated based on the severity. In an experimental design consisting of 4 factors and 3 levels, there are  $3^4$  or 81 possible outcomes. Table 7.5 depicts all the possible outcomes for one component, where 4 factors at 3 levels yield 81 outcomes.

**Table 7.5:** Possible Values for one component

run	Full Factorial Design				Numeric				Risk Index
	$\alpha$	$\beta$	$\gamma$	$\delta$	$\alpha$	$\beta$	$\gamma$	$\delta$	
1	L	L	L	L	1	1	1	1	0
2	L	L	L	M	1	1	1	2	0.125
3	L	L	L	H	1	1	1	3	0.25
4	L	L	M	L	1	1	2	1	0.125
5	L	L	M	M	1	1	2	2	0.25
6	L	L	M	H	1	1	2	3	0.375
7	L	L	H	L	1	1	3	1	0.25
8	L	L	H	M	1	1	3	2	0.375
9	L	L	H	H	1	1	3	3	0.5
10	L	M	L	L	1	2	1	1	0.125
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
75	H	H	L	H	3	3	1	3	0.75
76	H	H	M	L	3	3	2	1	0.625
77	H	H	M	M	3	3	2	2	0.75
78	H	H	M	H	3	3	2	3	0.875
79	H	H	H	L	3	3	3	1	0.75
80	H	H	H	M	3	3	3	2	0.875
81	H	H	H	H	3	3	3	3	1

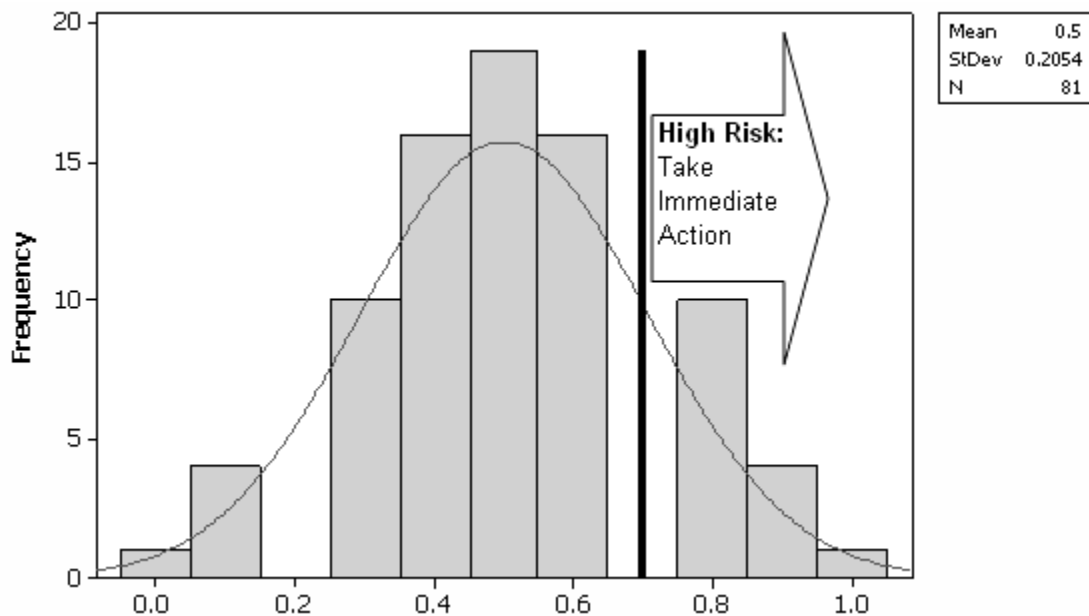
As can be seen in the table above, a low assessment for all factors yields low to no risk.

As the levels increases for all factors, so does the risk index. Table 7.5 is randomized and graphically depicted in Figure 7.5 below.



**Figure 7.5:** Risk Index Possible Values for one Component

As can be seen the risk value for this design has 81 outcomes ranging from zero (low risk) to 1 (high risk). In the case of company ABC, there are thousands of components in their bill of materials. It is not cost effective to mitigate every single component thus this effort to narrow down the selection and concentrate on the high risk components is a tactical and strategic approach to staying ahead of the curve. Figure 7.6 depicts the possible risk assessment for a typical item when the weights are evenly distributed across the 4 factors. In the figure below we hypothetically decide that a value above one standard deviation from the mean is considered high risk and flagged for mitigation.



**Figure 7.6:** Risk Mitigation

The cost mitigation analysis will determine the appropriate actions to be taken, where Figure 7.2 depicts the actions from most desirable (reallocation of stock) to least desirable (redesign) from ABC’s perspective. Reacting to obsolescence and initiating a life-time buy of the discontinued component may not always be the best approach as one

ties up capital in inventories which may itself become technically obsolete later as a newer version downstream may offer the functionality required of the customers in a few years. We will use the binomial options pricing approach in a hypothetical numerical example to determine the optimal decision.

### 7.8 Decision Analysis:

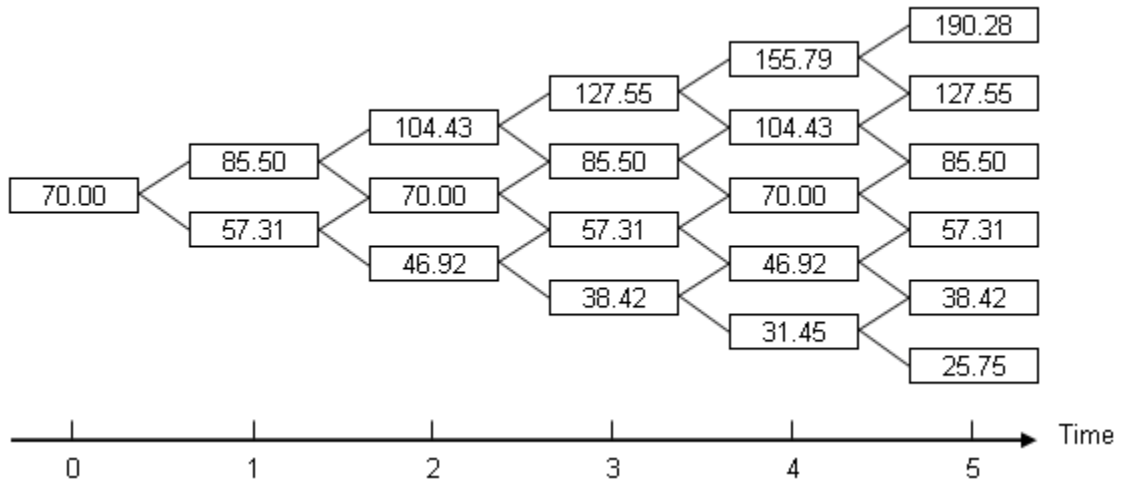
Performing a life-time buy, substituting the part or initiating a design refresh may all be possible approaches in successfully launching the new product. However, waiting to invest in a new technology when more information is available later on may also be very valuable strategic considerations for the manufacturer which should be explored.

In the contexts of company ABC, let's assume that orders have been placed for 5 units. The value of each unit is \$14 million. The cost of implementation is assumed to be \$12 million per unit. The costs include raw material purchases, production costs, labor costs, inventory holding cost and overhead as depicted in Table 7.6. The decision analysis utilizes a non-dividend paying American Call Option.

**Table 7.6:** Baseline Parameters

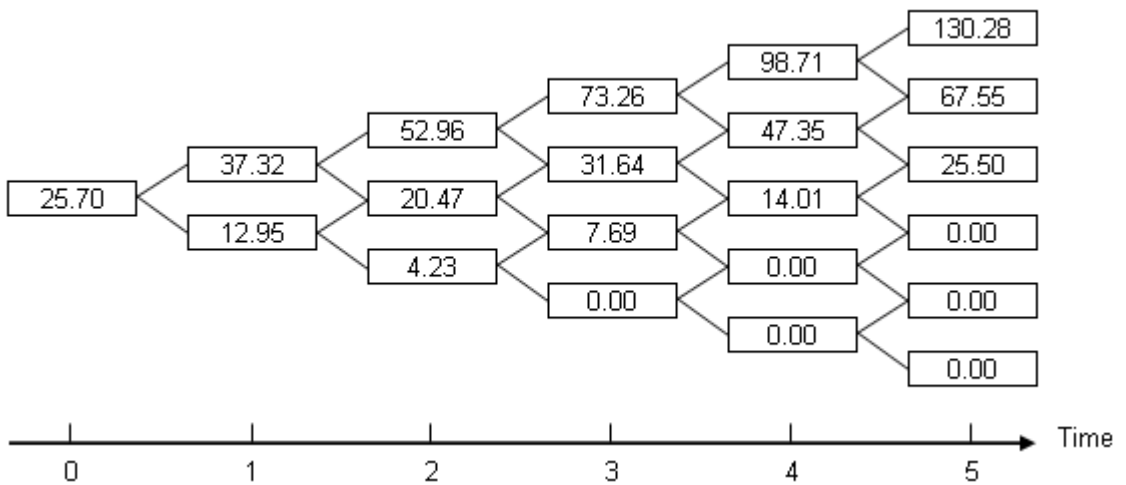
<b>Variable</b>	<b>Value</b>
Asset Value/Unit (\$)	\$14 million
Total Asset Value (\$)	\$70 million
Implementation Cost/Unit (\$)	\$12 million
Total Implementation Cost (\$)	\$60 million
Maturity (Years)	5
Risk-free Rate (%)	5%
Dividends (%)	0
Volatility (%)	20%
Lattice Steps	5
Stepping-Time (dt)	1
Up Step-Size (up)	1.2214
Down Step-Size (down)	0.8187
Risk-neutral Probability (prob)	57.75%

Figure 7.7 represents the underlying lattice results of the 5 period binomial model.



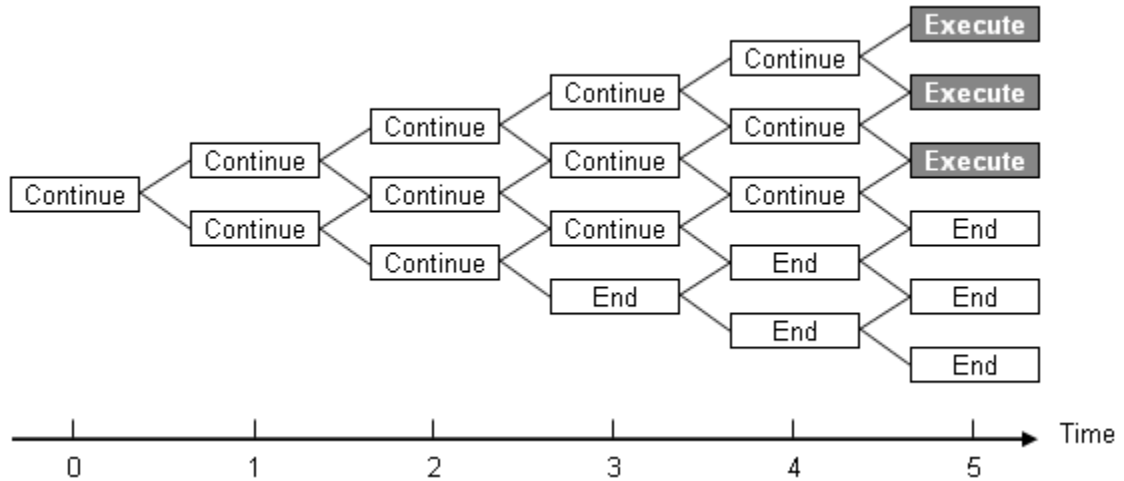
**Figure 7.7:** Asset Lattice

The first node shows the initial asset value of \$70 million, which jumps up to \$85.50 million or down to \$57.31 million in the first period. Next, the option value lattice is computed and shown in Figure 7.8.



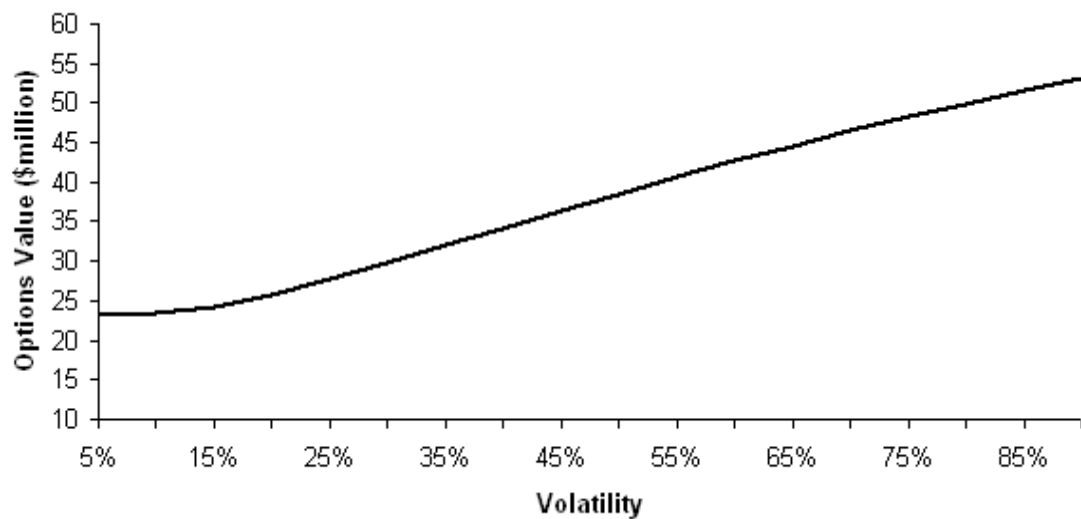
**Figure 7.8:** Option Value Lattice

The value of the option is \$25.70 million in the baseline model. Figure 7.9 shows the decision lattice.



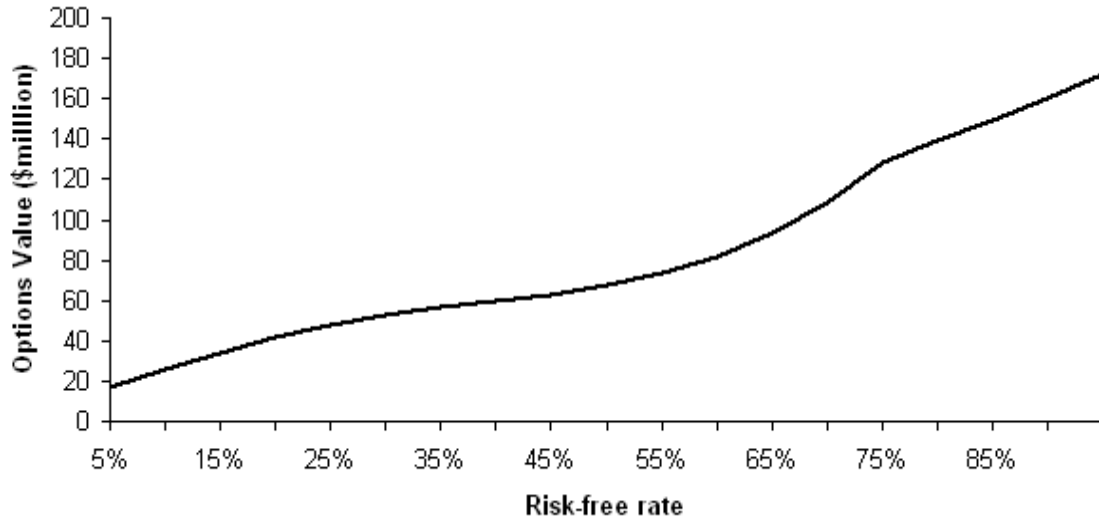
**Figure 7.9:** Decision Lattice

As can be seen from the decision lattice there are several different paths that can be taken to maintain a positive present value and thus an in-the-money position for the manufacturer. Tables 7.10 show the change in the Options value as a function of volatility which indicate that volatility contributes positively to the options value.



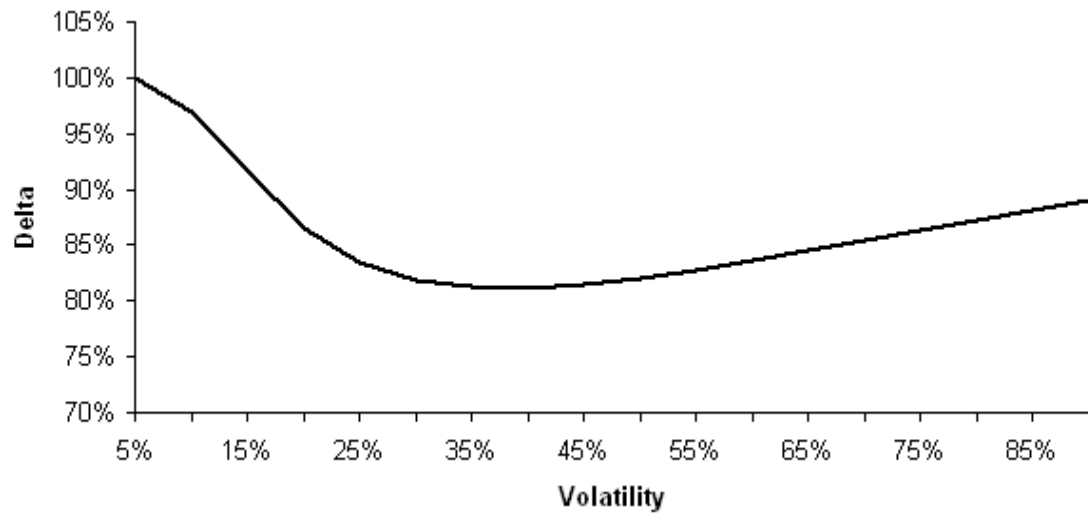
**Figure 7.10:** Options Value as a function of Volatility

Likewise, and increase in the risk-free interest rate in this case shows an increase in the options value in this example which is depicted in Figure 7.11.

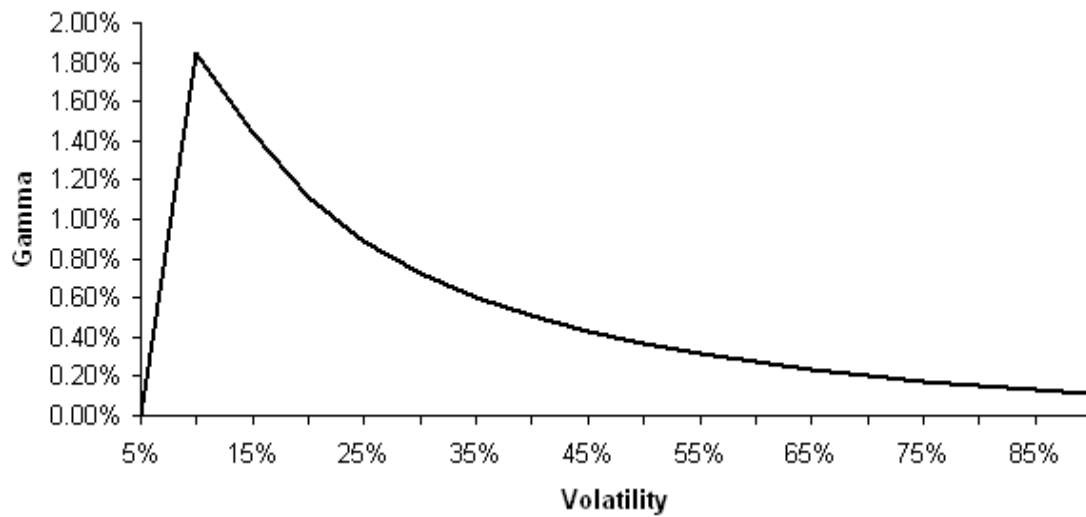


**Figure 7.11:** Options Value as a function of the Risk-free rate

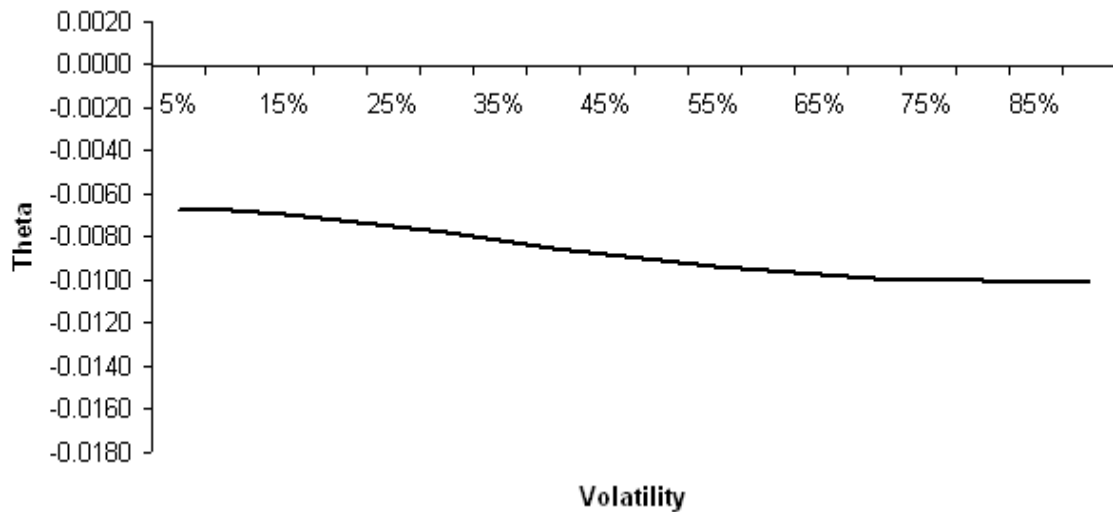
Figures 7.12, 7.13, and 7.14 depict the delta, gamma and theta sensitivities respectively.



**Figure 7.12:** Delta as a function of Volatility



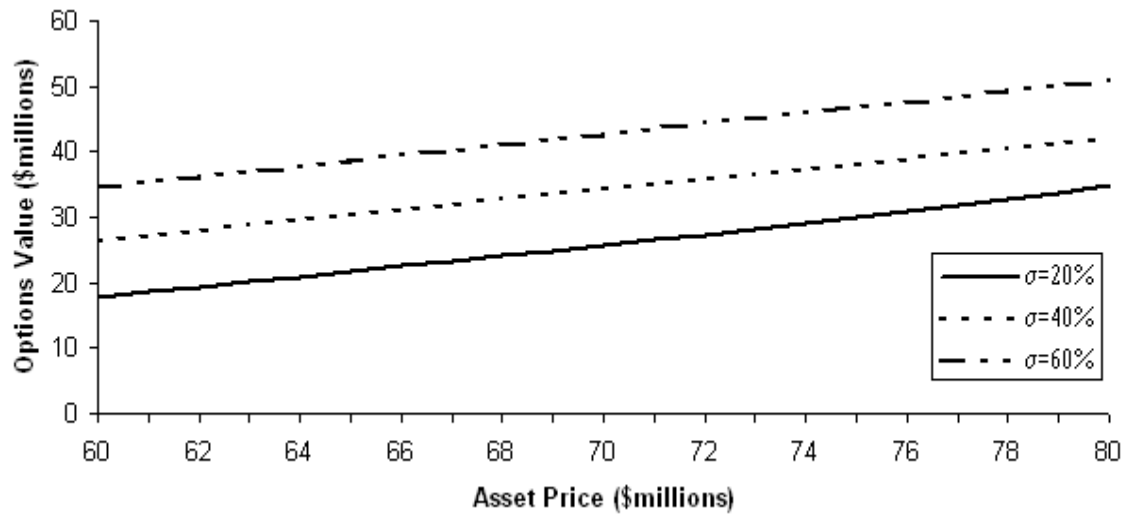
**Figure 7.13:** Gamma as a function of Volatility



**Figure 7.14:** Theta as a function of Volatility

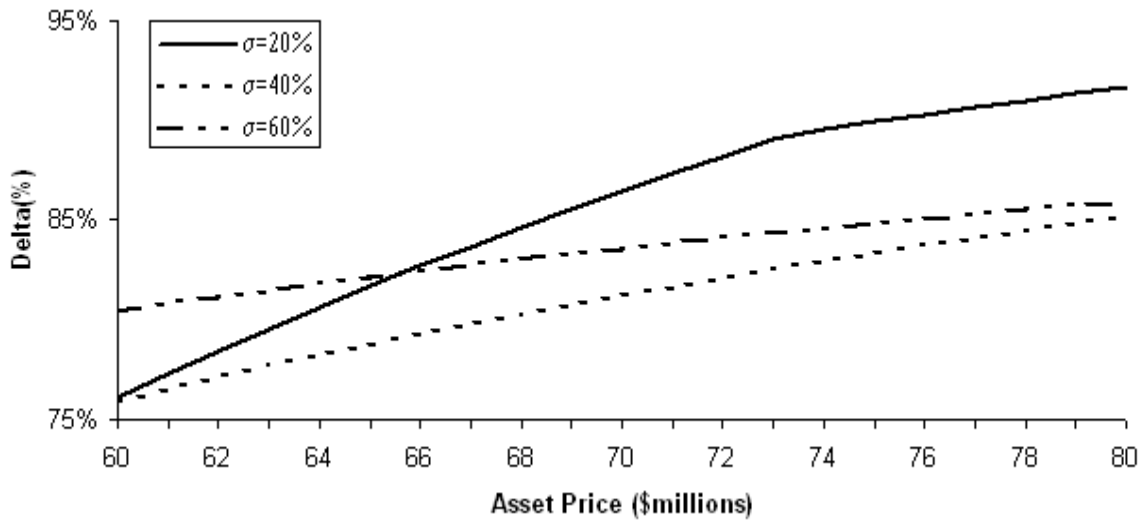
Simulations were performed for 3 different volatilities as a function of a small change in the asset price. The volatilities were held constant at  $\sigma = 20\%$ ,  $40\%$ , and  $60\%$  and represented in Figure 7.15 below. Figure 7.15 indicates a gradual increase in the value of

the option with a unit increase in asset value. The asset value changes over time as a result of changes in supply and demand spurred by market dynamics. Additionally, factors such as the functionality, technology, sustainability also have an impact on the asset value.



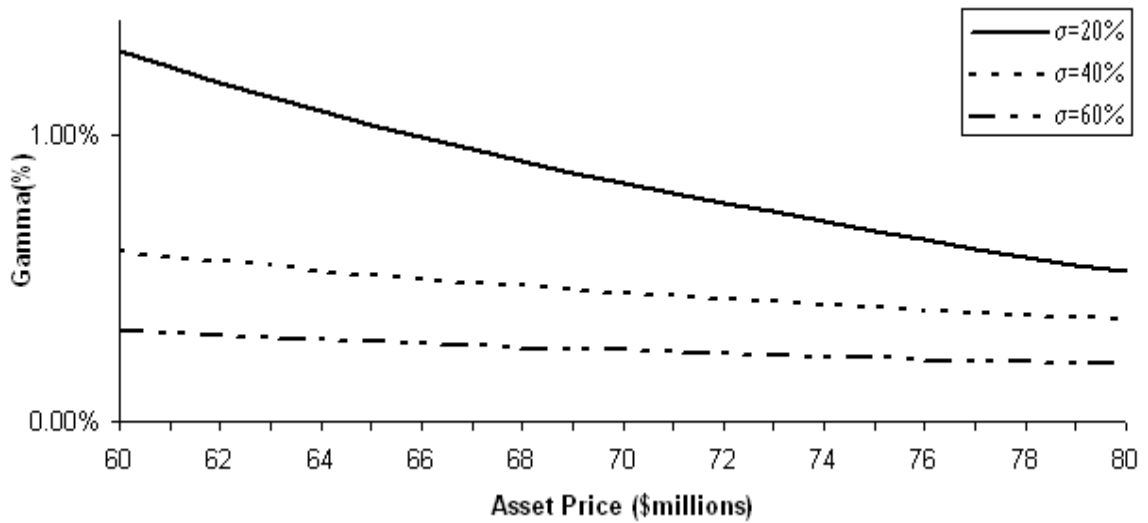
**Figure 7.15:** Options Value as function of Asset Price for 3 values of  $\sigma$

Figure 7.16 shows the delta sensitivity which is the percent change in the options value as a function of a unit change in the asset value. As can be seen, the options value increases for all 3 volatilities, however for  $\sigma = 20\%$ , the change in the option value has a steeper slope indicating a bigger change in the option value.



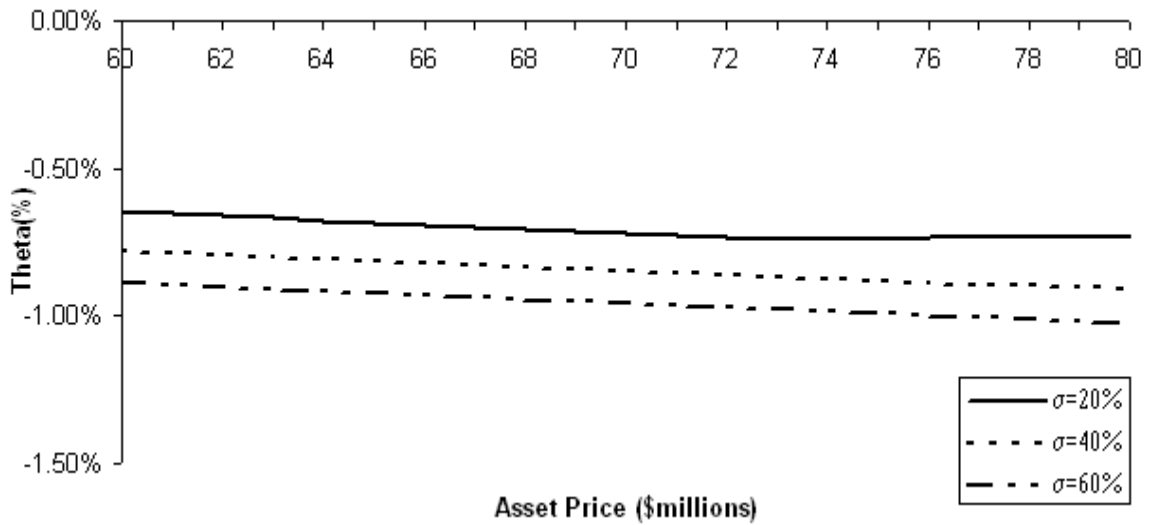
**Figure 7.16:** Delta for 3 values of  $\sigma$

Figure 7.17 represents the gamma sensitivity, which is the change in delta as a function of a unit increase in the asset price.



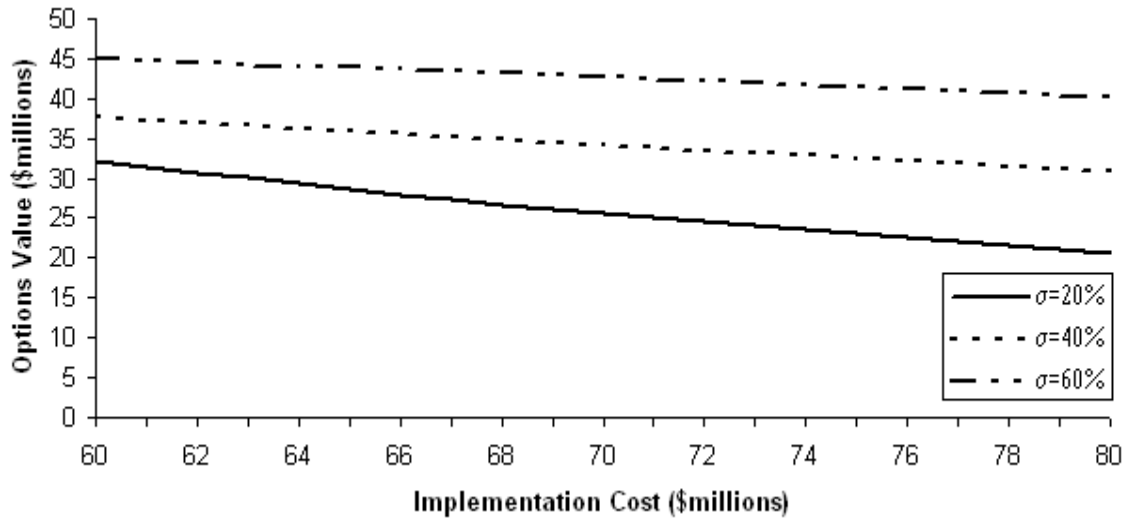
**Figure 7.17:** Gamma for 3 values of  $\sigma$

Figure 7.18, the theta sensitivity plot, indicates that there is no significant difference in the options value as a result of a one period closer to project completion.

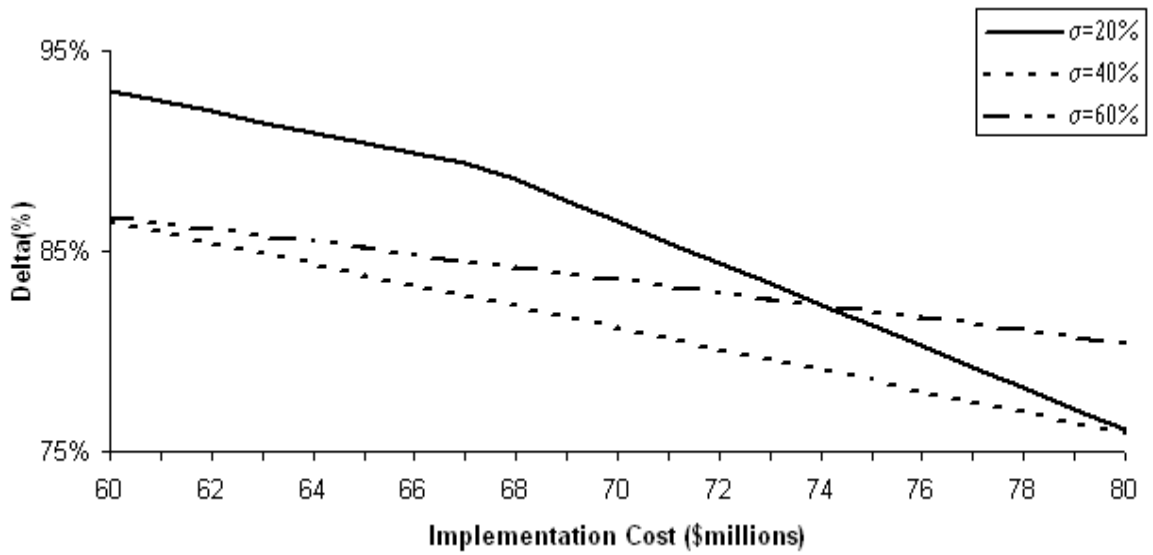


**Figure 7.18:** Theta for 3 values of  $\sigma$

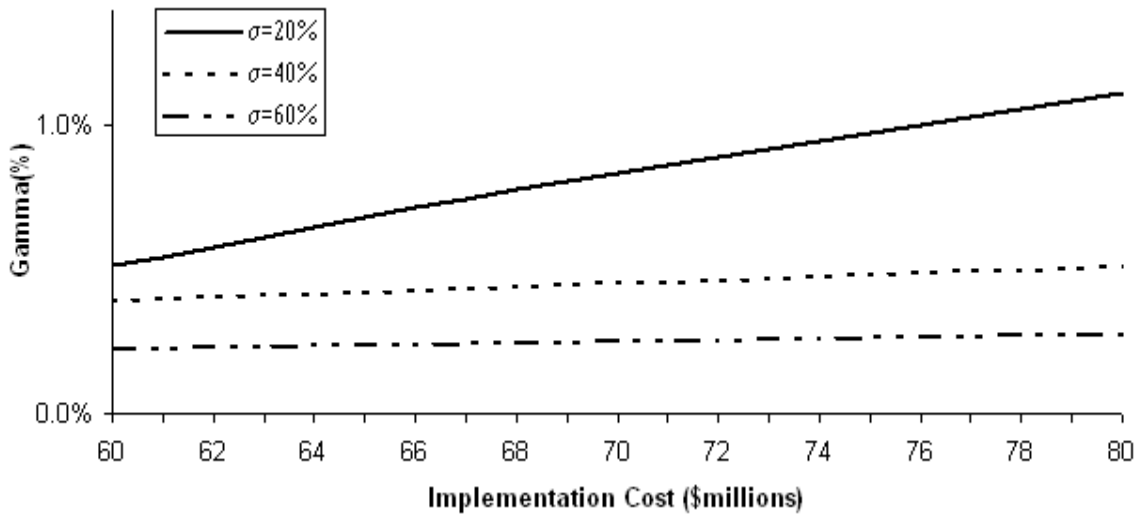
Similar to the analysis performed above on the change in asset price, the following four plots shows the sensitivities of the options value as a function of the implementation cost. Again, we perform the simulations for 3 values of volatility namely, 20%, 40%, and 60%. Over the course of a project, implementation costs can change as a result of many factors. For example the initial budget could have under/over estimated the costs as a result of “*hidden factories*”. Additionally, the impact of components obsolescence can have a significant impact due to expensive mitigation solutions. Figure 7.19 depicts the change in the options value as a function of a change in the implementation costs. As can be seen, and intuitive, is the fact that the value of the option decreases as the cost of implementation rises. Figures 7.20, 7.21, and 7.22 depicts the delta, gamma and theta sensitivities to the change in implementation costs.



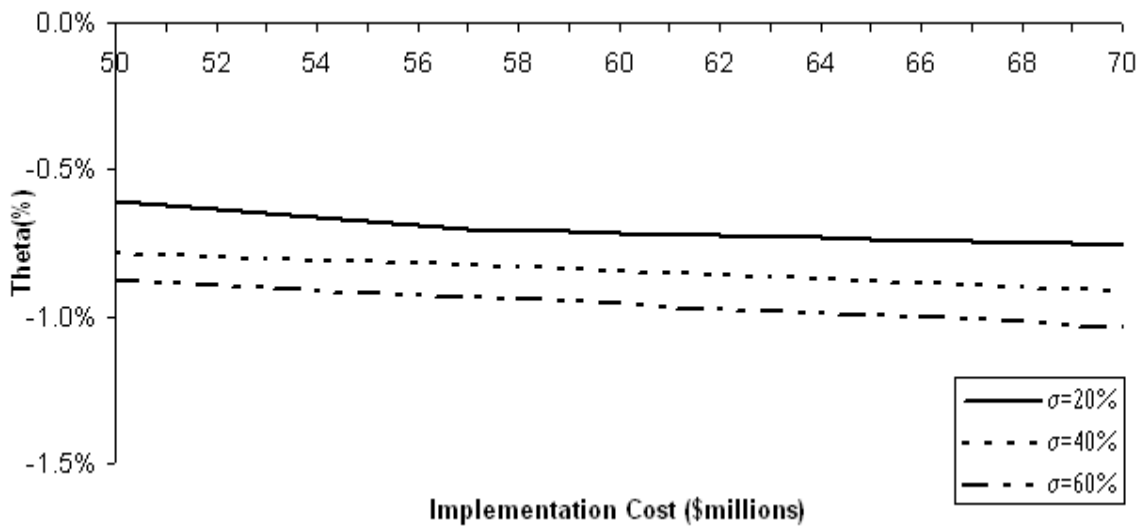
**Figure 7.19:** Options Value as function of Implementation Cost for 3 values of  $\sigma$



**Figure 7.20:** Delta for 3 values of  $\sigma$

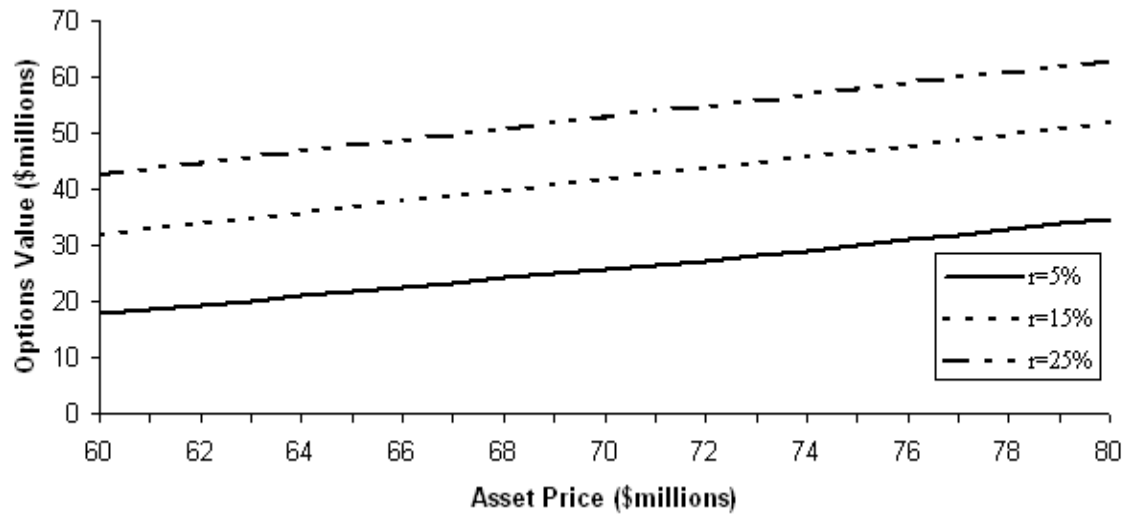


**Figure 7.21:** Gamma for 3 values of  $\sigma$

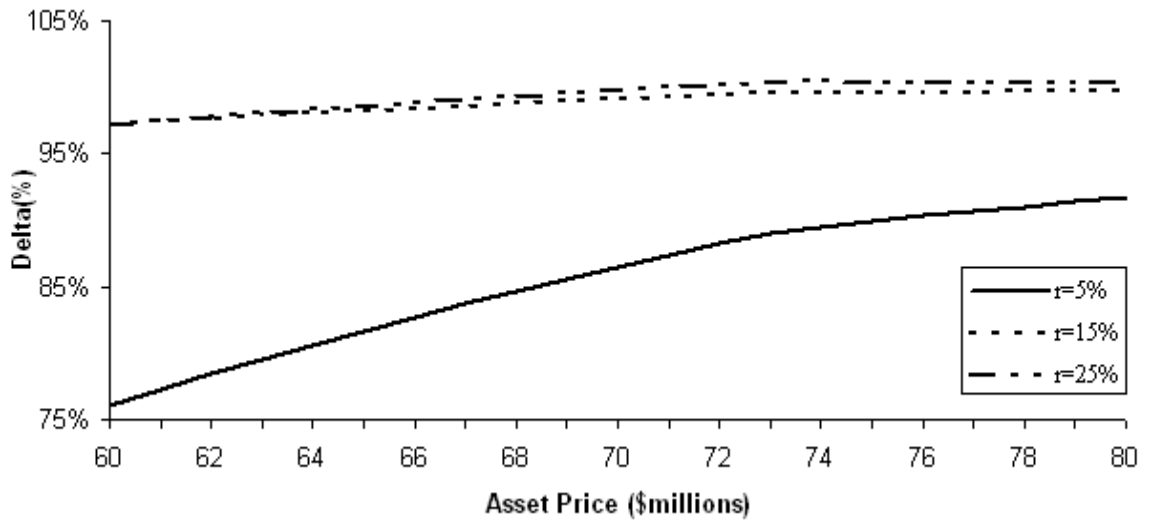


**Figure 7.22:** Theta for 3 values of  $\sigma$

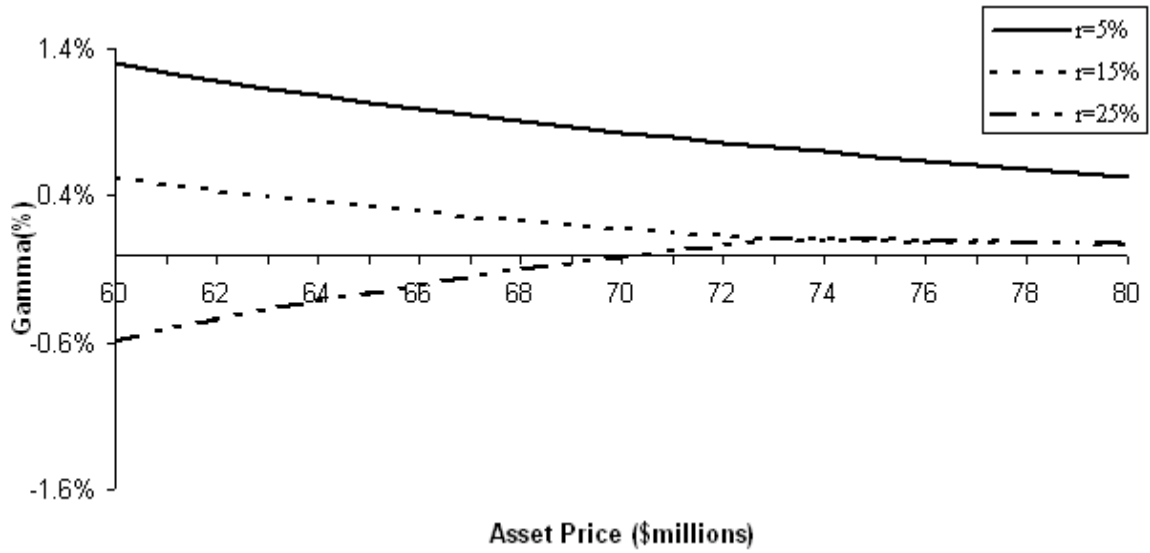
Plots 7.23 show the change in the asset price for 3 values of the risk-free interest rate, were  $r = 5\%$ ,  $10\%$ , and  $25\%$ . As can be seen an increase in the risk-free rate increases the value of the option. Plots 7.24, 7.25, and 7.26 depicts the sensitivities on delta, gamma and theta for the example depicted in plot 7.23.



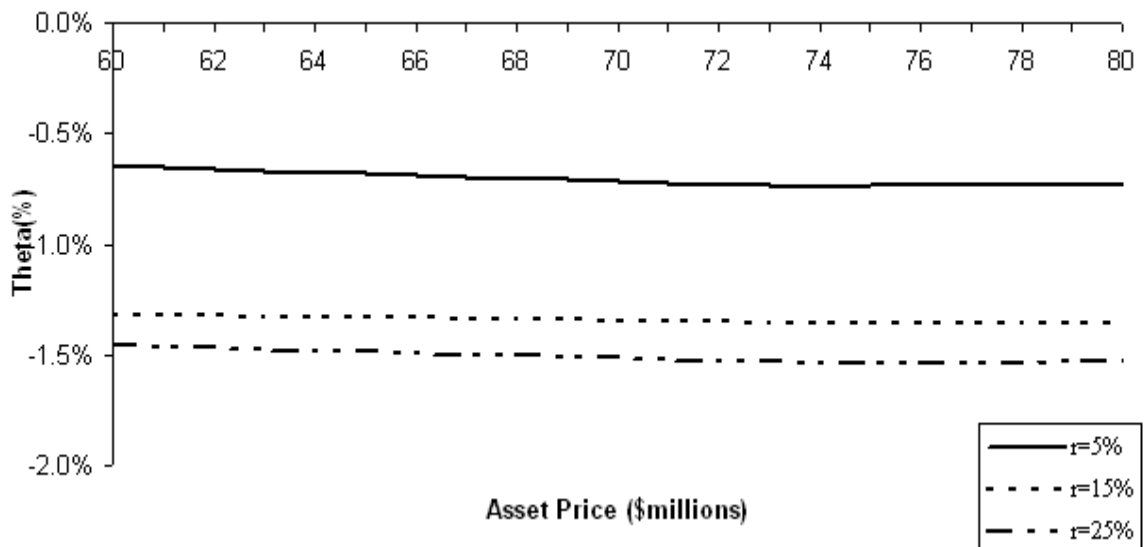
**Figure 7.23:** Options Value as function of Asset Price for 3 values of  $r$



**Figure 7.24:** Delta for 3 values of  $r$

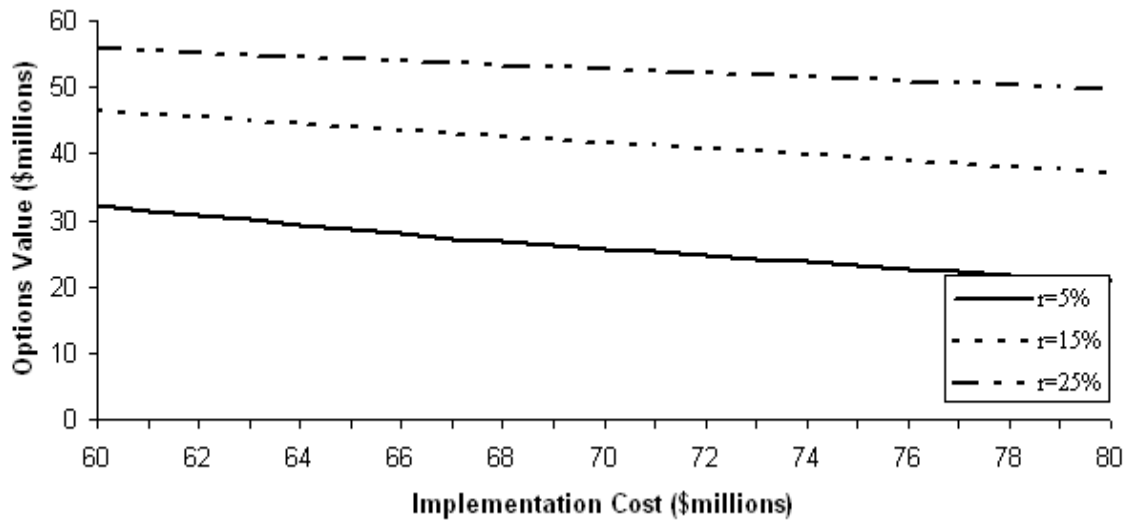


**Figure 7.25:** Gamma for 3 values of r

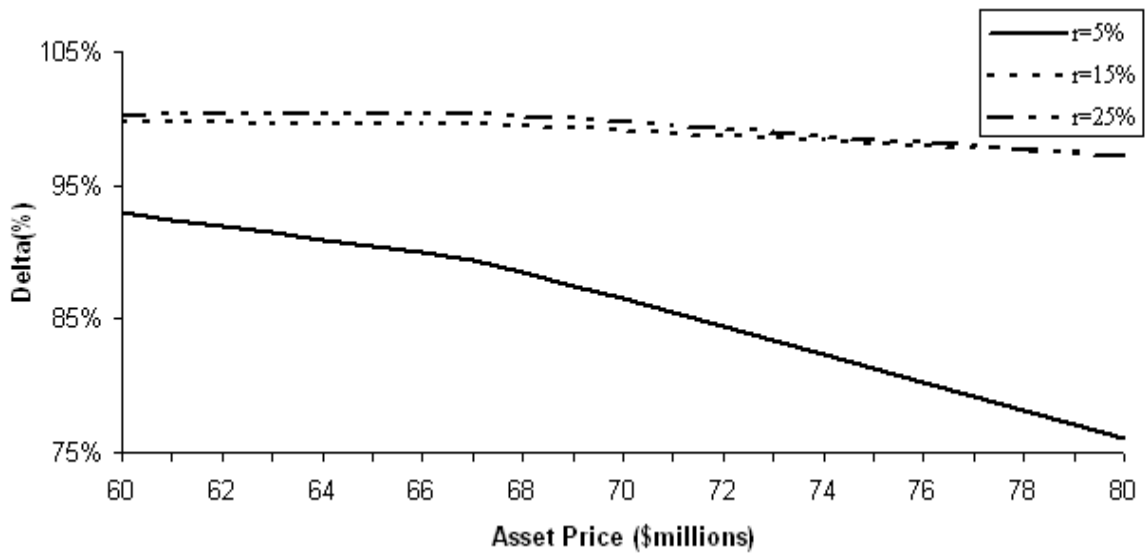


**Figure 7.26:** Theta for 3 values of r

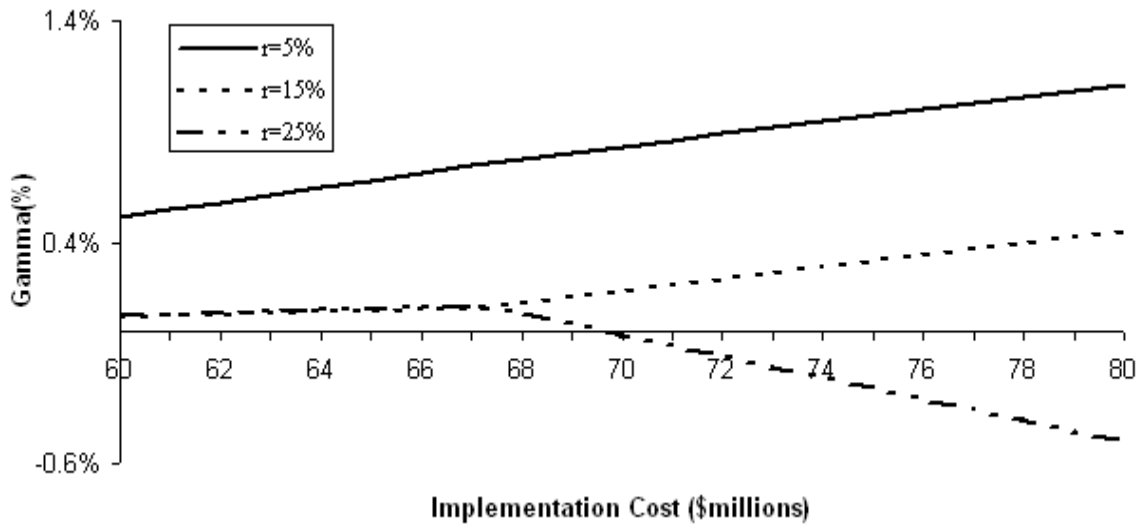
Similar analysis and sensitivities were performed on the risk-free interest rate as a function of implementation costs. The results are depicted in figures 7.27 to 7.30.



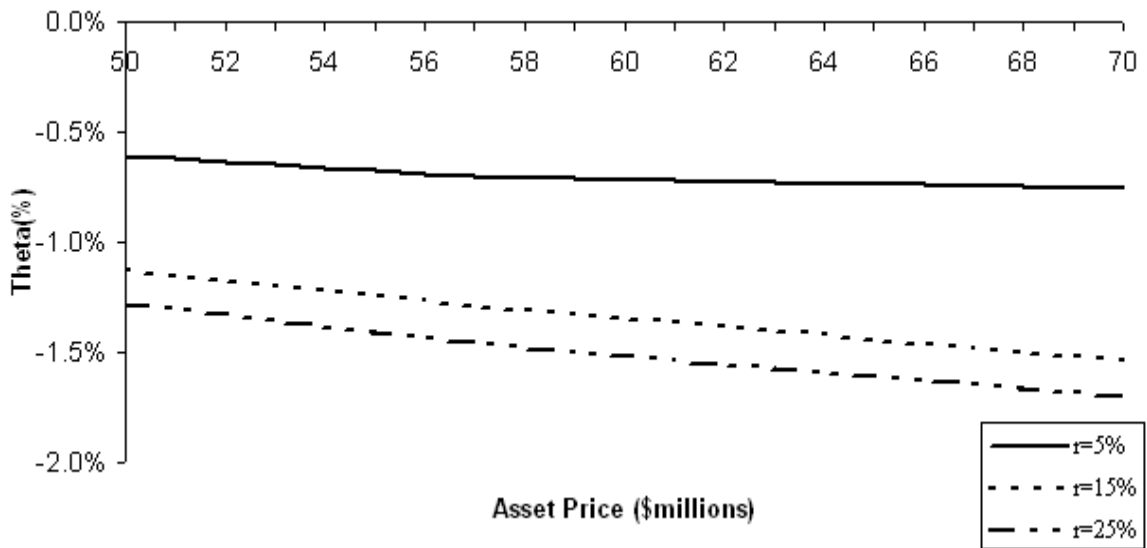
**Figure 7.27:** Options Value as function of Implementation cost for 3 values of  $r$



**Figure 7.28:** Delta for 3 values of  $r$

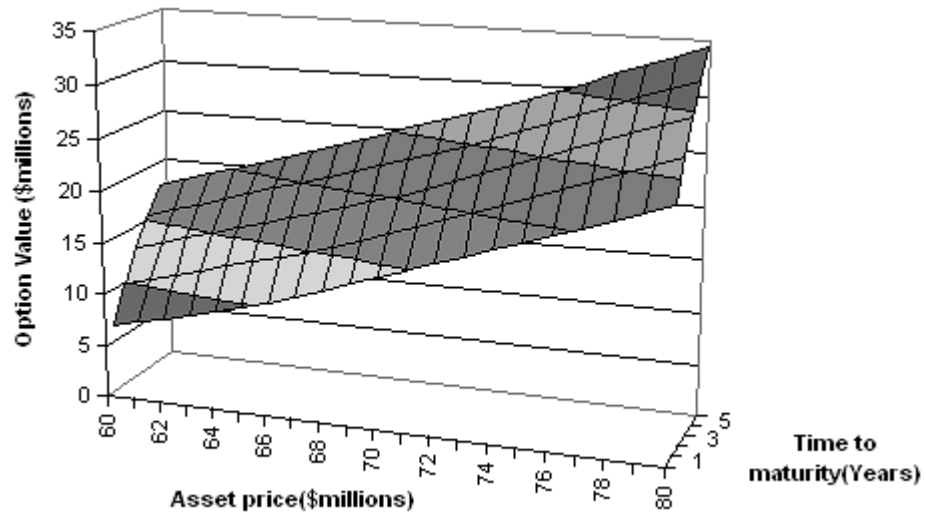


**Figure 7.29:** Gamma for 3 values of r



**Figure 7.30:** Theta for 3 values of r

Figure 7.31 shows a 3 dimensional plot of the change in options value as a function of asset price and the time to maturity of the investment.



**Figure 7.31:** Change in Options Value

In this way company ABC can proactively address their issues of obsolescence making the best informed investment decision. The 3 approaches described in this chapter, obsolescence, management and mitigation, and real options based approaches are a significant step in the direction of addressing obsolescence proactively.

## **CHAPTER 8**

### **CONCLUSION**

#### **8.1 Introduction**

The fundamental objective of this research was to develop a generalized approach to proactively managing and mitigating issues of component obsolescence in the “high-tech” electronics industry. This was accomplished through 3 main themes; obsolescence prediction, proactive mitigation and management, and options pricing decision making to determine the optimal decision.

#### **8.2 Theme 1 – Obsolescence Prediction:**

In the first major theme of developing approaches to predicting obsolescence, there are many different directions that can be employed. Firstly there are companies who offer product discontinuance notification services at a nominal cost. Typically they send subscribers of their services an email notifications based on what they receive from the OEM of the part. While this can be an advantage as it assists in the identification of component discontinuances, it also has its disadvantages. One disadvantage is that it is often limited to the manufacturer notifying the service provider of component discontinuance. However, there are many instances where the component manufacturer’s discontinuance notification is sent out late and in some cases, after the product has already been discontinued limiting the options of responding effectively. There are many examples of companies such as company ABC that find out about a discontinuance or obsolescence of a part when the part is needed in their production schedule. This often leads to negative ramifications, which includes scheduled delays and expensive

mitigation approaches. Thus, a combined approach of subscribing to the discontinuance service notification and prediction tools to complement it is advantageous.

A generalized approach and tool is presented in the case study to predict obsolescence of company ABC's components in their bill-of-materials. The algorithm developed to identify high potential risks is based on 4 key variables including market share, number of manufacturers producing the component in question, life cycle stage, and a qualitative risk rating of components by the company. The qualitative risk rating factor is obtained by the company in two different categories, the criticality and likelihood category. The criticality category consists of 5 factor rankings which include safety, functionality, cost, complexity, and commonality. The likelihood category include factors such as mean time before failure, in-service data received, development cycle, special manufacturing processes, COTS items, mil-spec items, or vendor items. All this information is collected and synthesized through the algorithm. The result is a classification of the level of risk of all products in the companies' bill of materials. The high risk items are singled out for mitigation. Thus allowing the company to proactively manage and mitigate the obsolescence effect, rather than reacting to it later on. This proactive approach is seen as necessary by all levels of management within company ABC as their previous approach of reacting after the effect has proven to be very costly. In addition to the algorithm that is performed at the bill of materials level, prediction can also be done on individual components. As an example, we chose the microprocessor. The microprocessor has evolved rapidly over time with shorter life cycles to discontinuance. The impact is significant in low volume complex electronic products with long life cycles. Simply changing from one processor to another is no simple task and often involves re-testing,

re-certification, re-qualification, redesign, and software reprogramming. Depending on the product that the processor is embedded in, it can prove to be critical and very costly, especially in the avionics industry. Thus a chapter was devoted to the computer processor to give an overview, discuss its complexities, and develop models to predict obsolescence of processors based on historic trends and future market requirements.

### **8.3 Theme 2 - Proactive Mitigation and Management:**

Secondly, an approach was developed in the case study to address proactive management of obsolescence. Being proactive about issues of obsolescence involves industry developing standardized approaches to dealing with issues of obsolescence. This approach or roadmap requires cross-functional participation including management, engineering, procurement, finance, and supply chain to collaborate in order for it to be effective. The obsolescence management team needs to develop repeatable processes that are sustainable and challenge the culture of the company to be cognizant of obsolescence at all levels of product development as well as establishing supplier and vendor sourcing relationship that minimizes the effects of component obsolescence.

### **8.4 Theme 3 - Options Pricing Decision Making:**

Thirdly, options pricing as a decision making tool is presented. Options pricing models can be used at various stages of decision making to determine the best outcome. Making difficult and strategic decisions about when to invest, what technology to invest in, waiting until a future point in time when a new technology may be available, are all difficult questions to answer. Financial options have been used widely to help decision-makers hedge their risks as it incorporates risk and uncertainty. Real options are

becoming more and more popular as it relates to non-financial or real assets. For example real options modeling may be used to decide on building a new manufacturing facility, whether to explore a new oil drilling venture, to proceed to the next phase in bringing a new drug to the market. Real options are based on the Black-Scholes model and have since expanded to include many extensions for use in different situations. In this dissertation we explore the binomial and trinomial model in particular as it relates to decision making in obsolescence management and mitigation. The advantages of using these models is that it has multiple nodes for decision making and not based on one decision point as in the case of traditional discounted cash flows, which is currently a standard practice in industry. The benefit of using the binomial and trinomial models is that it has many paths and allows the company to change direction in the future when more information becomes available. The generalized approach using the binomial model was used in the case study with company ABC and shows the decision maker can take many different directions depending on the value of the option as it relates to the asset value, the implementation costs, the risk-free rate, and the market volatility. Sensitivity analysis is also performed to indicate the effect of small changes in different parameters.

### **8.5 Contribution:**

This approach is novel. Although recent attention has been given to component obsolescence, in general, issues of component obsolescence are still dealt with reactively in many high-tech industries. Traditional discounted cash flows are widely used as a decision making method, ignoring the flexibility of multiple decision points and paths that is common among real options pricing approaches. The use of options pricing is first

of its kind as a decision making approach in obsolescence mitigation decisions. Thus the proactive management approach, component obsolescence prediction, and the use of real options including the binomial and trinomial models are an extension to the field and area of obsolescence management. Currently, billions of dollars are budgeted in the high-tech industry to cope with issues of obsolescence as inevitability. These companies including and not limited to the department of defense, avionics industry, power plants, and space based programs. The money is spent reactively as obsolescence occurs and often exceeds the budgeted amount. Thus an opportunity exists for developing robust approaches to minimize costs, but also create a competitive product that is sustainable and maximizes revenue generation.

### **8.6 Future Work:**

Real Options offers much promise to the area of technology obsolescence and management in the high-tech electronics industry as a result of the uncertainty associated with it. In this dissertation we only explored two extensions of the Black-Scholes model, namely, the Cox-Ross-Rubinstein binomial model (1979) and to some extent, the trinomial model developed by Boyle(1986). There are many additional extensions to the Black-Scholes model that can be explored in future work. For example Rendleman and Bartter's (1979) binomial model, where the volatility is constant for each time step. Leisen and Reimer developed a binomial tree in 1996, where the up and down steps are set in a way that has certain implications on the strike price, allowing the tree to converge in a certain way and is said to be more efficient. Rubinstein and Edgeworth include skewness and kurtosis in their generalized binomial model in 1998. Derman, Kani, and Chriss's implied trinomial trees (1996) offers more flexibility. In addition, Monte Carlo

simulation which was first used by Boyle (1977), will be explored in future work as it allows a range of stochastic processes to be incorporated.

The options pricing models were explored in a generalized sense. In follow-up work specific instance included but not limiting to the following mitigation options will be explored in the binomial calculations; reallocation of stock, part replacement, part substitution, repair, life time buy, reclamation, and redesign.

In this research we did not explore flexibility from a product design perspective. Embedding flexibility into the design architecture of a product or system should be the normal progression for companies to follow. Fast clockspeeds are quickly eclipsing the boundaries of most high-tech products thus newer revisions are occurring monthly and even weekly. In order to maintain a certain level of competitiveness in the marketplace the products have to be flexible for upgradability and sustainability. This allows developers and designers to quickly change from one-iteration to another without significant schedule delays. Modularity is an important aspect to focus on in future work as it embeds additional layers of flexibility into the design. Thus, an exploration of architecture modularity as a means of creating flexibility in the design is proposed for future. We know that the level of flexibility and modularity embedded into a design comes at a cost, but can be a strategic advantage. Thus evaluating flexibility of the design by using a variety of options pricing model, to account for risk and uncertainty as well as determine the cost/benefit analysis in arriving at the optimal decision will be explored in future work.

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