A Real Options Approach to Manage Flexible Contracts in the Telecommunication Networking Industry

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Abstract

One of the biggest challenges facing Original Equipment Manufacturers (OEMs) and Electronic Manufacturing Services (EMS) providers in the telecommunication networking industry is to predict the spending patterns of the telecommunication service providers due to uncertainties in the economy, intense competition, short product life cycle in the industry and many other factors. While studies over the years have focused on optimizing the expected profits by minimizing the risk of excess inventory, companies are also unwilling to forgo profits on unmet demand. This is especially so in a market that is worth well over $100 billion even during the economic downturn. Including the cost of damaged relationships and future market opportunities, the cost of lost sales can be very significant the increasingly competitive market.

This thesis explores the use of real options to enable a telecommunication networking company to structure their supply chain so as to better exploit the upside opportunities when actual customer demand significantly exceed forecasted demand and actual demand can only be confirmed when the delivery lead-time is less than the normal supply lead-time. The thesis sets forth a framework for developing real options analysis and evaluated three approaches against the current supply contract between the OEM and EMS provider. Recommendations that will allow the company to improve their profits in the event of surged demand were then made.

The main finding of the thesis is that in times of increased demand, the real options approaches studied all generated higher value for the company than simply relying on demand forecasting. However, beside projected demand, companies considering using real options must consider a number of parameters including the option price, strike price, cost of lost sales and salvage value of the product concerned. In the case of the company concerned in the study, it is recommended that they establish a safety stock option with their EMS provider.

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CHAPTER ONE - INTRODUCTION

1.1 Introduction

The effective management of supply chain is a complex and challenging task due to current business trends of increasing product variety, shorter product lifecycle, increasing outsourcing and collaboration/partnerships, globalization of businesses, and changes in technological advancements both in the information and product flow. In recent years, effective supply chain management is seen as an important capability for companies to gain a competitive advantage over its competitors. This is especially so as market competition and technological advances are constantly driving down profit margins.

One of the biggest challenges facing companies is the ability to respond to uncertain customer demands with the lowest possible resources i.e. matching supply with demand with the aim to maximize profits. To meet this challenge, companies have been focusing its efforts on achieving greater flexibility in the supply chain so that it can rapidly adjusts its production output to match market demand and to switch from one product variant to another. While there is much literature studying the approaches to manage uncertainties in the supply chain, Lee. H [2002, p.114] provided a framework to manage uncertainties in the supply chain as shown in Figure 1.1.

Figure 1-1 - Strategies to Manage Supply Chain Uncertainties

Demand Uncertainty

Supply Uncertainty	**Low** (Functional Products)	**High** (Innovative Products)
Low (Stable Products)	Efficient supply chain	Responsive supply chain
High (Evolving Products)	Risk-hedging supply chain	Agile[1] supply chain

Source : Lee, H. (2002)

[1] - As there are many definition of lean, agile and le-agile in the literature, the term agile is used synonymously with lean and le-agile in this paper.

Depending on the uncertainties faced by the industry, different strategy is appropriate to meet the supply and demand uncertainty in the industry. For the high-tech industry, the extremely short product lifecycle, perennial introduction of new technology and technological standards, sophisticated fabrication and production process, changes in competitor's offerings and fluctuations in discretionary spending on high-tech products makes both the supply and demand in the high tech industry highly uncertain. As such, it is crucial that high tech companies adopts the agile supply chain strategy and utilize a combination of risk-hedging and responsive strategies to manage the uncertainties faced by the industry.

The supply chain capabilities established by companies implementing an agile supply chain are largely focused on reducing the risk of these uncertainties while maintaining the capability to exploit opportunities offered by the uncertainties. Some of the supply chain capabilities built includes:

- Forecasting Planning and Management
- Inventory Planning and Management
- Product Modularization and Commonality
- Outsourcing
- Geographic Dispersion of Key Resources
- Forward Positions on Supply Contracts
- Postponement

One of the possible capability is to employ real options to exploit supply and demand uncertainties by mitigating the "downside" risk while maintaining the "upside" opportunities of these uncertainties [Billington et. al, 2002]. The idea is to create options, much like those used by financial institutions for managing interest rates, foreign exchange rates, stock prices etc., to substantially improve companies' performance and create value for their shareholders. Real options gives one the right but not the obligation to take some action (invest or not, buy or not etc.), now or in future at a pre-determined price on or before a pre-determined date [de Neufville, 2003].

1.2 Thesis Objective

The key research question of this thesis focuses on how a telecommunication networking company can structure their supply chain using real options to better exploit the upside opportunities when actual customer demand significantly exceed forecasted demand and the actual demand can only be confirmed when the delivery lead-time is less than the normal supply lead-time. Although real options can be used in many areas of the supply chain to mitigate the downside risks and preserve the upside opportunities e.g. sales option, manufacturing option, supply option etc., this thesis focus solely on procurement option. This is because the company concerned has outsourced majority of its manufacturing and supply operations. The objective is therefore to study the management of supply chain flexibility to meet surge demand in the telecommunication networking industry using real options analysis.

1.3 Organization of Thesis

The thesis is organized in six chapters. Chapter Two details the problem that the high-tech company faces and lays down the approaches that the study will focus. It also includes a background of the industry and the high tech company involved in the study. In Chapter Three, a review of the literature on Real Options is presented. The review also discusses and develops the approach that is appropriate for the specific problem that the study is confronted.

Chapter Four provides an overview of the model and assumptions required to replicate the real option analyses. It develops a basic model for the analysis, which is then built upon to adapt to the various feasible approaches. Chapter Five presents the results and findings of the simulation. It includes a sensitivity analysis of the impact of the various key parameters in the model.

Lastly, Chapter Six summarizes the findings and sets forth the recommendations for the company, as well as suggests some additional areas for further study.

CHAPTER TWO - THE TELECOMMUNICATION NETWORKING INDUSTRY

2.1 Telecommunication Networking Industry Background

The liberalization of the telecommunication industry and the proliferation of the internet in the '90s created the boom in the global telecommunication networking industry over the last decade. There were both strong competition and huge demand for innovative products by the customers. As a result, many Original Equipment Manufacturers (OEMs) were constantly introducing new products with greater sophistication and shorter life cycles. The need to focus on product innovation saw the OEMs increasingly turning to Contract Manufacturers (CMs) for some or all of their manufacturing and assembly operations. And as the industry grew, the increased production and supply chain services provided by CMs eventually evolved into the current outsourcing model in the industry where OEMs completely outsource their manufacturing and supply chain management.

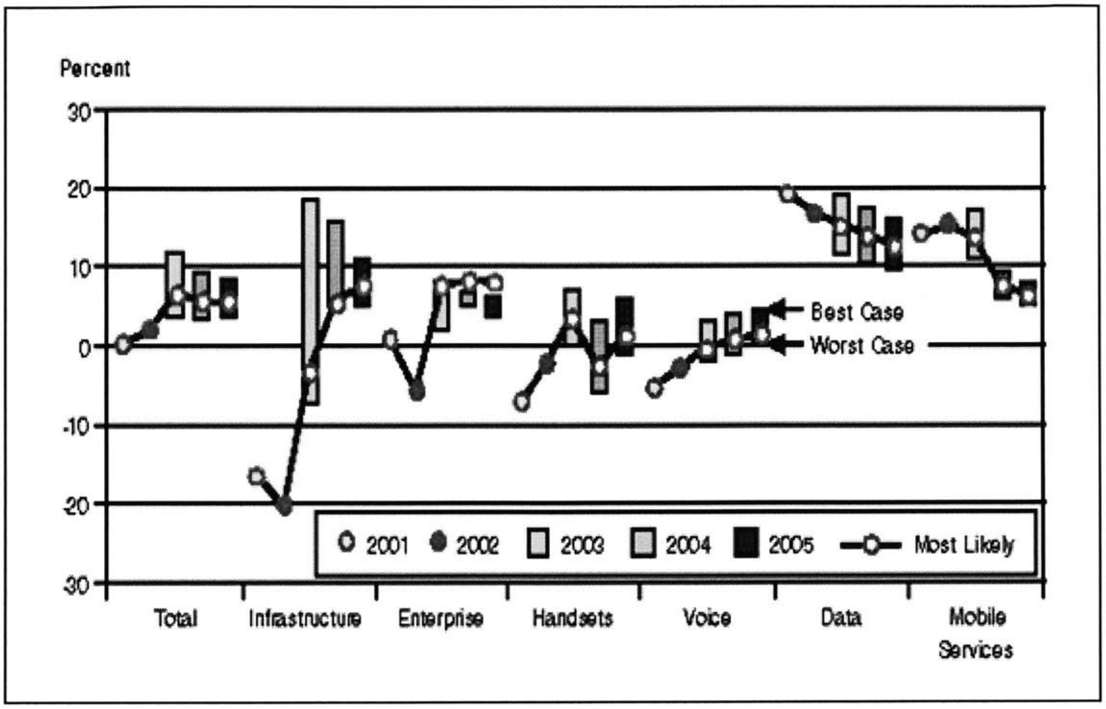
With the industry maturing in the late '90s, the role of the CMs in the entire production cycle was expanded to the extent that the CMs had to undergo major changes in their business model. As a result of this expanded role, CMs are now referred to as Electronic Manufacturing Service (EMS) providers. EMS providers are companies based on providing contract design, manufacturing, and related product services on behalf of OEMs. EMS providers are increasingly managing more and more critical supply chain activities for the OEMs, providing services from design to fulfillment. This leaves the OEMs to redirect their internal resources towards R&D and value-add to the products for reselling to the telecommunication companies.

Over the duration of the boom period in the '90s, the optimism in the market condition and demand generated a huge amount of investments in capacity and inventories within the industry. The rapid evolution and introduction of products in the industry saw the constant build up of inventories throughout the industry during the period. However, in the midst of this optimism, the telecommunication and Internet industries were suddenly hit by an unprecedented down cycle in 2000/01 – arguably the worst in its history. The depth and duration of the decline in spending by telecommunication service providers around the world was unexpected by most in the industry. As a result of this decline, the industry was laden with significant excess capacity that was built during the telecom boom in the late 1990s, and many OEMs and EMS providers also ended up stocking a huge amount of inventory; capacities and inventories throughout the supply chain were significantly underutilized. Many OEMs and EMS providers had to consolidate their positions; OEMs were cutting off orders to the EMS providers and EMS providers to their suppliers, expansion and growth strategies were put on hold etc. Over the last few years, companies have reviewed their operations and supply chain strategies, and utilization of supply chain capacities have been constantly improving.

However, the communication gap between the OEMs and EMS providers continues to persist in many instances. A survey by the European Business and innovation centers Network (EBN) in 2002 of more than 300 executives revealed that despite outsourcing a huge amount of functions to the EMS provider, OEM's perception of their EMS provider is far from ideal [Shah, 2002]. Although OEMs perceive that their EMS providers to be good followers of orders, they feel that the EMS providers do not anticipate their needs properly and have inferior supply chain management capabilities. As a result, despite clamoring by the EMS providers for information on market forecasts, product designs, and order status, nearly two-thirds of OEMs polled by EBN indicated a limited sharing of forecast information and the sharing of data with their EMS providers, when done, is only on a monthly or weekly cycle; about 7.5% or less of the OEMs claimed to be providing real-time information on production and forecast data. The economy is believed to have hit its bottom, and is widely forecasted to improve in 2004 or 2005.

Figure 3-1 shows the forecast of the telecommunication industry by the Gartner Group in June 2003. Although the projected growth in the telecommunication industry is expected to be roughly flat from 2003 to 2005, investments in telecommunication infrastructure is projected to grow significantly over the same period; 10% to 12% in 2004 and another 3 to 4% in 2005. Growth for data and mobile services is expected to decrease while growth in handsets, voice and enterprise services are expected to increase. Coupled with the belief that the excess capacity in the industry has almost worked its way out during the last few years, OEMs and EMS providers are again bracing themselves for the much awaited recovery in the industry which is worth well over $100 billion even during the down-turn.

Figure 1-1 - Forecast of the Telecommunication Industry



Source : Jun 2003 Gartner, Inc. and/or Affiliates

But unless issues pertaining to the communication gap are addressed, analysts warn that history may repeat itself. "These issues, and the question of how excess inventory is dealt with, have not been resolved. That, combined with the growing spending by EMS providers on components, could lead to another massive swelling in inventories, similar to the phenomenon that deepened and lengthened the electronics industry downturn of 2001. ...... Putting procedures in place to delegate EMS-OEM responsibilities properly is a task of paramount importance for the continued health and success of the global electronics industry" said Scott Hudson, an iSuppli analyst [Shah, 2002].

Coupled with the difficulties in predicting the spending patterns of the telecommunication service providers due to the many uncertainties in the economy and the intense competition and short product life cycle of the industry's products, OEMs and EMS providers are presented with huge risks and challenges in the design and delivery of their supply chain in this highly volatile and rapidly changing markets. Amongst the greatest risks is the unprecedented degree of uncertainty in demand. Product demand is extremely difficult to predict, even in the short term, because of new products, changes in technology and technological standards, changes in competitor's products etc.

Many studies over the years have focused on optimizing the expected profits based on historical data, market projections etc. But this means that if demand is significantly higher than expected, the company will have to forgo profits on unmet demand, including the cost of damaged relationships and future market opportunities. For example, major personal computer manufacturers were severely limited by their production capacity despite sharp increases in personal computer sales in 1992 that production costs increased significantly as a result of over-time pay and expedited transportation. In another case, a shortfall in critical components proved very costly in July 1999 when Agilent's inability to obtain key components resulted in a sharp drop in revenue, causing the company's stock price to plummet 25%. On the other hand, the high cost of inventory accumulation is unacceptable to companies, especially those managing short life cycle products, who have learnt the painful lesson of inventory accumulation during the economic downturn over the last few years [Billington et. al, 2002, p.32].

To satisfy the dynamic nature of supply and demand in a complex interaction of uncertainties in the industry, a dynamic supply chain strategy is required. The OEMs and EMS providers need to explore new approaches to build flexibility into their supply chains in order to cope with the high uncertainty in the industry without increasing their risk exposure to product inventory and obsolescence. This ability to manage the uncertainties in the industry, and even profit from it, is increasingly recognized as a key source of competitive advantage for the company.

2.2 Supply Chain of the Telecommunication Networking Company

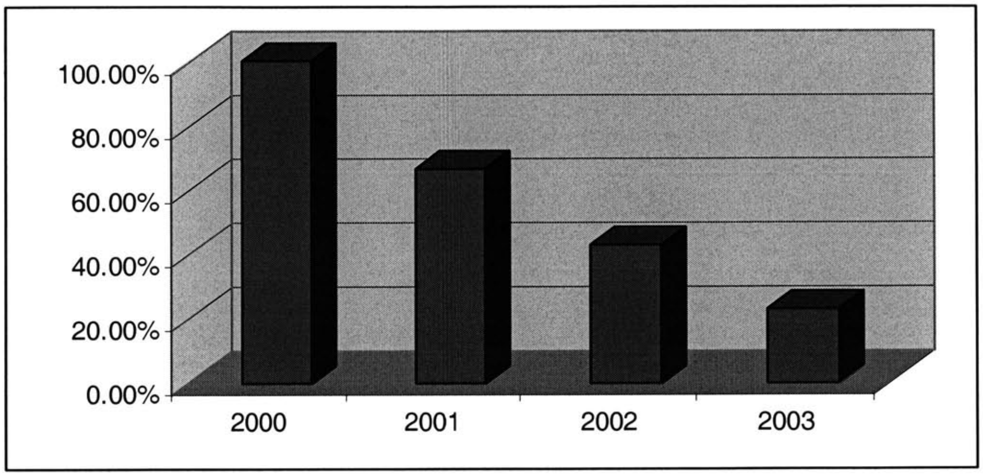
2.2.1 Overview of Company and its Supply Chain Organization

This research is based on a company, TeleWork (the real name of the company is not revealed for confidentiality reasons), who is a market leader in networking solutions for service providers with systems working in virtually all the world's largest service providers' networks. The company designs and delivers the systems, services and software that drive next-generation communications network. Like many in the industry, the company underwent a major restructuring exercise in the midst of the industry decline in 2000. The restructuring serves both as a means to get them through the downturn as well as to position them to grow profitably when the market recovers. As a result, beside huge reductions in costs and expenses, the restructuring improved the company's systems and processes to enhance services through efficiency, speed, quality and responsiveness. The company intends to emerge from the difficult times as the strongest player in the market and the partner of choice for their customers.

One of the key outcomes of the restructuring exercise is the renewed focus on the company's supply chain. A new supply chain set-up established within the company serves to unite all supply chain functions into a single organization. This renewed organization is responsible for the management and oversight of supplier and supply chain engineering and management, product and design chain engineering, test and component engineering, margin realization, procurement, manufacturing, logistics and distribution, outsourcing and contract manufacturing efforts as well as customer delivery.

The establishment was a significant step in moving the company from a vertical manufacturing environment to a virtual one. As part of the transition process, the supply chain unit developed new proprietary forecasting methods that accurately forecast what the profit margins will be in the future. In an effort to reduce inventory levels and its order cycle time in response to the weak market demand, the company managed to reduce inventory levels along with the number of warehouses and staging areas. As a result, the company managed to reduce the cost of inventories and warehouses by 80% between 2000 to 2003 (see Figure 2-2). In so doing, the company was also able to cut down on the number of suppliers by 80% facilitating closer collaboration with them.

Figure 2-2 - Reduction of Inventories & Warehouse in the Company



2.2.2 Company's Product Offering

TeleWork offers the industry's leading product portfolio in mobility, optical, circuit and packet switching and network operations software. Backed by a strong research unit, the company has assembled a range of products and services that is focused on next-generation wireless and wire-line networks. The company's product is generally characterized by its short one-year product life cycle. Rapid technological changes are also increasingly impacting product profit margins. This is further aggravated by increasing competition more so than in the 1990s. While the company managed to streamline its products during the downturn to focus on the most profitable opportunities with large service providers, it still maintained the most complete and competitive portfolio of products in the industry to meet the myriad needs of the customers. Currently, the company has thousands of products, each with thousands of components that can interoperate with the main hardware, to meet the diverse needs of their customers.

A product of the company typically consists of dozens of sub-assemblies which are manufactured, assembled and tested by different contractors. While the majority of the suppliers are sourced by the EMS provider, a few are self-sourced directly by the OEM to supply proprietary components for the product. Regardless of how the suppliers are sourced, the manufacturing of each of the sub-assemblies and components are then coordinated and assembled by the EMS provider. A product typically comprises a main assembly and a number of key components including the optics, amplifiers and the filters. And while the main assembly and some of the key components are supplied by the EMS providers, the optics which is a critical component of the product is usually supplied by the proprietary supplier to the EMS provider.

2.2.3 Supply Chain of the Company

2.2.3.1 Players in the Company's Supply Chain

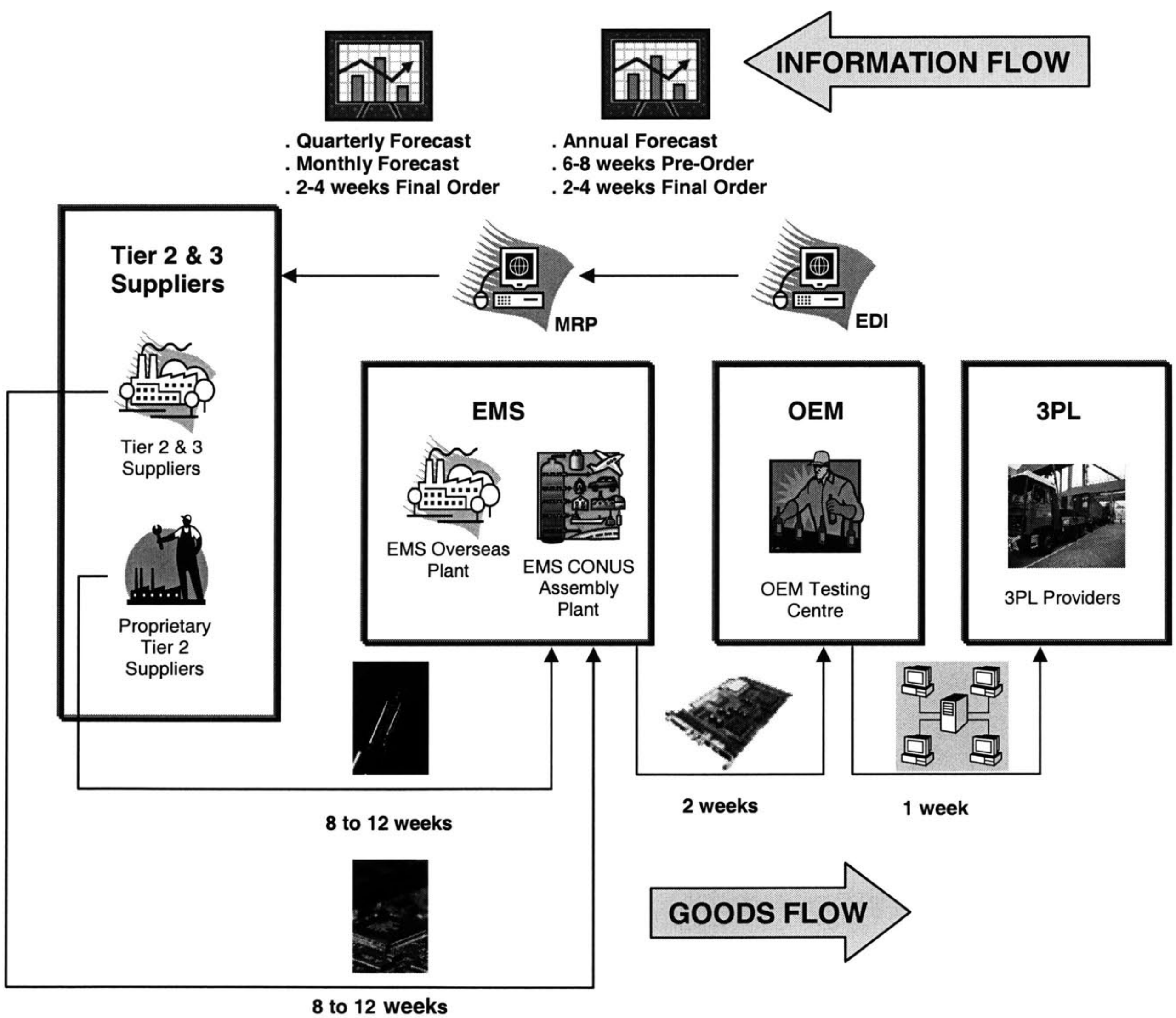
Since the restructuring, the company has moved from being vertically integrated (within the company) to a horizontally integrated company involving many partners multilaterally. Outsourcing their manufacturing and supply chain operations has been the main driver of change as it helps to distribute the associated risks of both supply and demand in the industry. In their current operation, there are two main categories of players in the company's supply chain; manufacturing and distribution.

Outsourcing of their manufacturing operations involve both the EMS providers and a small number of proprietary suppliers. Working with the EMS providers serves to improve efficiencies and achieve economies of scale in component production as the EMS providers are possibly supplying the same components to a myriad number of customers. The EMS provider also serves as the main coordination center from which the company's entire manufacturing operation is managed. It provides a spectrum of electronics manufacturing services such as printed circuit board assembly and test; prototype build; system assembly; repair; enclosure; backplane and supply chain management for the current and future generations of these products. On the other hand, the company continues to maintain the sourcing, assembly and testing of a limited number of proprietary products within the supply chain. These are usually important and proprietary components like the optics that differentiates the company's products from its competitors.

For finished goods inventory, the Company outsourced the management of the supply chain and distribution to third parties. This allows the company to better respond to their customers around the world given the global nature of its manufacturing operation.

2.2.3.2 Product's Supply Chain

Figure 2-3 - Typical Supply Chain of the Company



Forecasting of demand is performed by the company's Regional Office over a one-year horizon using proprietary forecasting methods. The forecast is then circulated within the company for consensual agreement between the sales, marketing, operations and supply chain departments before it is forwarded to the suppliers. Each month, the annual forecast is updated using a Pre-Order Forecast which is based on on-going contractual discussions between the company and their customers. This is typically between 6 to 8 weeks before the required delivery. The Final Order is eventually updated between 2 to 4 weeks prior to the required product delivery.

Upon receiving the consensus demand forecast from the company, the EMS provider enters the quarterly forecast into the Manufacturing Resource Planning (MRP) system. The MRP process for the product will explode the Bill Of Materials (BOM) that in turn places demand to the Tier 2 and Tier 3 suppliers. As orders are received, the company will forward it to the EMS provider and these orders will then take the place of the forecast to drive demand. Therefore, each week, there is a combination of demand placed for both actual and forecasted orders. Thousands of parts, often from China and Europe belonging to many different contractors, are then brought to a single location at a specific time and assembled into a finished product. And since the EMS provider also operates multiple manufacturing plants across the world, the production lead time across the entire supply chain is significantly longer than the forecast lead time. Tier 2 suppliers will typically take between 8 to 12 weeks to complete the production. The EMS providers will require an additional 2 weeks to assemble the product before sending it to the company for testing purposes.

While the above addresses the planning production, the actual request of material from the EMS provider is done via a separate process, triggered by an order requirement or a buffer replenishment requirement that usually takes between 2 to 4 weeks. Finished goods inventories that are part of the final order are then distributed globally by the transportation supplier. Any surplus inventories that are not consumed will be managed by the third party logistics provider until such time that they are required.

2.2.3.4 Supply Chain Coordination

Supply chain coordination for the manufacturing process is achieved mainly through a modified quantity flexibility contract. Such quantity flexibility contracts are commonly used in the electronics industry including companies like IBM's printer division, Sun Microsystems, Solectron and Hewlett Packard and Compaq etc. [Anupindi and Bassok, 1998; Tsay and Lovejoy, 1999]. Introduced by Bassok and Anupindi [1997], the contract advocates that the buyer provides a forecast of future orders to the supplier which can be updated within the agreed period. The buyer is required to purchase a minimum quantity at an agreed price, while maintaining an option to purchase up to a maximum quantity at the same price. This then fully protects the buyer on a portion of the buyer's order. However, unlike a typical quantity flexibility contract where the options quantity is owned by the EMS provider, the ownership of the option quantity in the contract between the company and its EMS provider is negotiated each month. This is due mainly to the understanding that the long production lead-time does not allow the company to confirm its order earlier, and producing two months prior to the confirmation of order will inevitably result in discrepancies. As a form of risk-sharing, the transfer of finished goods ownership between the company and the EMS providers are therefore negotiated on a monthly basis. This inevitably results in ambiguous rules, metrics and guidelines that governs the relationship between them.

2.2.4 Main issues confronting the Company's Supply Chain

Given the pace at which the market picked up in the mid 90s and declined in the late 90s, as well as the long duration of the economic downturn, there is wide speculation that the growth rate will be very rapid when the industry recovers. It is therefore paramount that the company positions itself to capitalize on the recovery when it happens. Otherwise, the missed opportunity in products sales will in turn affect the company's service business and significantly affect the company's bottom line in the long run. However, abandonment of vertical integration has resulted in the company having less control over the supply chain. The long production lead time that is integrated over many manufacturers and suppliers has limited the flexibility in the supply chain. While the company has introduced sophisticated procurement and sales contract management to manage the supply chain, it continues to face many challenges.

On numerous occasions, due to the stochastic nature of the demand, confirmed orders can differ from the forecast by up to 200%. These spike demand can at times consume the inventory for the entire quarter. To make matters worse, Tier 2 and 3 suppliers can take between 2 to 4 weeks to react to the changes in the final order. As a result, sales are lost due to stock outs. This is undesirable given the projected pace of market recovery. There is therefore a need to explore alternative methods to anticipate these surge demands, and not lose out on the opportunity.

Another risk as identified in the company's financial report that directly impacts its supply chain is the reliance on third parties to manufacture most of their products, given the complexity and diversity of the company's products especially. Not only is there concern with regards to the reliability of the delivery lead time, there is also concerns about their ability to keep pace with technological advances in the industry.

The challenge for the company is therefore to plan production and inventories to provide competitive customer service while maximizing profits. In the face of such highly uncertain demand environment, companies typically adopt a mathematical approach to determine an "optimal" forecast and inventory position which is then translated into forecast and inventory management policies. This involves formulating a mathematical model describing the behavior of the demand and inventory system. An optimal forecast and inventory policy with respect to this model is then derived using historical data to facilitate production and inventory management decisions. However, forecasting given a stochastic spiky demand pattern is not accurate and may result in lost opportunities in times of surge demand. This is further complicated by the short order lead-time that the Company has; the lead time of the confirmed order is shorter than the typical production lead-time and does not allow the other hedging policies like postponement or intermediate decoupling tactics etc. to be adopted.

Another possible approach to overcome these uncertainties is to create options at costs below their value to mitigate the company's risk exposure while at the same time enhance the shareholder value through a low cost structure and higher revenue stream. The introduction of procurement contracts in their dealings with EMS provider offers the company the opportunity to embed options into the contracts as it seeks to enhance channel profits. In this way, the risk of expanding the channel capacity in the face of uncertain demand can be shared across players within the supply chain. Models that have been implemented include postponement which focuses on product differentiation until precise information is available, dual response to focus on expediting production, and multiple sourcing to focus on achieving assurances of supply [Billington et. al, 2000]. However due to the long production lead time, these options are not feasible to the company. There is therefore a need to explore alternative models for the company.

2.2.5 Models Explored in the Study

The models developed in this thesis serve to explore the possibilities of instituting real options in existing contracts in order to maximize profits given the uncertain demand environment. The models developed are based on balancing production quantities and holding of finished goods inventories to study the impact of sudden surge in demand on the Company's net profit over the product lifetime. The idea is to establish a long term contract that meets the defined fraction of expected demand derived from consensual forecast, coupled with short term flexible options contract that have higher unit prices but guaranteed availability to cover short term fluctuations.

Such approaches are not new and were expounded by Billington et. al. who highlighted that "inventory is in fact a form of insurance, a costly real option that pays off in periods of high demand, but expires almost worthless in periods of low demand. As an option, the expected cost of inventory increases with the degree of volatility (of demand), and can be a significant drain on profitability in periods of high economic uncertainty." [Billington et. al, 2002, p.35].

The options models considered feasible by the company based on its adaptability into its existing quantity flexibility contract with its EMS provider were studied. The idea is to adapt the quantity flexibility contract existing between the company and its EMS providers. The company will continue to provide forecasts of future orders to the EMS providers based on the agreed periods. The company is then required to purchase an agreed quantity at an agreed price (wholesale price), while maintaining an option to purchase up to a maximum quantity at the price higher than the agreed price (strike price). To share the risk of holding the optional units, the company will pay the EMS provider an agreed rate (option price) for each option unit.

The real options model studied to expand the company's resources in times of surge demand are as follows:

a. Fixed Production Model. The first model targets a fixed production quantity based on the average projected annual demand. While the annual, quarterly and monthly consensus demand forecasts will continue to be provided by the OEM as part of the quantity flexible contract, the surplus between the production and forecasted quantities will serve as option units.

b. Fixed Percentage Excess over Forecast Model. The second model is based on having a structured agreement with the EMS provider to produce more than the consensual demand forecast every month. The excess quantity to be produced, which serves as the option quantity, will be based on a fixed percentage over the monthly consensual demand forecast.

c. Safety Stock Model. The third model is to buffer the maximum possible surge demand as safety stock i.e. the options quantity is the safety stock. The safety stock is derived from past demand data of similar products in the company's portfolio based on the consensual assessment of the prevailing economic situation. This model is similar to Hewlett Packard's approach which requires its suppliers to keep inventory at or near HP's factories at their own risks (since uncertainty in demand is not completely resolved) and expense (and the supplier bears the carrying costs) [Billington et. al, 2002]. But unlike the HP case, the difference in this model is that the OEM will share part of the risks with the EMS provider by paying an option price.

CHAPTER THREE - REVIEW OF REAL OPTIONS ANALYSIS LITERATURE

3.1 What are Real Options?

The term 'real options' was coined by Stewart Myers in 1977 to value 'real assets'. It was premised on the Nobel Prize winning Options Pricing Theory developed by Fischer Black and Myron Scholes [Black and Scholes, 1973] for the valuation of market tradable assets. While financial options are used to manage uncertainties in the value of such assets as stocks, commodities, foreign exchanges etc. in the financial markets, Real Options Analysis (ROA) extends the concept to manage risks caused by movements in 'real' assets such as capital projects, R&D projects etc. ROA accounts for the uncertainty in the value of the underlying asset by considering various outcomes. Strategic decision-making flexibility can then be exercised to achieve a higher valuation for the economic opportunity. As such, the value of the option increases with the level of uncertainty in the decision. This is because of the asymmetry in the option - the higher the price rises, the higher the payoff is; however, if the price falls or project fails, one will lose only the price of the option.

Acquiring an option gives one the right but not an obligation to take some action (invest or not invest, buy or sell an asset etc.) now or in the future at a pre-determined price (known as the exercise or strike price) on or before a pre-determined date (also known as the maturity date). Although the option will be acquired at some cost, it provides one with asymmetric returns in that it is only exercised when there are advantages to do so. Choosing not to exercise the option will only result in the loss of the cost to acquire the option. To this end, real options recognizes that flexibility has a value and defines its value.

3.2 Why Real Options Analysis?

"One of the key uses of real options analysis is project ranking and selection" [Mun, 2002, p.241]. ROA provides an integrated framework to facilitate decision making under uncertainty.

It provides managers with an assessment of the value of available economic opportunities so that managers can decide if commitment to one or more of these opportunities is worthwhile given the risks, and if so, at what price should they pay to acquire the opportunities. "Real options involves small scale commitments that limit sunk costs and build flexibility to reinvest, divest, or invest in the future. This flexibility is what makes real options valuable." [Courtney, 2001]

ROA is premised on the assumption of non-arbitrage pricing. As Baxter and Rennie [1996] explained, arbitrageurs will bid away any arbitrage opportunity and move the market in the opposite direction, thereby enforcing a price for the option; hence the term arbitrage-enforced pricing option. This means that payoff of the complex investment opportunity can be replicated by a portfolio of simple financial instruments in a risk-free environment. To this end, assets with the same risk distribution will trade at the same price since the price is not dependent on the expected value. This enables ROA to steer clear of the flaws of averages common to the expected pricing approaches and partially alleviate the problem of discount rate changes over the life of the project. These are the significant advantages of ROA over the other common project evaluation approaches.

3.2.1 Comparing ROA with Net Present Value (NPV) Approach

Discounted Cash Flow (DCF) methodologies have been the most frequently used economic evaluation method. It is a method of evaluating an investment by estimating the future cash flows of the project taking into consideration the time value of money.

Net Present Value =

Net Present of Total Future Revenue – Net Present of Total Future Costs [3.1]

One of the most popular DCF methods is the Net Present Value (NPV) approach. The NPV approach derives the present value of an investment's future net cash flows minus the initial investment. If positive, the investment is made, otherwise it is not. It applies a discount rate, commonly determined by the cost of capital (or opportunity cost of the value of investment for the project), to determine the present value of projected future project cash flow.

However, choosing projects with higher NPV may be shortsighted as it does not guarantee an economically optimal solution. This is especially so in a highly uncertain technological environment such as that in the IT or telecommunications industry. This is because the NPV approach does not adopt a holistic view of the problem to take into account managerial flexibility that allows the elimination or effective hedging of risks involved in the project. It assumes passive project management and hence derives the net wealth contribution based on one expected scenario. As a result, NPV rules out the possibility of adapting to the situation to exploit the upside opportunities while minimizing the downside risks in the project, and systematically undervalues projects.

As an example, consider a management prioritizing a list of three projects involving different models of Personal Digital Assistants (PDAs). In Model A, the company will manufacture standard PDAs, while Model B will see the company investing in the latest PDAs with higher end capabilities. Model C further enhance Project B by allowing the PDAs to read Radio Frequency Identification (RFID) tags. The investment capital, projected demand and unit price for each of the projects are as follows:

Table 3-1 - Example of NPV of Investment Project

Model	Investment Capital	Unit Price	Expected Demand	Expected Revenue	NPV
A	$10MM	$80	1,000,000	$80MM	$70MM
B	$12MM	$115	900,000	$103.5MM	$91.5MM
C	$17MM	$150	700,000	105MM	$88MM

The traditional Net Present Value (NPV) is derived by deducting the investment capital from the expected revenue. As such, the NPV for models A, B and C are $70MM, $91.5MM and $88MM respectively. Hence, the projects are prioritized in the order B, C and A.

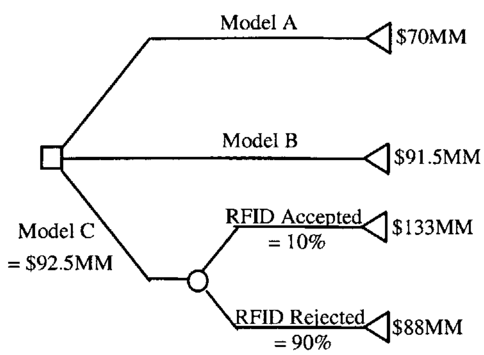
However, this approach can only take into consideration the expected demand and provide no information as to the possible upside or downside in the demand. If we consider the possible increase in demand for Model C, say by another 5%, as a result WalMart's and the Department of Defense's mandate for their suppliers to adopt the new technology by 2005, then the NPV for Model C will increase to $9.33MM, which is higher than Model B. This will change the project prioritization to C, B and A. The next section discusses how real option takes into account such possibility.

3.2.2 Comparing ROA with Decision Analysis

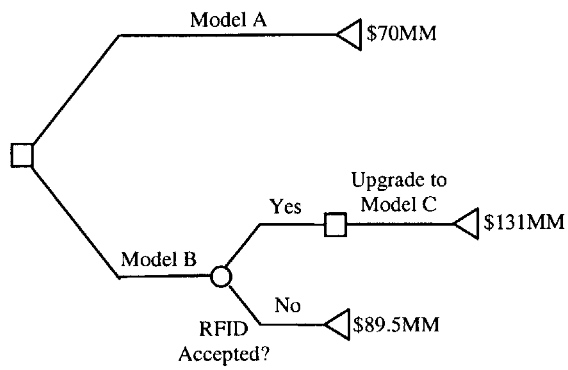
Another commonly used method is Decision Analysis (DA). DA is a "technique used to aid decision-making under conditions of uncertainty by systematically representing and examining all of the relevant information for a decision and the uncertainty around that information" [Cochrane, 2003]. The available choices are typically plotted on a decision tree with a series of decision and chance nodes, ending with terminal nodes. At each decision node, where the manager faces a decision on the options available, is linked to numerous chance or terminal nodes where the probabilities of each outcome are predicted to allow the computation of expected outcome. The best choice that allows the manager highest profit or greatest success will be chosen using a combination of the probability and value of each chance. It uses the NPV as input and to a large extent corrects the disadvantages of NPV in that it structures the problem in the face of uncertainty and recognizes that uncertainty resolution reveals the most appropriate decision at each point of time.

Using the example discussed previously for NPV, we further suppose that there is only a 10% chance of RFID being accepted. When that happens, the demand for Model C will increase to 1MM, increasing the revenue to $150MM and NPV to $133MM ($150MM-$17MM).

Figure 3-1 – Comparison of Decision Analysis and Real Options Analysis



(A) Decision Analysis



(B) Real Options Analysis

Figure 3-1(A) shows the analysis using DA. Taking into consideration the probability of RFID adoption, the NPV of Model C is deemed as $92.5MM ($133MM x 10% + $88MM x 90%). As a result, the projects are prioritized as C, B and A using decision analysis. However, decision analysis is not the optimal stand-alone methodology because subjective probabilities are required. The decision rule in DA is simple : "choose the one that offers the best average value, where average means expected value : a weighted average of the outcomes by their probability of occurrence" [de Neufville, 2003]. The difficulties and errors in forecasting the relevant discount rates and probabilities of occurrence are compounded over time, and the resulting calculated values are often inaccurate if not erroneous. In the event that RFID is rejected, then the higher capital investment will result in the company achieving a lower NPV i.e. $88MM.

Real options overcome this by allowing the management to build flexibility into their decisions. Instead of choosing between Model B or Model C, the management can recognize the inherent uncertainties and choose to build flexibility into their design by building a Model B that can be easily changed to Model C, albeit at a higher cost. The decision to switch to Model C can then be taken only when the adoption of RFID is certain.

In the same example above, suppose the initial investment in Model B will be increased to $14MM (instead of $12MM originally) if the management chooses to include design flexibility into Model B. This will allow the production plant to be changed to manufacture Model C at a later time, albeit at an additional cost of $5MM when Model C is to be introduced. Figure 3-1(B) shows the revised decision tree when real option analysis is adopted. Due to the higher $2MM investment in the flexibility, the NPV for Model B is $89.5MM while that for Model C is $131MM. However, with this flexibility, the management can achieve a higher NPV of $89.5MM as oppose to $88MM using DA, while retaining the flexibility to switch to Model C and exploit the opportunities offered by RFID if it is eventually adopted.

The above example clearly shows the flexibility that ROA offers. While DA overcomes the limitation of NPV, it is ultimately still a "one-scenario" analysis and does not recognize the inherent uncertainty involved in the decision. While ROA does not offer as high a NPV as DA if RFID is to be adopted, it certainly allows the company to achieve a higher NPV if RFID is not adopted. This is the key difference between DA and ROA. Furthermore, DA requires the user to input the probabilities of occurrences and at times the discount rate of the analysis. While not explicitly shown in the example, ROA overcome the problem using the volatility of the inherent uncertainties and as such, does not require the user to estimate or "guess" the specific number to be used for the analysis. One other main disadvantage of DA is that the analysis tree can become very "bushy". For a simple decision as demonstrated in the example, there are already 4 branches involved in the analysis. For a 12 year 5 periods tree, an analysis involving ((((2x3+1)x3+1)x3+1)x3+1) = 202 branches will be needed. This will make sensitivity analysis very cumbersome. ROA valuation tools, which will be discussed in later sections, simplify this.

3.3 Types of Options

Since the introduction of the topic in 1977, numerous academic and some practitioner articles on the theory and application of real options have been published. However, interest in the concepts and techniques increased substantially only in the mid-1990s and since then, various types of real options have been developed. Table 3-2 provides a list of the main categories of real options that are commonly applied.

Table 3-2 - Categories of Common Types of Real Options

CATEGORY	DESCRIPTION	IMPORTANT IN
Option to Defer	Management holds a lease on (or an option to buy) valuable land or resources. It can wait (x years) to see if output prices justify constructing a building or plant, or developing a field.	All natural resource extraction industries; real estate development; farming; paper products.
Time to Build Option (Staged Investment)	Staging investment as a series of outlays creates the option to abandon the enterprise in midstream if new information is unfavorable. Each stage can be viewed as an option on the value of subsequent stages, and valued as a compound option.	All R&D intensive industries, especially pharmaceuticals; long-development capital-intensive projects, e.g., large-scale construction or energy-generating plants; start-up ventures.
Scaling Option (e.g., to expand, to contract, to shut down or restart)	If market conditions are more favorable than expected, the firm can expand the scale of production or accelerate resource utilization. Conversely, if conditions are less favorable than expected, it can reduce the scale of operations. In extreme cases, production may halt or start up again.	Natural resource industries such as mine operations; facilities planning and construction in cyclical industries; fashion apparel; consumer goods; commercial real estate.
Option to Abandon	If market conditions decline severely, management can abandon current operations permanently and realize the resale value of capital equipment and other assets in secondhand markets.	Capital intensive industries, such as airlines and railroads; financial services; new product introductions in uncertain markets.
Option to Switch (e.g., outputs or inputs)	If price or demand change, management can change the output mix of the facility ("product flexibility"). Alternatively, the same outputs can be produced using different types of inputs ("process flexibility")	Output shifts: Any good sought in small batches or subject to volatile demand, e.g., consumer electronics; toys; specialty paper; machine parts; autos; Input shifts: All feedstock-dependent facilities, e.g., oil; electric power; chemicals; crop switching; sourcing.

CATEGORY	DESCRIPTION	IMPORTANT IN
Growth Option	As early investment (e.g., R&D, lease on undeveloped land or oil reserves, strategic acquisition, information (network/ infrastructure) is a prerequisite or link in a chain or interrelated projects, opening up future growth opportunities (e.g., new generation product or process, oil reserves, access to new market, strengthening of core capabilities). Like interproject compound options.	All infrastructure-based or strategic industries, especially high-tech, R&D, or industries with multiple product generations or applications (e.g. computers, pharmaceuticals); multinational operations; strategic acquisitions.
Multiple Interacting Options	Real-life projects often involve a "collection" of various options, both upward-potential enhancing calls and downward-protection put options present in combination. Their combined option value may differ from the sum of separate option values, i.e., they interact. They may also interact with financial flexibility options.	Real-life projects in most industries discussed above.

Source: Trigeorgis, L. (1993)

For this study, options for positioning inventory to meet surge demand is akin to expanding the scale of production or accelerating resource utilization when the need arises. The option to expand (scaling option) will allow the Company to expand their pool of resources in times of favorable market conditions.

3.4 Approaches to Real Options Analysis

Several approaches to ROA have also been proposed and adopted for calculating the real option value since its inception in 1977. Although there are considerable differences in the application, assumptions and mechanics of the various approaches, the ultimate goal of all approaches is to facilitate the selection of an investment that maximizes the wealth of a firm's shareholder; each approach provides a real option value that indicates the buy/sell price for the investment being evaluated. Borison [2003] categorized the major analytical approaches into five main groups.

The classic and subjective approaches are built around the replicating portfolio concept and are applied to market-driven investments, while the Market Asset Disclaimer (MAD) approach is applied to privately-driven investments. The revised classic approach and integrated approach either adopt one or both of the above i.e. market value for market-driven investments and management's subjective estimate of the equivalent market value for privately-driven component of the investment. The main difference between the approaches lie in the adoption of two key assumptions namely the nature of the market and the source of data for the computation of real option value as summarized in Table 3-3.

Table 3-3 – Summary of Major Analytical Approaches to Real Options

Approach	Nature of Capital Markets for Underlying Assets	Data Source
Classic Approach	Complete with respect to all corporate investments.	Capital Market
Subjective Approach	Complete with respect to all corporate investments.	Subjective Judgment
MAD Approach	Absent with respect to all corporate investments.	Subjective Judgment
Revised Classic Approach	Complete with respect to market-dominated corporate investments; absent with private-dominated corporate investments.	Capital Market for market-dominated investments; subjective judgment for private-dominated investments.
Integrated Approach	Complete with respect to all corporate market risks of corporate investments; absent with respect to private risks of corporate investments.	Capital Market for market risks; subjective judgment for private risks.

Source : Borison, A. (2003)

3.4.1 Classic Approach (No Arbitrage, Market Data)

The term 'classic' refers to the most direct application of finance option theory to calculate the real option value. This approach was covered extensively by Amram and Kulatilaka [1999] although a number of authors also recommended the approach including Brennan and Schwartz

[1985], Trigeorgis and Mason [1987] and Copeland, Koller and Murrin [1994]. Amram and Kulatilaka [1999] advocated that the classic approach to real option value represents the 'financial market value' and is therefore based on valuations in the financial markets. To this end, the value estimates the incremental wealth created by an investment and therefore assumes that all corporate investments have equivalents in the capital markets. The approach therefore makes the standard replicating portfolio assumption of financial option pricing and is valued based on the standard no arbitrage arguments. This also means that the approach assumes that the asset price movement can be described by geometric Brownian movement which will allow standard financial tools like Black-Scholes to be applied. However, both Amram and Kulatilaka [1999] as well as Borison [2003] recognized the existence of "tracking error" due in part to untracked risks. Borison [2003] further found that the approach gives a poor quality of result despite its ease of usage.

3.4.2 Subjective Approach (No Arbitrage, Subjective Data)

This is similar to the classic approach in that it is based on no-arbitrage arguments and uses financial options pricing tools. However, it does not include the explicit identification of a replicating portfolio but based it entirely on subjective estimates of inputs instead of market traded assets. Howell et al. [2001] and Luehrman [1997] are the main proponents of this approach. While the authors recognized the need to maximize shareholder value as in the classic approach, the assumptions underlying the subjective approach are essentially the same as that of the classic approach. But unlike the classic approach which values option based on data from traded markets, the authors relies on subjective assessments e.g. discounted cash flow calculation for option value derivation.

Luehrman included other assumptions about the form of the probability distribution that characterized project returns i.e. whether the assets can be regularly bought and sold, as well as assumptions about the ability of investors to continually adjust their portfolio. Even when the Black-Scholes' assumptions fail to hold, Luehrman felt that this approach still "yields qualitative insights but the numbers are less reliable" [Luehrman, 1998, p.14]. Given the many subjective assumptions in the approach and no attempts were made by the authors to justify the use the assumptions, it is not surprising that Borison [2003] found that the quality of result obtained via this approach is poor.

3.4.3 Marketed Asset Disclaimer [MAD] Approach (Equilibrium-Based, Subjective Data)

The MAD approach contends that there is no need to rely on the existence of a traded replicating portfolio as with options pricing. Proponents of this approach, Copeland and Antikarov [2001], Trigeorgis [1999] and Brealy and Myers [2000], argue that the application of net present value (or discounted cash flow) to "fixed" corporate investments can be used to derive the options value. They further add that the same source of data for the value calculation is appropriate; the same as that used in subjective approach. Copeland and Antikarov [2001], the originator of the name MAD, argue that since the goal of the firm is to create value, and NPV "systematically undervalues every investment opportunity" because of its inability to incorporate management flexibility, MAD can expand the concept of NPV to provide a more accurate estimate of value for corporate investments. "After all, what has better correlation with the project than the project itself." [Copeland, Koller and Murrin, 2000, p.406]. They justified that MAD makes assumptions no stronger than those used to estimate the project NPV." [Copeland and Antikarov, 2001, p.67] The market data used in this calculation is therefore the risk-adjusted cost of capital or discount rate. MAD assumes that there is no arbitrage opportunity even though the shareholder's value is maximized using the management's subjective inputs. Copeland and Antikarov [2001] made a second assumption that asset price also follows the geometric Brownian motion [Copeland and Antikarov, 2001]. This provides the rationale for using binomial lattice to value options in the MAD approach.

3.4.4 Revised Classic Approach (Two Investment Types)

As the name implies, the revised classic builds on the classic approach to calculate real option value and is elaborated most extensively by Dixit and Pindyck [1994] although Amram and Kulatilaka [2000], who were earlier proponents of the classic approach, also adopted the approach. The revised classic approach suggests that real options as advocated by the classic approach should be used when investments are dominated by market-priced risks (public risk), but management science approaches such as dynamic programming and decision analysis should be applied when the investment risks are limited to the corporation (private risk). In the presence of both risks in the investment, the decision as to which approach to adopt is taken up front based on whether public or private risks dominate the investment. However, Dixit and Pindyck [1994] qualified that the contingent claim analysis [the term used by them to refer to the revised classic approach] requires one important assumption: the stochastic changes in the value of the investment project is such that one can always find an asset or construct a dynamic portfolio of assets to perfectly correlate the value of the investment. They added that this assumption should hold for most commodities which are traded on both spot and futures market, and to the extent that the manufactured goods correlate with the values of the shares or portfolios. Unlike the classic approach, this approach acknowledges the possibility that this assumption may not hold. In this case, Dixit and Pindyck [1994] proposed the use of dynamic programming while Amram and Kulatilaka [2000] proposed the use of decision analysis to value the option. Although the discount rate to be adopted was not explicitly discussed by the Amram and Kulatilaka [2000] in their proposal to use decision analysis, it is fair to assume that the common practice of Weighted Average Cost of Capital (WACC) should be applied.

3.4.5 The Integrated Approach (Two Risk Types)

The integrated approach shares the same view as the revised classic approach in that public-risk investments can be valued using the classic approach while dynamic programming/decision analysis approaches should be employed when investment are corporate specific. However, the integrated approach acknowledges that most realistic problems have both kinds of risk and suggests that both risks should be considered when valuing options. First described in depth by Smith and Nau [1995], the approach though named differently, was also advocated by Smith and McCardle [1998], Constantinides [1978], Luenberger [1998] and Neely [2001]. The fundamental assumption in this approach is that the market is "partially complete" because the "beliefs (probability assessment) and preferences (risk attitudes) of the individual classic participants may be important." [Borison, 2003, p.21]. To implement this approach, Smith and Nau [1995] developed what they termed as a risk-adjusted decision tree which explicitly identify public and private risks. Opportunities for hedging public risks are incorporated while opportunities for arbitrage are removed. The other authors proposed a similar approach although Constantinides' proposal is phased in that projects are valued by first adjusting for market risks and then discounting the cash flows at a risk free rate.

3.4.6 Identifying the Relevant Approach

The real options approach adopted for supply chain and supply contract studies have thus far been myriad and varying due to the application of differing underlying assets in the study. In the case of the telecommunications networking industry, there is currently no financial market on which the telecommunications networking assets are traded. As such, the MAD approach which adopts the application of net present value to "fixed" corporate investments is used to derive the options value.

The MAD approach, following Copeland and Antikarov [2001], involves a moderate amount of effort in building a spreadsheet cash-flow model to simulate the cash flow of the underlying assets. To this end, the inputs required for the computation of NPV are identified and the NPV is computed using the Weighted Average Cost of Capital (WACC). Finding the volatility of the underlying asset is very difficult for real options as historical information are usually not available or are not reflective of the future situation due to uncertainties in the project. As a result, an estimation of the volatility is derived using Monte Carlo simulation of the value of the project. Using the resulting distribution from the simulation, an appropriate valuation tool is identified to estimate the value of the option.

3.5 Real Options Valuation Techniques

Having identified the approach, it is then important to select the appropriate real options technique to value the option. To this end, there are 3 main categories of techniques, all of which are based on the arbitrage-enforced pricing methods namely (1) Black Scholes Model, (2) Binomial Lattice and (3) Simulation.

3.5.1 Black Scholes Model

One of the most common valuation tools is the Black-Scholes Formula which based its analysis on the no-arbitrage condition. The Black-Scholes formula states that the price of the option at time zero for a European call option on a non-dividend paying stock is

$$c = S_0 N(d_1) - Xe^{-rT} N(d_2) \qquad [3.2]$$

where $d_1 = \dfrac{\ln(S_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$

$$d_2 = \frac{\ln(S_0 / X) + (r - \sigma^2 / 2)T}{\sigma\sqrt{T}} = d_1 - \sigma\sqrt{T}$$

S_0 = Current stock price

X = Strike price of the option i.e. price to pay for the stock when the option is exercised.

r = Risk free interest rate

T = Time to maturity of the option i.e. time after which the option can be exercised.

σ = Volatility of the stock

and N(x) is the cumulative probability distribution function for a variable that is normally distributed with mean zero and a standard deviation of 1.0.

For example, the current price (S_0) of a product is \$100 and a European option i.e. the option can only be exercised at maturity, is called on the product with the time to expiration being a year. The volatility of the product price over the year is 30%, the risk free interest rate is 5% and the strike price is given as \$120. The computation of the price of the option using Black Scholes Formula is as follows:

We first compute d_1 and d_2,

$$d_1 = \frac{\ln(S_0 / X) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}}$$

$$= \frac{\ln(\$100/\$120) + (1.05 + 1.3^2 / 2)1}{1.3\sqrt{1}}$$

$$= 1.317$$

$$d_2 = d_1 - \sigma\sqrt{T} = 1.317 - 1.3\sqrt{1} = 1.017$$

Using [Eqn 3.2], the option price c is

$$c = S_0 N(d_1) - Xe^{-rT} N(d_2)$$

$= \$100 \times N(1.317) - 120 \times e^{-1.04x1} \times N(1.017)$

= **\$6.866**

It is important to understand the two key assumptions of the formula namely no-arbitrage condition and Geometric Brownian Motion (GBM) representation when using the Black-Scholes formula. Arbitrage involves getting profit by simultaneously entering 2 or more markets to exploit the differences in the value of a particular stock between the markets. An arbitrageur enters one market to buy a stock and almost simultaneously selling it in another market, hence making a profit. This is a reasonable assumption as the forces of supply and demand will very quickly cause the stock price to rise or fall. GBM refers to random fluctuation of stock prices as a result of the influence of a large number of independent random factors acting together to affect the stock price. Each factor, on its own, is trivial in the total influence. The idea was adapted from the original Brownian motion proposed by Albert Einstein who demonstrated the random bombardment of heat-excited water molecules using a pollen immersed in the water. He proved that each of the molecule motion step (in the x- and y- directions) is an independent random variable, which laid the groundwork for the understanding of stochastic processes.

In addition, the constraints imposed as a result of the assumptions made in deriving the formula also limit its employability in real options. Firstly, the formula is only applicable for European options. This is usually not applicable for real options when the discretion to exercise is based on the prevailing circumstances. Furthermore, the formula only allows one source of uncertainty in that there can only be a single risky underlying asset. The underlying asset also pays no dividends.

3.5.2 The Binomial Lattice

The other commonly used real option tool is the binomial lattice method which was developed by Cox, Ross and Rubinstein in 1979. The method is based on a simple representation of the evolution of the value of the underlying asset. Consider a stock whose price is S_0 when an option priced as C is offered. Assuming that time at maturity is T, the price of the stock can either move up or move down to uS_0 or dS_0 respectively, where u is the factor that the stock moves up in each time period (known as the "up multiplicative factor") and d is the factor that the stock moves down in each time period (known as the "down multiplicative factor"). Suppose also that when the stock price moves up, the payoff is C_u and when the price moves down, the payoff is C_d.

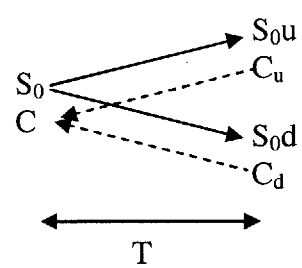


Figure 3-2 - Stock and Option Price in a Binomial Tree

In trying to replicate a portfolio to match the returns of the above stock, consider a portfolio comprising a long position of x shares and a short position in one option. If there is an up movement in the stock price, the value of the portfolio at the maturity date will be

$$S_o ux - C_u$$

And when the share price drops, the value is

$$S_o dx - C_d$$

In a risk free environment, the two are equal. Therefore

$$S_o ux - C_u = S_o dx - C_d$$

$$\Rightarrow \quad x = \frac{C_u - C_d}{S_0 u - S_0 d} \qquad [3.3]$$

Due to the non-arbitrage condition, the portfolio should earn risk free interest rate, r. As such, the present value of the portfolio is

$$(S_o ux - C_u)\, e^{-rT}$$

This must equal the cost of establishing the portfolio which is $S_o x - C$. Hence

$$S_o x - C = (S_o ux - C_u)\, e^{-rT}$$

$$\Rightarrow \quad C = S_o x - (S_o ux - C_u)\, e^{-rT}$$

Substituting x from Equation [3.3],

$$C = e^{-rT} [\, pC_u + (1-p)\, C_d \,] \qquad [3.4]$$

where

$$p = \frac{e^{rT} - d}{u - d} \qquad [3.5]$$

A common way to identify volatility, σ with u and d is

$$u = e^{\sigma\sqrt{T}} \qquad [3.6]$$

$$d = e^{-\sigma\sqrt{T}} \qquad [3.7]$$

To show how the tool is used, we will use the same example discussed in the previous section to develop a 2-period binomial lattice to price the option. Using [Eqn 3.6] and [Eqn 3.7],

$$u = e^{\sigma\sqrt{T}} = e^{0.3\sqrt{0.5}} = 1.2363$$

$$d = e^{-\sigma\sqrt{T}} = e^{-0.3\sqrt{0.5}} = 0.8089$$

Substituting u and d into [Eqn 3.5],

$$p = \frac{e^{0.05(0.5)} - 0.8089}{1.2363 - 0.8089} = 0.5064$$

$$\Rightarrow q = 1\text{-}p = 0.4936$$

With the various parameters established, we will then proceed to build the binomial lattice starting with the current price of the product

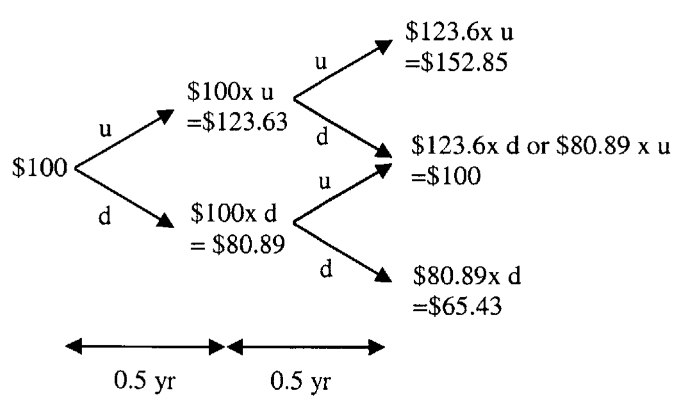


Figure 3-3 – Binomial Representation of Growth of Product Price

With the possible price of the product at the end of the year, the management will decide if the option should be exercised. From the values derived above, the option should only be exercised when the product price is greater than the strike price of $120. As such, when it reaches $152.85, the option will be exercised to make a net profit of $32.85 ($152.85-$120). It will not be exercised when the product price is less than the option strike price, hence profit is $0. Using this information, we will "roll back" the binomial lattice using the derived p and q to compute the price of the option.

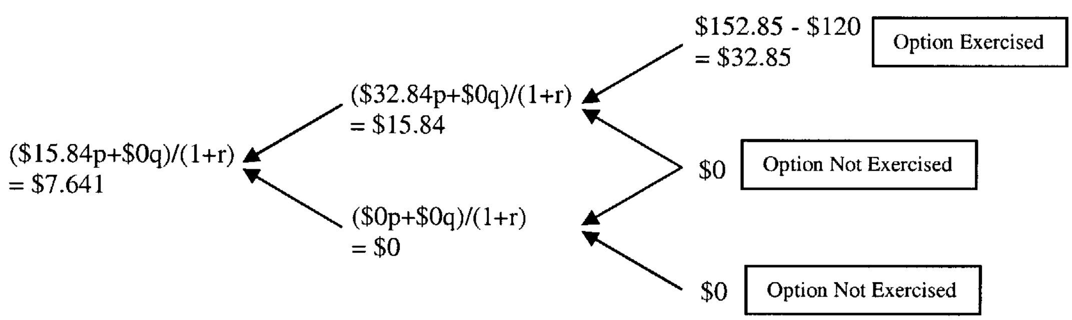


Figure 3-4 – Binomial Representation of Call Option

From Figure 3-4, the price of the option is determined as **$7.64**.

3.5.3 Simulation

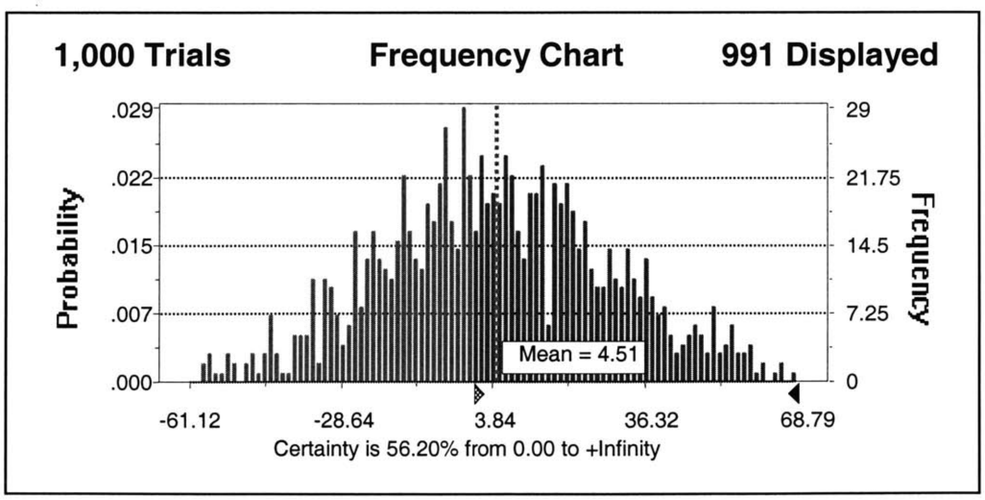
Simulation methods are usually employed in cases where the Black-Scholes formula is not applicable and it is very difficult to build or solve the binomial lattice. Simulation techniques replicate the underlying asset's stochastic behavior by rolling out a huge number of possible evolution paths of the underlying asset over time. The simulation is usually done through Monte Carlo Simulation using the probability distribution function of the uncertainties in the underlying asset in a risk-free environment. The arithmetic mean of the many simulation cycles is the estimated value of the payoff of the option. One of the key advantages of the simulation model is its ability to handle path-dependent options where the value of options are not only dependent on the value of the underlying asset, but also on the particular path taken by the underlying asset.

For example, if there are a number of possible approaches that can be taken by the underlying asset, and each path is dependent on a certain outcome of a random variable, then the simulation can be programmed to automatically choose the path and compute the outcome. In the case of binomial lattice, it will need to involve careful identification and selection. This is difficult especially if the lattice involved is huge.

Another reason for using the simulation technique is its simplicity which allows practitioners to employ the technique frequently. This is especially so when the user is required only to know the value and price of the option without having to know the timing to exercise the option. The advancement of computer technology allows the construction of options valuation models using a normal laptop. Simple models can be easily simulated using Excel add-ons such as @Risk or Crystal Ball. With these software, hundreds and thousands of simulations can be easily simulated for the payoff distribution and option value.

Using the example discussed earlier, the price of the option derived using Crystal Ball as **$4.51**.

Figure 3-5 - Distribution of Product Price by Simulation

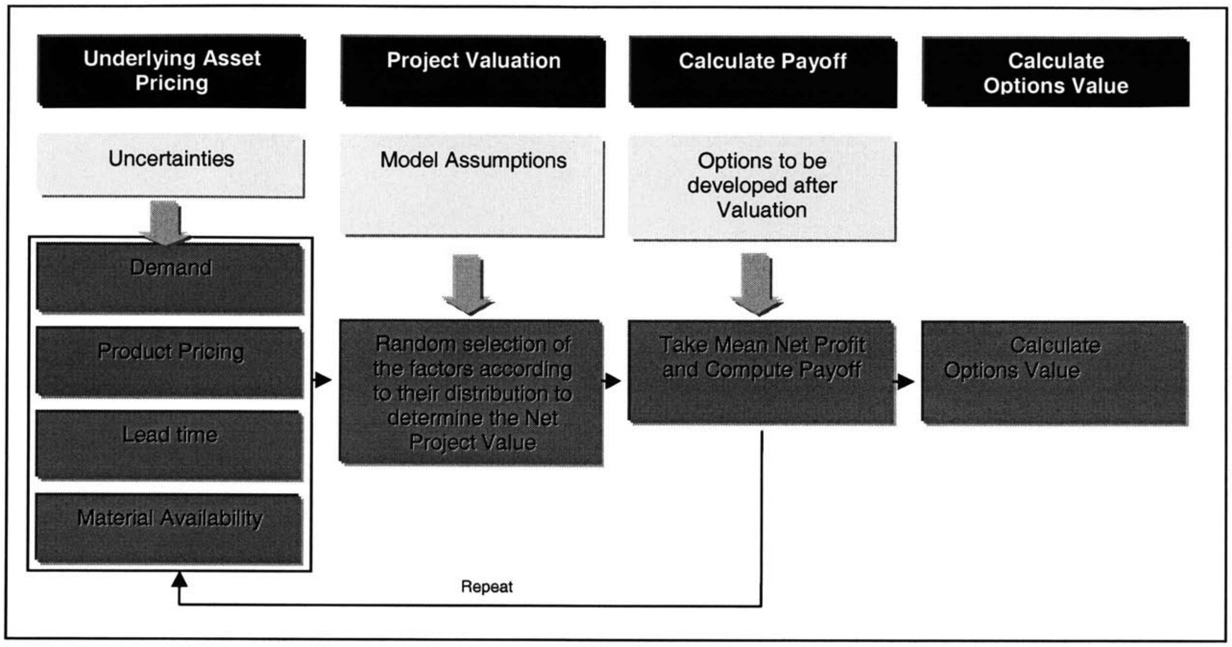


3.5.4 Identifying the Appropriate Technique

In the case of the study, the problem requires having the choice to exercise the option whenever there is a surge in demand. As such, it is necessary that an American option which gives one the right to exercise the option whenever necessary as opposed to the European option which can only be exercised on the maturity date. Therefore, the Black Scholes formula cannot be adopted. The binomial lattice technique, while applicable, is not necessary in the study for two reasons. Firstly, the timing to exercise the option is straight forward. As the Company does not practice dynamic pricing, it will exercise the option whenever demand exceeds supply (in this case, forecast). Secondly, the different options considered in the study all hinged on finished goods inventories based on the same underlying asset. As the timing to exercise the options are the same in all instances i.e. when demand exceeds supply, there is no management decision in the tree. Hence, the various options considered will return the same value although the mechanics of each option differs. The simulation technique is therefore the most appropriate method in the study. Not only will simulation derive the value the model, it will also allow the simulation of various approaches to the option to identify the best approach; a characteristic that is essential in the study.

3.6 Real Options Analysis Process

Figure 3-6 – Real Options Analysis Process



Having identified the approach and valuation technique for the valuation of the project using real options analysis, the analysis will follow the following main four steps as shown in Figure 3-6.

The first step involves identifying the underlying asset and the uncertainties of the project which will necessarily include approximating the probability distribution of the uncertainties. The identification of the underlying assets and uncertainties will enable the selection of the appropriate approach to the analysis. Next is the building of model and assumptions which include identifying an appropriate method for the analysis. The third step is to compute the payoff of the project and develop options as a result of the valuation. The average payoff is then computed.

3.7 Summary

Real options analysis is clearly the superior analytical method compared to the more widely used approaches such as DCF, NPV and DA in an uncertain environment. The DCF (NPV) approach rules out the possibility of adapting to the situation to exploit the uncertainties in the decision, while the DA approach, while not ruling out the possibility, does not offer the flexibility to switch from one scenario to another. DA can also get complicated as the number of time periods and/or scenario increases. However, the application of ROA is a more complex process and it is necessary that the correct approach and techniques be identified for the planning and execution of the analysis. Given the problem of positioning sufficient inventory in the supply chain to meet surge demand, it will be appropriate to acquire a scaling option using the MAD approach. And since the Company does not practice dynamic pricing, the timing to exercise the option is a straight forward decision. As such, the simulation technique will be employed for the study.

CHAPTER FOUR - REAL OPTIONS MODEL DEFINED

4.1 Model Development

The basic model is developed based on the expected profit in a single buyer, single supplier relationship based on the relationship between the OEM and EMS provider. It employs the output of the sophisticated forecasting tool that the Company has invested in but includes options contract as a generic model. This is then extended to handle the need for the Company to synchronize the delivery of the main assembly and a key component within the product before final delivery to the customer.

The basic (2 component) model is then adapted to the options model studied. The three feasible options models considered were based on the company's assessment of its adaptability into its existing quantity flexibility contract with its EMS. They include the fixed production model, fixed percentage excess over forecast model and the safety stock model.

4.2 The Basic Model

In a single-buyer, single-supplier system, the buyer makes one ordering decision in advance of the beginning of the delivery horizon due to the long production lead-time, and one nearer to the start of the horizon. Firstly, each month, he orders Q_f units at a wholesale price of W_i per unit to be available by the start of the horizon for the month. The unit cost of ordering and unit cost of administration are C_o and C_a respectively.

In addition to Q_f, the buyer also purchases O_i options at a unit option price of W_o for the month. In the event that the option is exercised during the month, he may choose to purchase O_p units at a price of W_p. The model is based on the assumption that each option allows the buyer to purchase one right to buy one unit of good. The model also assumes only one component product in the order. This will later be relaxed to include a main assembly and a key component whose delivery must be synchronized before the product is delivered to the consumer. As the model is based on an uncoordinated supply chain, it is assumed that the EMS provider does not have any production capacity limitation nor raw material constraints, and any un-utilized capacity will be scheduled for other products by the EMS provider.

Although the finished goods are usually held by the EMS provider until delivery request by the OEM, the OEM will own all inventories once it is forecasted for the month and will incur a holding cost C_h per unit per week. We have also assumed that the EMS provider has the necessary warehouse space to accommodate the finished goods inventory regardless of the amount of products held. As such, the holding cost C_h is taken as constant for the simulation.

The buyer will tests the product at a unit product cost of C_p and sells the product to the consumer at a standard unit price P, regardless of the wholesale cost of the product. It is however assumed that $P > W_o > W_i$ which is reasonable given that there should be profits made regardless of the costs of the products. Given the stochastic nature of the demand, it is assumed that the demand pattern and sales pattern are similar. Demand D(t) represents the actual market demand for the product in week t, while S(t) serves as the number of products sold by the company within the week t. Note that sales can only be less than or equal to demand and not vice versa. The product is then transported to the consumer at a unit cost of C_t.

Figure 4-1 –Scenarios Considered in the Model

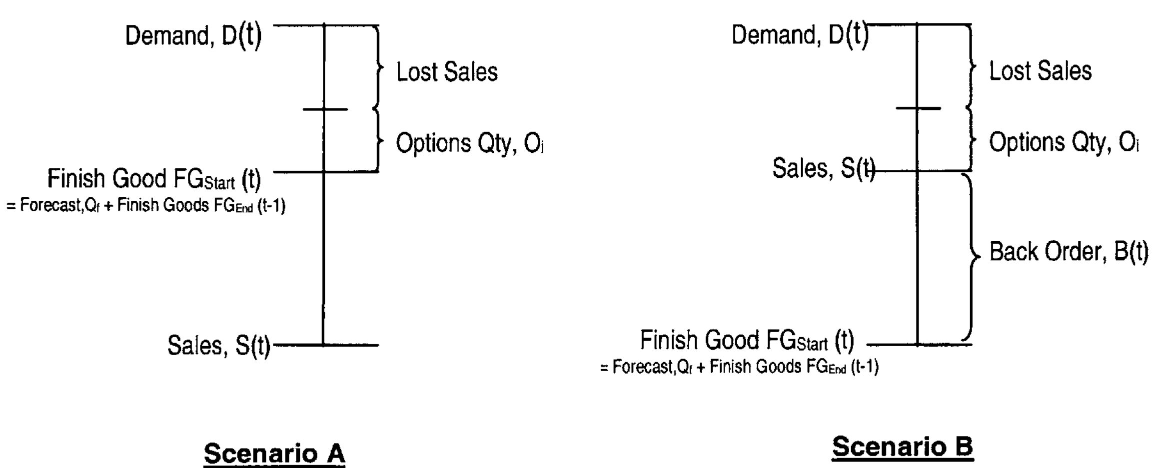
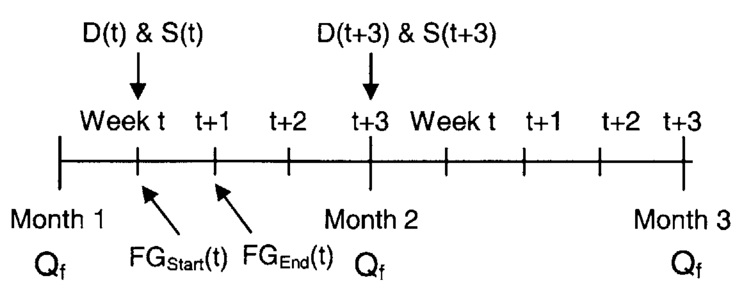


Figure 4-1 shows the possible scenarios considered in the model. In scenario A, when demand D(t) is greater than the sum of sales S(t) and Finished Goods Inventory holding at the end of the previous week, FG_{end}(t-1), the company will exercise the options quantity that it holds. For the remaining demand that the options quantity is unable to fulfill, the customer will drop the order and seek alternative supply, resulting in lost sales that amounts to a cost of C_l per unit. In scenario B when sales S(t) is greater than sum of the initial order quantity Q_f and FG_{end}(t-1), the difference will be made up through back order; the back order quantity being B(t) costing C_b per unit. This will then be delivered via expedited transportation at a cost of $C_{t(fast)}$ per unit. If order quantity Q_f is greater than sales S(t) at the end of the month, the buyer will not only incur holding cost as computed in C_h, but the remaining inventory will be passed on to the next month. However, if there are no sales S(t) for 3 consecutive months, the buyer can choose to salvage Q_f-FG_{end}(t-1) at a unit price of P_s.

4.2.1 Model Notations

The model adopted the following notations:

Figure 4-2 – Timeline of Notations Used in Model



Q_f(t) - OEM's forecasted quantity at the beginning for each month with t representing the week before the start of the month.

D(t) - Product demand at week t. Each month is represented by t+1 to t+4 (or t+5).

S(t) - Product sales at week t.

B(t) - Back order quantity at week t.

O_i - Options quantity catered in the contract.

O_p - Options quantity exercised when demand exceeds sales.

$FG_{Start}(t)$ - Finished goods inventory at the start of week t

$FG_{End}(t)$ - Finished goods inventory at the end of week t

P - Unit price of product sold to the telecommunication companies.

P_s - Unit salvaged price of the product.

W_i - Unit wholesale price of the product charged by the supplier.

W_o - Price of rights to options (Option Price) per unit charged to the company (buyer).

W_p - Unit price of product when options are exercised (Strike Price) to the company.

C_o - Unit ordering cost.

C_a - Unit administrative cost.

C_b - Unit back order cost.

C_l - Unit lost sales cost.

C_h - Unit holding cost.

C_p - Unit testing cost at the company.

C_t - Unit transportation cost.

$C_{t(fast)}$ - Unit expedited transportation cost for back order deliveries.

4.2.2 OEM's Profit Function

There is asymmetric distribution of bargaining power in the OEM-EMS relationship as OEMs have access to many alternative high value EMS providers in the industry. As such, the model developed is based solely on the expected profit for the OEM. It is however important to note that the EMS provider will not be disadvantaged in the options contract, and will be no worse off than the no options approach. This is derived using the expected revenue and expected cost of the products within each month.

We first develop the OEM's expected revenue in the month starting week T. This is given by the Equation [4.1] as follows:

$$\text{Revenue} = P\sum_{t=T}^{T+4} S(t)$$

$$+ P\sum_{t=T}^{T+4} B(t)$$

$$+ P\sum_{t=T}^{T+4} O_p(t) \; for\ t{=}T\ to\ T{+}4$$

$$\text{Where } O_p(t) = 0 \;\; if\ D(t) - \{FG_{start}(t) - S(t)\} <= 0$$

$$\text{else } O_p(t) = O_i - [D(t) - \{FG_{start}(t) - S(t)\}] \;\; if\ O_i > D(t) - \{FG_{start}(t) - S(t)\}$$

$$\text{else } O_p(t) = O_i \;\; if\ O_i <= D(t) - \{FG_{start}(t) - S(t)\}$$

$$+ P_s \left| FG_{end}(T-1) - Q_f(T) \right| \quad \text{if } \sum_{T-12}^{T} S(t) = 0 \qquad [4.1]$$

The monthly revenue of the OEM comprises four terms. The first term is the OEM's revenue from sales within the month. The second term is the revenue from backorder satisfied within the month. The third term is the expected profit from exercising the option each week; the quantity of option purchased is computed as the amount of excess demand over sales that cannot be satisfied by the finished goods inventory of the prior week. If the finished goods inventory holding is greater and the difference between demand and sales for the week, then options exercised is zero. The last term is the salvage cost of finished goods at the end of the month if there are no sales over the last 12 weeks.

The expected costs to the OEM in the month starting week T is given in Equation [4.2]:

$$\text{Cost} = [Q_f + \sum_{t=T}^{T+4} B(t)] \cdot [W]$$

$$+ W_p \sum_{t=T}^{T+4} O_p(t) \ \textit{for t=T to T+4}$$

$$\text{Where } O_p(t) = 0 \ \textit{if} \ D(t) - \{FG_{start}(t) - S(t)\} <= 0$$

$$\text{else } O_p(t) = O_i - [D(t) - \{FG_{start}(t) - S(t)\}] \ \textit{if} \ O_i > D(t) - \{FG_{start}(t) - S(t)\}$$

$$\text{else } O_p(t) = O_i \ \textit{if} \ O_i <= D(t) - \{FG_{start}(t) - S(t)\}$$

$$+ C_h \sum_{t=T}^{T+4} FG_{end}(t)$$

$$+ C_p \sum_{t=T}^{T+4} [S(t) + B(t) + O_p(t)]$$

$$+ C_b \sum_{t=T}^{T+4} B(t)$$

$$+ C_l \sum_{t=T}^{T+4} \{D(t) - [FG_{End}(t) + S(t) + O_i]\} \text{ if } D(t) > S(t) \text{ and } O_i < D(t) - \{FG_{start}(t) - S(t)\}$$

$$+[Q_f + \sum_{t=T}^{T+4} B(t)] \cdot [C_o]$$

$$+[Q_f + \sum_{t=T}^{T+4} B(t)] \cdot [C_a]$$

$$+ C_t \sum_{t=T}^{T+4} [S(t) + O_p(t)]$$

$$+ C_{t(fast)} \sum_{t=T}^{T+4} B(t)$$

$$+ O_i.W_i \qquad [4.2]$$

The first term in Equation [4.2] represents the purchase cost of all ordered and back ordered product quantities. The next term is the cost of option quantity purchased. The third term represents the holding costs based on the ending finished goods inventory each week. The fourth is the cost incurred by the OEM to test all units sold, either through normal sales, back order or options. The fifth and sixth terms are the back order cost and the cost of lost sales respectively. The cost of lost sales is only incurred when demand D(t) is greater than the sum of finished goods holding at the end of the week, $FG_{End}(t)$, sales S(t) and available options. The next two terms are the ordering cost and the cost for general and administration which are incurred for all ordered and back ordered quantities. The following two terms represents the normal transportation for sales and options quantities, and the expedited transportation costs for back ordered quantities. The last term is the cost of purchasing the rights to the option.

The objective is therefore to maximize the profit of the OEM over the lifetime of the product with O_i as the decision variable.

$$\underset{0 \le O_p \le O_i}{Max} \sum_{t=0}^{Lifetime} \pi(t) \cdot e^{-rt} \qquad [4.3]$$

where r = weighted average cost of capital

4.3 Dual Component Model

The Company's system however is slightly different from the basic model in that one of the key components within the assembly managed by the EMS is sourced directly by the OEM. Both the main assembly (ma) and key component (kc) must be available before the product can be assembled for the consumer. To this end, the revenue and cost functions of the OEM will be modified to include both assembly and component.

From Equation [4.2] for revenue, Revenue = $Revenue_{ma}$ + $Revenue_{kc}$ [4.4]

From Equation [4.3] for cost, Cost = $Cost_{ma}$ + $Cost_{kc}$

+ Holding Cost when ma is available but kc is not

+ Holding Cost when kc is available but ma is not

The additional holding costs are a result of the need to coordinate the delivery of both the main assembly and key component for the eventual delivery to the consumer. Any shortage in the key component will incur holding cost in main assembly, and vice versa. The cost is a function of the expedited delivery lead-time (LT) for the back order. While the delivery lead-time is largely predictable, there were occasions when the delivery time is late by as much as 100%.

The revised cost function is therefore

$$\text{Cost} = \text{Cost}_{ma} + \text{Cost}_{kc} + C_h[\sum_{t=T}^{T+4} FG_{End(ma)}(t + LT_{kc}) + \sum_{t=T}^{T+4} FG_{End(kc)}(t + LT_{ma})]$$

where LT$\in \{2,3,4\}$weeks [4.5]

The revised objective function for the OEM is therefore

$$\underset{0 \le O_p \le O_i}{Max} \sum_{t=0}^{Lifetime} [\pi_{ma}(t) + \pi_{kc}(t)] \cdot e^{-rt} \qquad [4.6]$$

with $O_{i(ma)}$ and $O_{i(kc)}$ being the decision variables.

4.4 Real Options Models

We defined the following 3 models for the study namely:

a. Fixed Production Model.

b. Fixed Percentage Excess over Forecast Model.

c. Safety Stock Model.

4.4.1 Fixed Production Model

The first model targets a fixed monthly production rate so that all suppliers will produce a fixed number unless the forecasted demand is higher than the agreed production rate. The numbers to be produced is based on the monthly average of the projected total annual demand. However, the annual, quarterly and monthly consensus demand forecasts will continue to be provided by the OEM as part of the quantity flexible contract. When the consensus demand forecasted is lower than the agreed fixed production numbers, the difference between the fixed production rate and forecasted numbers will act as option units (O_i) in [Eqn 4.2]. Beside paying for the forecasted quantity, the OEM is also required to pay an option price (W_i) for each of the option unit. In the event that the OEM exercises the option, additional W_p per unit (strike price) will be paid.

$$O_i = \text{Fixed Production (FP)} - Q_f \qquad [4.7]$$

On the other hand, if the consensus demand forecast exceeds the agreed fixed production quantities, the production numbers will be increased to meet the consensus demand forecasted. In this case, there will not be any option planned for the month. As in the basic model, finished goods inventories will be salvaged if no sales occurred over a three-month period.

4.4.2 Fixed Percentage Excess Over Forecast Model

The second option considered is based on having a structured agreement with the EMS to produce a fixed percentage more than the consensus demand forecast every month. The excess quantity to be produced, which serves as the option quantity (O_i) in [Eqn 4.2], will be based on a fixed percentage α over the monthly consensual demand forecast. The idea is to systematically replicate the forecast such that if actual demand exceeds the forecast, the options quantity will make up for some of the shortages. On the other hand, if demand is lower than forecast, the OEM does not end up holding on to excess inventory that it has to get rid of.

$$O_i = \alpha Q_f \quad [4.8]$$

On the other hand, if demand is less than forecast, the OEM will lose only the cost of the option which is a fraction of the total cost. However, these units will cost more (W_p) when the option is exercised. Units that are not utilized will be rolled over to the next month.

4.4.3 Safety Stock Model

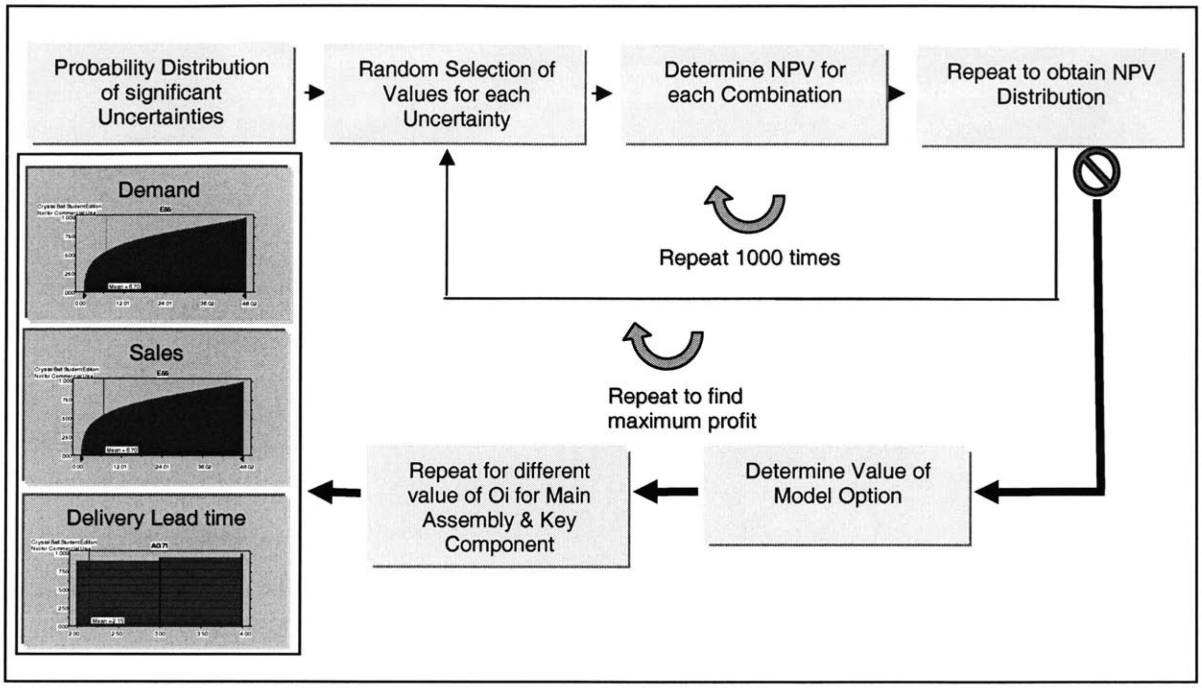
The third model considered is to buffer the maximum possible surge demand as safety stock i.e. the options quantity is the safety stock. This figure is derived from past demand data of similar products in the company's portfolio based on the consensual assessment of the prevailing economic situation.

O_i = Maximum D'(t) where D' is historical demand of similar products [4.9]

4.5 Simulating the Models

With the definition of the models established, the profits of the various models are computed using Excel spreadsheets with the uncertainties in the demand, sales and backorder lead-time simulated to replicate the volatility of these uncertainties in the profit function. A Monte Carlo numerical simulation is then conducted using Crystal Ball, an Excel add-in software that expands the spreadsheet forecasting capabilities. The software acts to generate random numbers based on the probability distribution function of the identified uncertainties to define the probability distribution of the net profit of each model. This is repeated by varying the number of main assembly and key components to be planned as option units for the month to find the highest profit possible for each of the model.

Figure 4-3 – Monte Carlo Numerical Simulation for Real Options Models



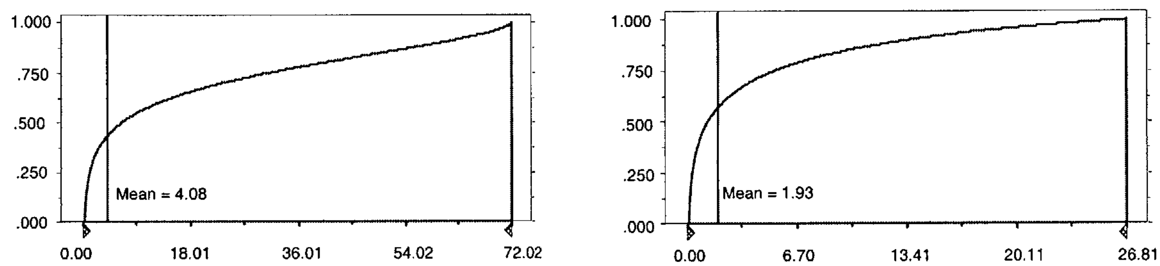
The simulation is performed in the following steps:

1. The probability distributions for all cells depicting the key uncertainties in the profit function are defined. In this case, the cells for monthly demand, monthly sales and expedited production lead time are defined for the two component model without options and the fixed production model, the fixed excess percentage over forecast model and the safety stock model. The probability distributions for each uncertainty were calculated using the historical sales or best estimates provided by the company.

As demand information is not available, demand for the product is estimated to follow the same probability distribution as sales albeit at double the scale. This is because the company's experience indicates that demand can be as high as 200% of sales. Sales historical data was generated using the company's IT system, while the expedited delivery lead-time was estimated based on the company's experience with the suppliers. Crystal Ball's automated "distribution fitting" function performs a mathematical fit to determine the set of parameters for each distribution that best-fit the product's historical data on demand, sales and delivery lead-time.

Figure 4-4 shows the probability distribution for demand of Main Assembly and Key Component. The "distribution fitting" function recommends Beta Distribution for both. The Main Assembly's distribution has an Alpha of 0.03, Beta of 0.56 and a Scale of 72.02, while that for Key Component is Apha=0.55, Beta=2.55 and Scale 103.12 respectively.

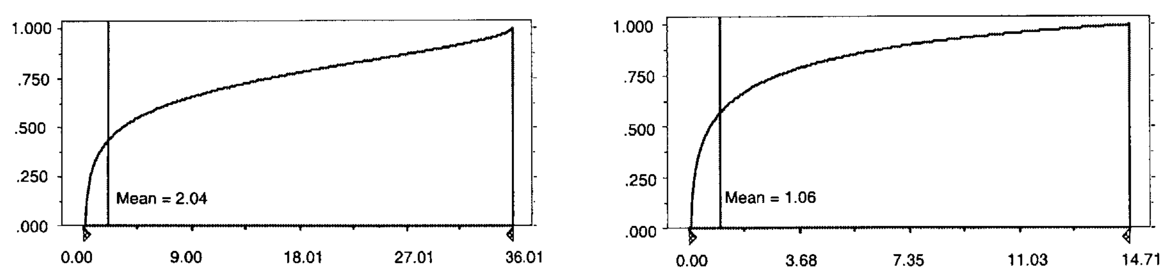
Figure 4-4 - Probability Distribution For Demand



(a) Main Assembly **(b) Key Component**

Figure 4-5 shows the probability distribution for sales of Main Assembly and Key Component which are again based on the "distribution fitting" function which recommended Beta Distribution with an Alpha of 0.03, Beta of 0.56 and a Scale of 36.01, and Apha=0.55, Beta=2.55 and Scale 56.56 for Main Assembly and Key Component respectively.

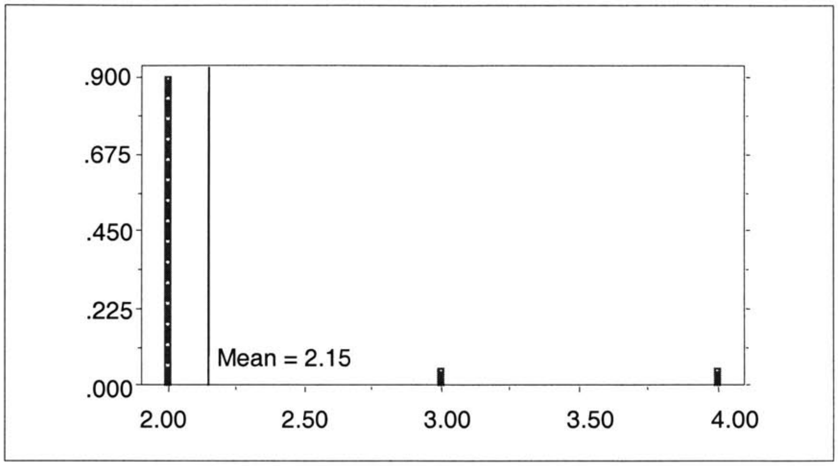
Figure 4-5 - Probability Distribution For Sales



(a) Main Assembly **(b) Key Component**

As estimated by the company, 90% of the expedited delivery can be achieved within 2 weeks. However, there is a 5% chance that the delivery is delayed by 1 or 2 weeks. As such, the probability distribution for delivery lead-time is as shown in Figure 4-6.

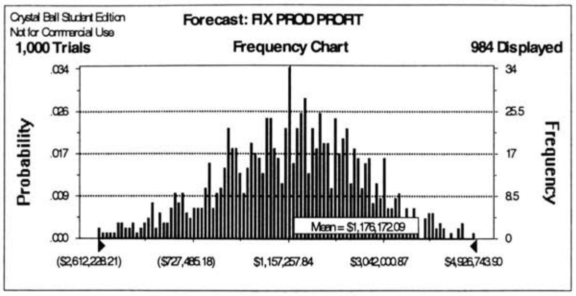
Figure 4-6 - Probability Distribution For Delivery Lead-Time



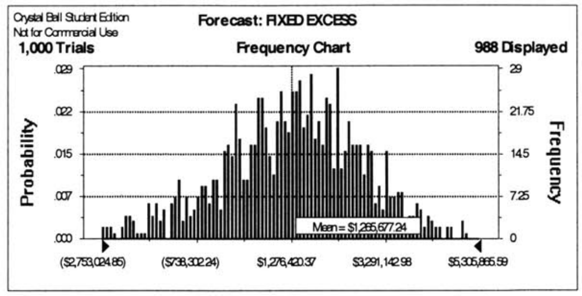
2. Next the decision variables are defined. The number of options quantity for both the main assembly and key component in each of the model is then input. For the fixed production model, the number of main assemblies and key components to be produced each month is defined. In the case of the fixed excess over forecast, the percentage of excess for both the main assembly and key component is defined. As for the safety stock model, the number of safety stock for the month is defined for both the main assembly and key component.

3. Once the options quantity is defined for all models, the simulation is performed using Crystal Ball. For each cell representing the uncertainties, a random number is generated and the net profit for the variables is computed. This is repeated over 1000 cycles to determine the range of possible profits for the decision variables. A frequency histogram of the net profit of each of the model is then plotted. Each histogram displays the mean profit achieved by the model as well as the range of possible outcomes for the model's net profit with the likelihood of achieving each of them as shown in Figure 4-7.

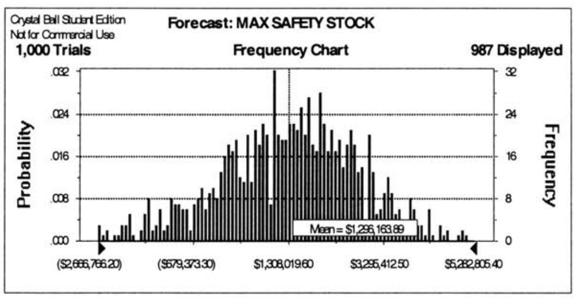
Figure 4-7 – Histograms of Models Generated by Simulation



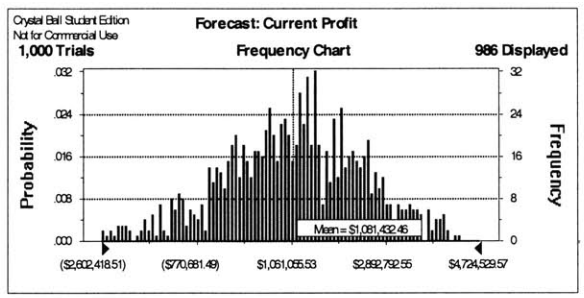
(a) Fixed Production Model



(b) Fixed Excess Over Forecast Model



(c) Safety Stock Model



(d) No Options Model

4. The value of the option with the defined decision variables for each model is then calculated as the difference between the mean value of the net profit of the model without option and the net profit generated from each of the models established.

5. Steps 2 and 3 are then repeated by varying the decision variables to obtain the net value of the option for each model. A graph for each model can then be plotted with the number of main assembly and key component as the x and y axes, while the option value as the z axis.

CHAPTER FIVE - SIMULATION RESULTS AND ANALYSIS

5.1 Results of Simulation

The value of the option to expand the finished goods inventory is defined as the value of the difference in net profit between the models with and without options. As such, the values of the option in the various models were evaluated with reference to the value-add that the option gives over the no options approach. However, the differences in the option parameters in each of the models affect the value derived. Hence, it was necessary to ascertain the best option parameters to use in each of the three models in the initial simulation. This is to allow a more equitable comparison of the value that each options model can offer.

To ascertain the best option parameters for each of the three models, the initial numbers used are shown in Table 5-1. To make sure that the EMS provider is not worse off in the options contract arrangement, the starting options price is assumed to be 25% of the wholesale price; this takes into consideration the salvage value of the product by the EMS provider. The strike price for the initial simulation is assumed to be 125% of the wholesale price. This will allow the company to derive at least 50% of the profits achieved during normal sales when they are exercising the option. The assumed option and strike prices will make it worthwhile for the company to engage in options contract arrangements with their EMS provider.

Table 5-1 – Initial Parameters Used for the Simulation

MODEL	INITIAL PARAMETER USED
Fixed Production Rate	Average Demand for the Product in the Previous Year
Fixed Percentage Excess over Forecast	15% of the Forecasted Numbers
Safety Stock	Maximum Sales for the Product in the Previous Year

The result of the simulation for the fixed production quantity model is shown in Figure 5-1. The model offers value when the company engages the EMS provider to produce a fixed quantity every month over the product lifecycle. However, the number to produce is small; one each for both the main assembly and the key component. If the number of agreed production quantities increases, the value of the option contract decreases. This is especially true for the number of main assemblies. When the agreed production number for the main assembly exceeds 3, there is no longer any value in having the option; the net profit offered by the current quantity flexibility contract is higher than that derived from the fixed production option contract. It is also noted that the effect of the number of main assembly production on the option value is more significant than that of the key component. This is because the lower cost of the key component results in lower absolute profit as compared to the main assembly; the profit from the key component is only about 25% of the main assembly.

Figure 5-1 – Value of the Fixed Production Quantity Model

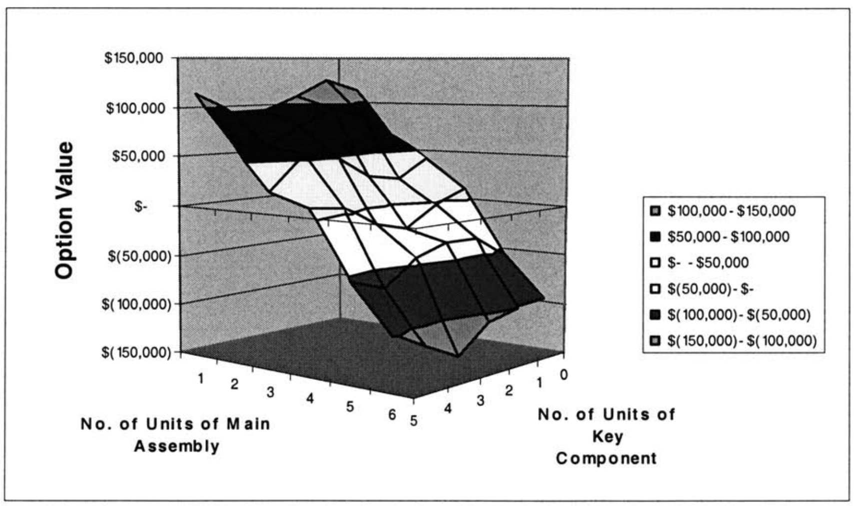


Figure 5-2 shows the value of the option with the fixed percentage excess over forecast model. Like the fixed production model, the options in the model offer value when the planned options quantity is a small percentage over the monthly forecasted numbers. It is highest when the planned option quantity is 5% of the forecasted number for the main assembly production and no option quantity is planned for the key component production. As we increase the percentages over the forecasted main assembly and key components production for the option, the value of the option contract decreases. And when the planned options quantity for the main assembly is 15% of the forecasted production quantity, the company derives no value in having the options contract as compared to the no options contract. Again, the value of the options contract is more sensitive to the number of main assembly to be produced as options. As explained earlier, this is due to the lower profits generated from the key component.

Figure 5-2 – Value of the Fixed Excess over Forecast Model

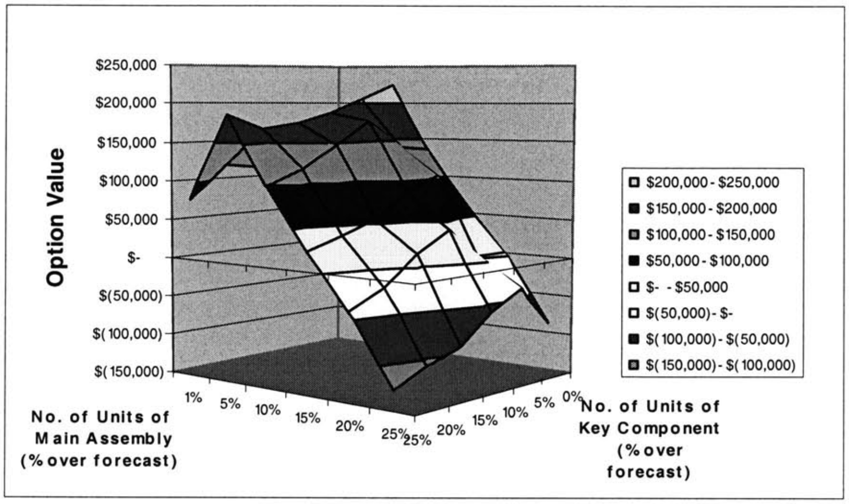
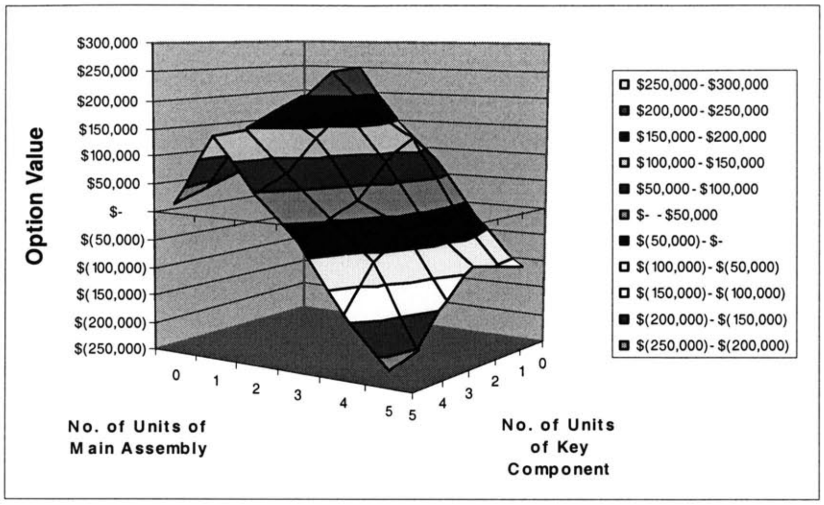


Figure 5-3 shows the results of the simulation for the safety stock model. The result is similar to the others in that the value of the option is higher with lower safety stock. The highest value of the option is obtained when the option safety stock for the main assembly is 1 and that for the key component is 0. Like the other models, the value of the option decreases as the safety stock numbers increases. In this case, there is no value in having the options contract when the safety stock for the main assembly is higher than 3 units. Again the effect of the number of safety stock for the key component on the options contract is not as significant as that for the main assembly due to its lower cost.

Figure 5-3 – Value of the Safety Stock Model



From the simulation, it was ascertained that the maximum value that can be derived from each of the various options models are as follows:

Table 5-2 –Parameters Resulting in Highest Option Value in the Simulation

MODEL	OPTIONS PARAMETER
Fixed Production Rate	Main Assembly : 1 unit Key Component : 1 unit
Fixed Percentage Excess over Forecast	Main Assembly : 5% over forecast Key Component : 0% over forecast
Safety Stock	Main Assembly : 1 unit Key Component : 0 unit

All three options models offer higher value than the no options contract. At their respective peaks, the safety stock model offers the highest value (about 25% more than the contract without options). The value of the fixed percentage excess over forecast model is about 20% more than the no options contract, while the fixed production model offers the lowest value (about 10% higher than the no options contract). The company will therefore achieve the greatest value by fixing the options quantity i.e. the safety stock options model, rather than pegging the options quantity to the demand forecast as is the case in the fixed production and fixed percentage excess over forecast models. Determining the number of units for the options contract based on the forecast will result in the value of the options contract being dependent on the accuracy of the forecast. And since it is extremely difficult to forecast in the highly volatile market that the company is in, relying on the forecast to determine the options contract will also be highly inaccurate and therefore undesirable.

Analyzing the spread between the highest possible options value and lowest possible options value of each model, it is noted that the fixed production model offers the lowest spread ($280K) as compared to the safety stock model ($368K) and the fixed excess percentage over forecast model ($364K). This indicates that while the fixed production model offers the lowest value amongst the three models, it is also the least risky. The safety stock model while offering the highest value, it also comes with the greatest risks. At its minimum, the safety stock option costs about $20K more than the fixed production model, although this is still better than the no options model. Considering that the higher value ($250K) that can be derived from the safety stock model, this is a small price to pay (only 10% of the $250K) and should not deter the company from investing in safety stock model options contract.

5.2 Sensitivity Analysis of Simulation Result

5.2.1 Option Price vis-à-vis Strike Price

Using the derived option parameters of each model that provides the highest value, the effect of the option price vis-à-vis strike price for each of the three models were simulated by varying option price and strike price as a percentage of the wholesale price. Understanding the relationship between the option and strike prices will facilitate the negotiation of contract with the EMS providers. The resulting graph for the fixed production, fixed excess over forecast and the safety stock model is shown in Figure 5-4, Figure 5-5 and Figure 5-6 respectively.

Figure 5-4 – Sensitivity of the Fixed Production Model to Option vs Strike Price

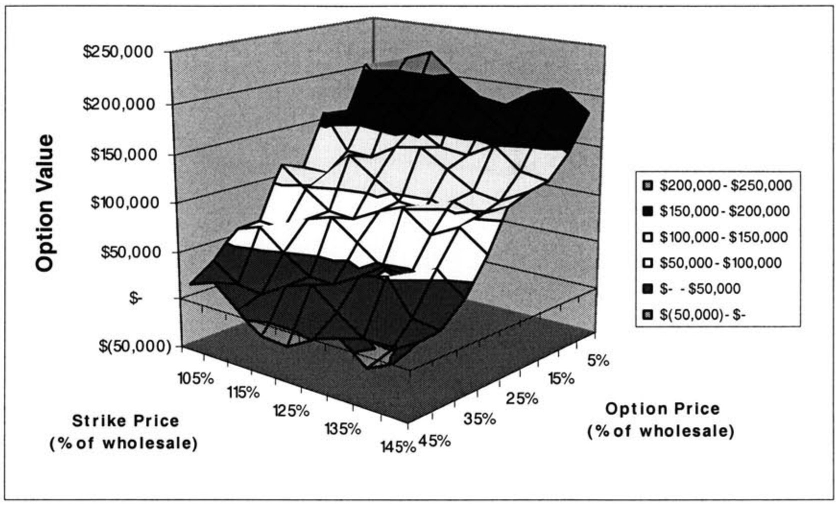


Figure 5-5 – Sensitivity of the Fixed Excess over Forecast Model to Option vs Strike Price

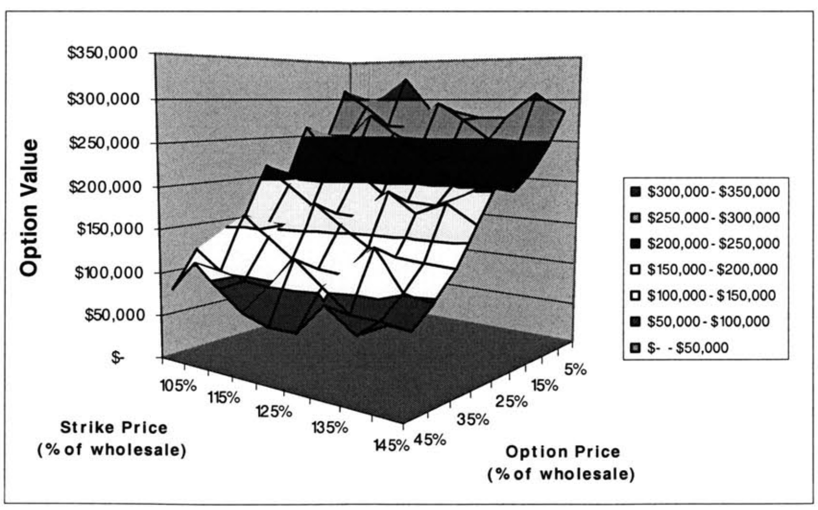
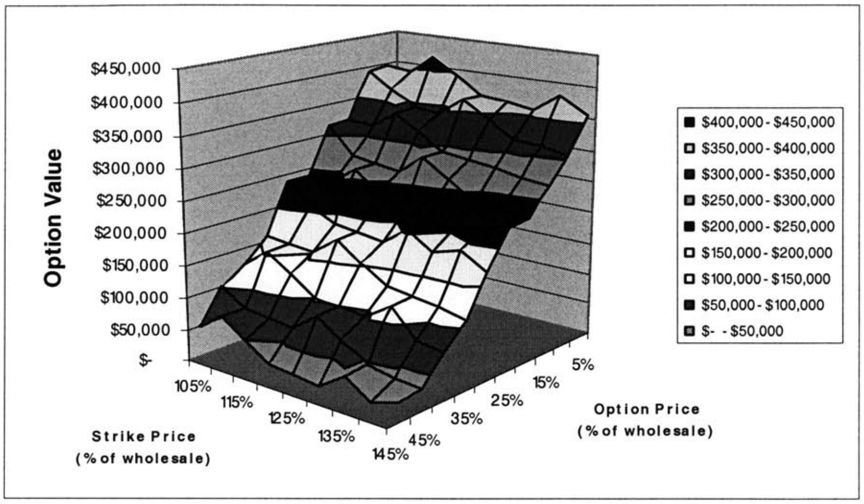


Figure 5-6 – Sensitivity of the Safety Stock Model to Option vs Strike Price

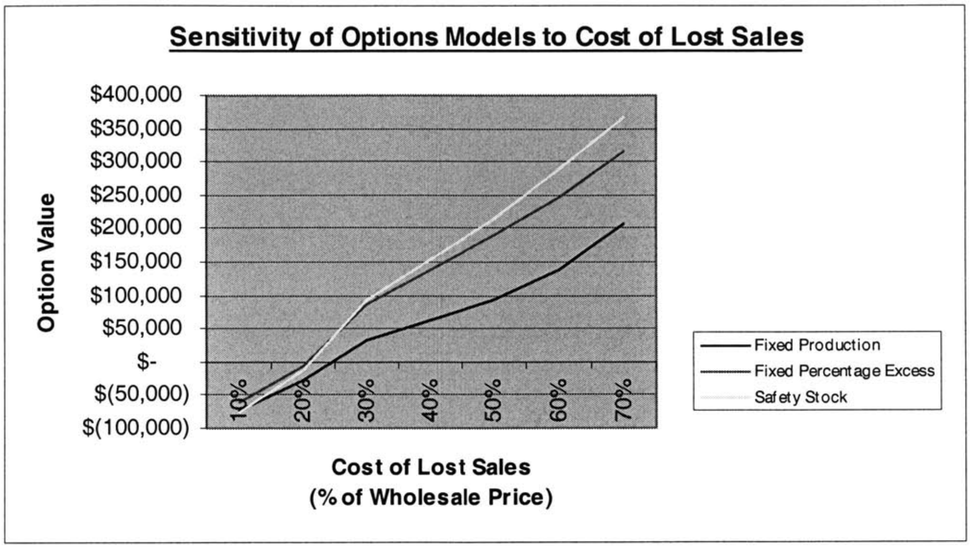


The values of the options contract in all three models considered are significantly more sensitive to options price than the strike price of the option. This is due to the uncertainty involved when investing in options. As one pays the option price prior to knowing the demand, it is a fixed cost that will be incurred even if demand does not exceed supply. On the other hand, the strike price is a variable cost that will be incurred only when the option is exercised. Profits will definitely be made when that happens. However, it is noted that the value of all the options contracts are quite robust to the total combined option cost (sum of option price and strike price) of the option units. Although the company sells the product at 200% of the wholesale price, the value of the option contract is still positive when the combined cost of the option units is priced at 190% of the wholesale price. This is despite having to incur other costs components in the supply chain like holding costs, transportation costs etc. The reason for this is that the cost of lost sales affects the overall value of the options contract more than the other cost components of the supply chain. Hence, holding on to excess options inventory and reducing lost sales improves the overall profitability of the company more than being out of stock.

5.2.2 Cost of Lost Sales

Because the number of lost sales significantly affects the overall profitability of the company, it is important to understand the impact of the cost of lost sales when considering having options to hedge against surged demand. By fixing the option parameters and the various prices, the effects of the cost of lost sales on the value of the option models is derived as Figure 5-7.

Figure 5-7 – Sensitivity of Option Models to the Cost of Lost Sales

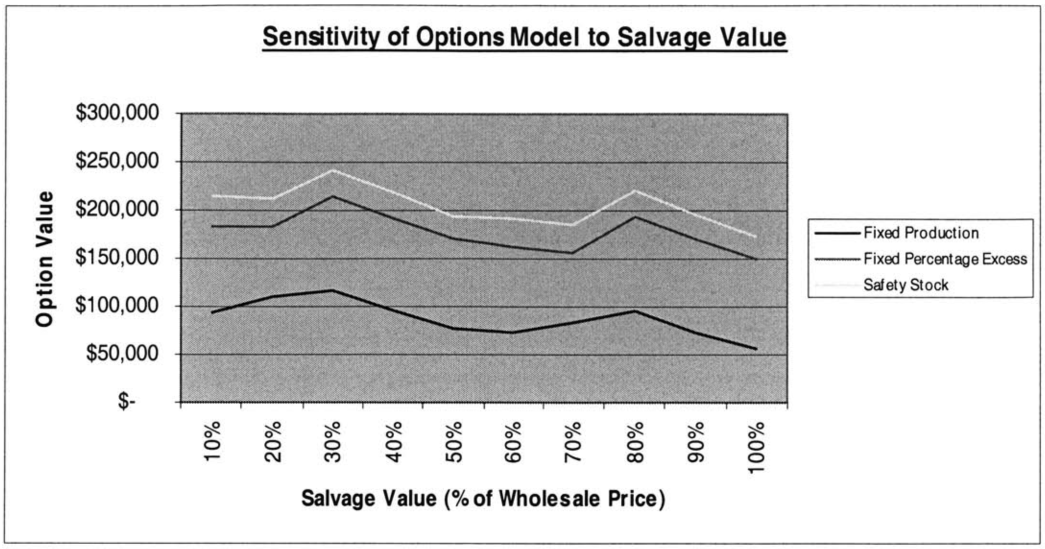


The figure shows that there is little value in the option if the cost of lost sales is low compared to the wholesale price. However, if it exceeds 20% of the wholesale price, then it is necessary to consider the value of the option. It is noted that besides offering the lowest option value, the fixed production model is also the least sensitive to the cost of lost sales as compared to the fixed percentage over forecast and safety stock models. The cost of lost sales needs to be as high as 50% of wholesale price before it offers a significant option value, when the other two models offer the same value at 30% of wholesale price.

5.2.3 Salvage Value

The salvage value of the product changes the effects of inventories on the overall profit of the current system. It is therefore important to understand the effects of the salvage value on the value of the option. Figure 5-8 shows the results from the simulation.

Figure 5-8 – Sensitivity of Option Models to Salvage Value



It is observed that the value of the option is decreasing as the salvage value of the product increases. Its effects on the various models are quite similar with the option value decreasing at almost the same rate in all three models. And despite the small quantity catered as options in the models, the effects of salvage value is about 40.9%, 18.6% and 18.9% for the fixed production, fixed excess over forecast and safety stock models respectively when the salvage value changes from 10% to 100% of the wholesale price.

5.3 Summary of Results and Analysis

5.3.1 Options Contracts Offer Higher Value

Establishing options contracts to hedge against possible surges in demand provides greater value than simply forecasting the future demand when companies are faced with uncertain stochastic customer demand. Amongst the 3 options approaches studied, options contract offers an average increase of 15% in value over a contract without options, with the safety stock model offering the highest value at 25% over the contract without options.

5.3.2 Higher Option Value has Higher Risks

Table 5-3 shows the spread of the options value derived from the 3 models studied. Although the safety stock model offers the highest value amongst the 3 approaches studied, it also has the biggest spread between the maximum and minimum possible values obtained during the simulation.

Table 5-3 – Maximum and Minimum Profit of the 3 Models

Model	Net Profit			Max-Min Spread
	Minimum	Mean	Maximum	
Fixed Production	-$2,369,036	$1,305,263	$4,922,780	$7,291,816
Fixed % Excess	-$2,460,845	$1,403,333	$4,912,377	$7,373,222
Safety Stock	-$2,391,096	$1,430,165	$4,986,188	$7,377,284

At the minimum, the safety stock model can cost $20K more than the fixed production model although its maximum makes $75K more. Hence, while the safety stock model offers the highest value, it also poses the greatest risk in terms of possible gains and loss.

5.3.3 Maintain a Small Number of Option Units for Spiky Stochastic Demand

The quantity of option units planned for each of the 3 models studied is small and the net value of the option decreases when the quantity of option units increases. This phenomenon is a result of the great spikes in the demand over a small duration of the product lifecycle; there were a couple of weeks when the demand was more than 200 units, while many other weeks had no demand. Hence, holding too many option units throughout the product lifecycle will result in high options cost and negate the value of the option contract. On the other hand, too few option units will not allow the company to meet the increased demand during the upswing. For the company, they will achieve the highest value by maintaining one unit of main assembly and key component as option. To this end, establishing options contract alone will not effectively allow the company to meet huge increases in demand when it is significantly higher than the forecast. Company will need to complement options contract with improved forecasting and inventory policies to better anticipate huge increases in demand.

5.3.4 Approach for Options Contract Dependent on Forecast Accuracy

In the 3 approaches studied for the options contract, the safety stock model provides the highest value, followed by the fixed percentage excess over forecast and then the fixed production model. However, it is noted that the safety stock model is also the only model that is not dependent on the monthly forecast by the company; the option units for both the fixed percentage excess over forecast and the fixed production model is a function of the monthly forecast. When we vary the forecast for each run, it is noted that when the forecast is able to anticipate whether the demand will increase or decrease in the month ahead, the fixed percentage excess over forecast model offers greater value than the other models even if the forecasted numbers are not accurate. Given the correct projection in the increase and decrease of demand, the fixed percentage excess over forecast approach is better able to meet any unanticipated demand than the other models. This is because when the demand is projected to increase, it will plan an increased number of option units but if demand decreases, it will reduce the number of option units and will not incur significant option costs.

5.3.5 Options are Valuable Even When Total Options Cost is High

The profitability of options contracts are quite robust to changes in the total options costs. Although the company's product is sold at 200% of the wholesale price, the value of the option is still positive when the combined cost of the option units is priced at 190% of the wholesale price. This is despite having to incur other costs components in the supply chain like holding costs, transportation costs etc. The reason for this is that the cost of lost sales affects the overall value of the options contract more than the other cost components of the supply chain. Hence, holding on to excess options inventory and reducing lost sales improves the overall profitability of the company more than being out of stock. It is however important to note that the option value is sensitive to the option price established in the contract. While the various models can still generate positive value with the option price pegged at 45% of the wholesale price, the decrease in the value of the option is significant and companies will need to consider their risk profile in establishing such options. The strike price on the other hand has a subtle effect on the net value since it will always contribute to the option value when the option is exercised.

5.3.6 Cost of Lost Sales is an Important Factor Affecting the Value of Options

An important parameter that greatly impacts the value of the option is the cost of lost sales of the product. Lost Sales occur when a customer responds to an out-of-stock situation by canceling the demand. It was noted that if the cost of lost sales is low, the value of the options contract can be negative. In such instances, it may not be wise to establish options in supply contracts. However as the cost of lost sales increases i.e. when it is more than 25% of the wholesale price, the net value of the options is positive. Hence, companies need to carefully understand the actual cost of lost sales when evaluating options contract. This is because besides losing the gross profit margin, the loss may extend far beyond the margin on the product which is actually out of stock. Some of the other common costs that are attributed as cost of lost sales include profits from possible after-sales service and maintenance, profits from sale of complementary products and accessories, costs of marketing and advertisements, cost of sales efforts etc.

In addition, there are a couple of components which are difficult to estimate. Lost customer costs can arise from out-of-stock situations. While it may be difficult to assign "costs" of a single out-of-stock situation to a lost customer, one market research have suggested that, on average, every fifty lost sale units of a product might result in one lost customer [Caplice, 2003]. This lost customer will then respond to the out-of-stock experience by taking all future businesses to another firm. Another component that is difficult to assign a value is the "ill will" that may be caused as a result of the out-of-stock situation [Caplice, 2003]. This is included to recognize that some customers will eventually "punish" the firm for poor inventory availability. While most firms are uncomfortable with the inherently subjective nature of these "penalty" components, it demonstrates the difficulties faced in estimating the "true" cost of a lost sale.

From the above perspectives, the cost of the lost customer is determined as the net present value of the stream of lost gross margins of all the future purchases of this item and other complementary accessories which now will not occur. This kind of cost analysis is inherently "soft" and subjective, but it is well worth considering. Under-estimating the "true" cost of lost sales may result in companies mistakenly concluding that options contract are not valuable for their products.

5.3.7 Increase Salvage Value to Increase Value of Option

The salvage value of a product will inevitably increase the net profit of a contract. But with options contract, increasing the salvage value of a product will further boost the value of the options contract. In our case, doubling the salvage value of the product can increase the value of options contract by as much as 20%. This is because any unused option units will now have a higher salvage value thereby increasing the net profit of the contract. Companies involved in options contract can therefore negotiate for a lower options price, if not the strike price. Hence, companies involved in options contracts should consider modularizing their products such that most, if not all, of the components can be salvaged for other uses.

CHAPTER SIX - RECOMMENDATIONS

6.1 Review of the Thesis

The thesis aims to study the possible approaches for a high tech company adopting real options in its supply management to exploit opportunities of surge in demand given that demand is highly uncertain and spiky. Chapter Two presents the changes in the telecommunication networking industry since the economic downturn in 2000, and highlighted how the industry and companies have consolidated, eliminated the inventory obsolescence and adopted many other measures to ensure a lean and flexible supply chain. However, they continue to be challenged by the highly volatile customer demand despite investing in sophisticated forecasting and inventory management techniques. In preparation of the widely anticipated up-swing in the industry in 2004 or 2005, companies that are better able to exploit any increase in customer demand will gain the edge over its competitors.

Chapter Three reviews the literature on real options to illustrate the benefits and challenges of using real options. Although there are many types of real options, approaches and techniques involved in ROA, the review establishes that an option to expand using the MAD approach through simulation will better serve the purpose of the thesis. Following the ROA process, Chapter Four defines the model for the ROA. The basic model establishes the underlying NPV for ROA and extended it for a two component model. This is then adapted to the three possible approaches explored by the company namely a fixed production, a fixed percentage excess over forecast, and a safety stock model. Chapter Five presents the comparison of the results of the three approaches studied and provides an analysis of the key parameters affecting the value of the option.

6.2 Recommendations

All the three options models explored offered higher value than the model with no options. The company will do well to consider establishing options in their contract with the EMS providers.

And while the safety stock model offers the highest return with a manageable spread as compared to the other models, its adoption depends on the risk profile of the company concerned. Given the highly stochastic and spiky nature of the demand, it is undesirable to cater too many units in the option. Options contract alone will not allow the company to meet surges in demand if it is significantly higher than the forecast – the option units should only be used to cater for stochastic changes in demand. The company will need to complement options contract with good forecasting and inventory policies. This is especially so for the main assembly which affects the options value more significantly than the key component due mainly to the big cost differences between the two – this may not be the case for a different product.

In considering the value of the option, the company will also need to consider the option price vis-à-vis the option strike price. While it should be willing to compromise on the strike price, the option price will affect the value of the option more significantly and has to be considered carefully. To improve its bargaining position, the company can consider designing the product such that its increases its salvage value if it is not sold. In addition, the company must take into account the potential cost of lost sales. Given that the company offers a very broad range of telecommunication products, involves itself in maintaining the equipment and provides after-sales services for the equipment that it sells, the cost of lost sales to the company is likely to be high and needs to be carefully considered. If it is indeed the case, the company will benefit significantly from the establishment of options contract with its EMS provider.

6.3 Future Study

This thesis is premised on the assumption that there is asymmetric relationship in the channel and that the OEM has the necessary bargaining power to implement the option in their contract with the EMS providers. However, it is not clear if the EMS providers will benefit from such a contract. The extension of the model to include the EMS providers and possibly the Tier Two and Three suppliers throughout the supply chain will establish the viability of the EMS providers and Tier Two and Three suppliers in entering such a contract. The effects of channel coordination on the relationship will then be an important component to study.

Another possible future study is on the effects of spot market on the contract. There is currently no active spot market for the telecommunication networking components and bulk of the procurement is performed under relationship-based contracts. As a result, the underlying for the simulation was based on the projected NPV. However, efficient spot markets offer flexibility in that it allows the company to immediately purchase or sell a commodity. It was for this reason that HP launched an electronic marketplace focusing on component parts and finished goods. This has since developed into a multi-company electronic exchange called the "high-tech marketplace," or converge.com. Spot markets have also evolved for trading memory chips, other hardware components, and even manufacturing capacity. The impact of such spot markets on the relationship will certainly assist companies considering options contracts with the suppliers.

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