A FLOOR SPACE VALUATION METHOD FOR AUTOMOTIVE ELECTRONICS MANUFACTURING

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Gokhan Sarpkaya, son of Oktay Sarpkaya and Gulser Pehlivaner, was born on December 25, 1969 in Istanbul, Turkey. He graduated with Bachelor of Science degree (E&E Engineering (Computer)) from Turkish Naval Academy in August 31, 1993. After working as a Navy Officer in Turkish Navy, he entered University of Pittsburgh in January, 1999, and graduated with a Master of Science degree (Industrial Engineering), in December, 1999. Sarpkaya taught undergraduate operations research classes at Turkish Naval Academy from 2000 to 2002 before he came to the United States to continue his further studies in Industrial and Systems Engineering at Auburn University College of Engineering, Auburn, Alabama, United States.

DISSERTATION ABSTRACT

A FLOOR SPACE VALUATION METHOD FOR AUTOMOTIVE ELECTRONICS MANUFACTURING

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Manufacturing complex products in order to survive the competition in the automotive electronics industry requires high volume manufacturing combined with high levels of quality and automation at a very low cost. All of the above require carefully engineered logistics, effective material handling, material identification and tracking at individual component levels, irreversible equipment and tooling investment, and dedicated floor space. Since electronics manufacturing facilities also require specific facility systems, floor space becomes an extremely valuable asset. Effective utilization of this valuable asset results in competitive advantages where the embedded flexibility to manage the capacity to generate more revenue or more cost savings significantly contributes to the profitability of enterprises.

Considering the business volume generated by the automotive industry, the primary goal of this research is to formally investigate the contribution of effective floor space valuation to strategic decision making in automotive electronics manufacturing industry. Thus it is intended to describe a conceptual framework by developing a method to evaluate the value of the additional floor space generated by manufacturing logistics investments.

The scope of this research is limited to plant level capital investment decisions of a global publicly held high-volume high-mix automotive electronics manufacturer, where the facility in question is located in the United States of America. The specific focus of this research is the valuation of the additional floor space generated by automated capital equipment replacement for the logistics department of Continental Automotive Systems, Inc. Huntsville facility. The aforementioned equipment is fully depreciated, outdated, and causing extreme downtime, thus interrupting the manufacturing operations. Several decision alternatives are analyzed and a floor space valuation method utilizing traditional discounted cash flow techniques, decision tree analysis, and real options analysis is developed. The results of the conceptual framework are discussed in order to provide better understanding for the implications of the model, and an outline for future research opportunities is discussed.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

According to the 17th Annual State of Logistics Report published by the Council of Supply Chain Management Professionals (hereafter CSCMP), logistics costs during 2005 were $1.2 billion and were equal to 9.5 percent of the Gross Domestic Product. The largest share of the increase can be accounted for by rising transportation costs, which represent approximately 63 percent of total logistics costs. Inventory carrying costs rose to 15 percent in 2005, surpassing the 2001 level. The average investment in all business inventories in agriculture, mining, construction, services, manufacturing, wholesale, and retail trade was $1.76 trillion, a new record high.

The 16th Annual State of Logistics Report states that in North America, nearly $115 billion was spent on outsourced value-added logistics services worldwide. Armstrong & Associates, Inc. reports that gross revenues for contract logistics services grew by 16.3 percent in 2004 to $89.4 billion. For the tenth consecutive year, U.S. growth in third-party, contract logistics services exceeded the U.S. economic growth. Warehouse based integrated services grew by 7.1 percent in 2004. United States based third-party logistic providers (hereafter 3PL) with international operations grew by 34 percent. Armstrong attributes some of the growth to acquisitions, where large 3PL's grow through the acquisition of smaller logistics providers to broaden their offerings.

According to the CSCMP, logistics management activities typically include

- Inbound and outbound transportation management
- Fleet management
- Warehousing
- Materials handling
- Order fulfillment
- Logistics network design
- Inventory management
- Supply/demand planning
- Management of third party logistics services providers

The 16th Annual State of Logistics Report explains the distinct elements of warehousing industry as the public and general warehousing that is generally operated as a profit center and contracted out and the private warehousing that is operated by corporations as a part of conducting their primary line of business. In addition, the values measured include value-added services similar to those offered by 3PL's. While there is no regularly released data series that captures the entire warehousing industry, the public warehouse segment is measured at regular intervals by the U.S. Department of Commerce. Periodically, special studies are undertaken to measure the size and scope of the private sector.

Figure 1.1 below summarizes the U.S. logistics costs over time. The impact of rising fuel costs over transportation costs is easily observed. Fluctuating, slightly increasing trends in inventory carrying costs, which account for approximately 39 percent of the total logistics costs, according to the 17th Annual State of Logistics Report, are due to higher interest rates and increasing investments in main industries, resulting in increased inventories.

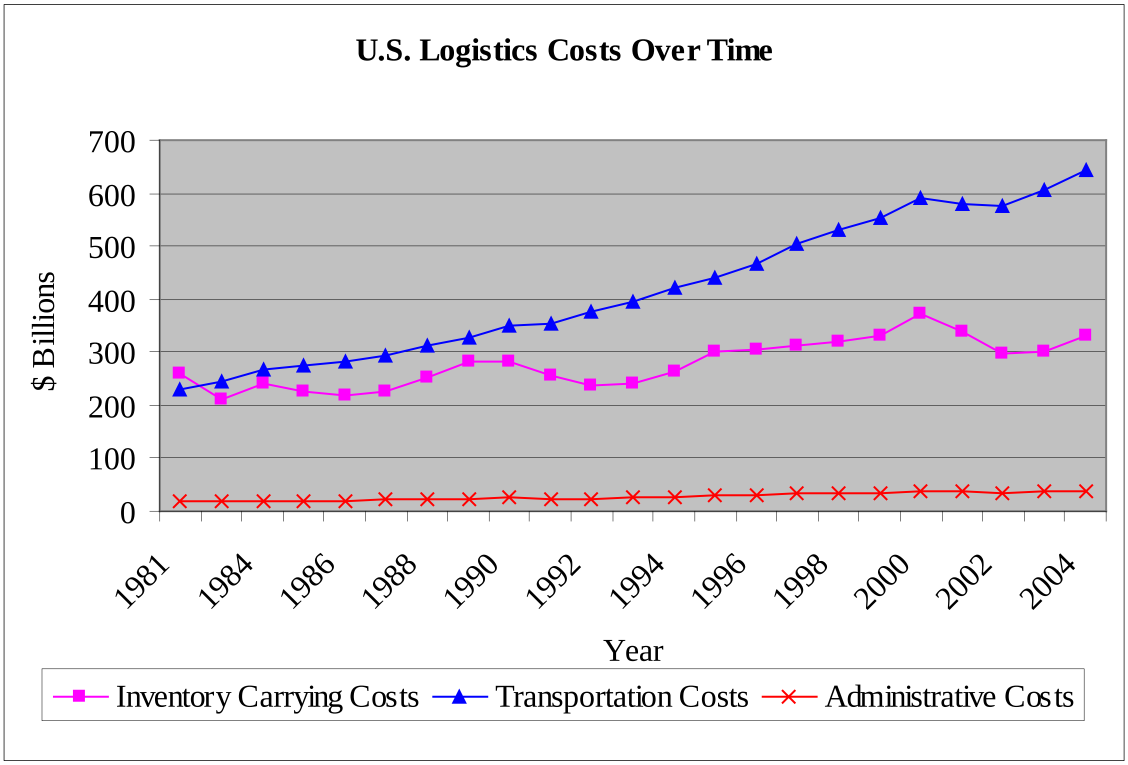

Figure 1.1 U.S. Logistics Costs Over Time

The 17th Annual State of Logistics Report breaks the inventory carrying costs down into three sub-categories for the most recent five years, as indicated in Table 1.1 below.

Table 1.1 U.S. Inventory Carrying Cost Breakdown (In Billions of US Dollars)

Year	2001	2002	2003	2004	2005
Interest	53	25	17	23	58
Taxes, Obsolescence, Depreciation, Insurance	191	198	206	227	245
Warehousing	76	78	78	82	90

The report also indicates that the cost of warehousing increased substantially in 2005 based on expenditures for public warehousing reported by the Commerce Department's Census Bureau and corroborated by several other studies. According to ProLogis, a leading global provider of distribution facilities and services, the warehouse leasing market continued to be tight in 2005. They reported that vacancy rates dropped to 7.3 percent at year-end 2005 from a high of 9.7 percent the year before. In addition, burgeoning demand has led to higher rents, which increased an average of 5 percent in 2005. New warehouse construction has increased, also a sign that investors have confidence that the market will continue to grow.

The 17th Annual State of Logistics Report indicates that warehousing costs account for approximately 25 percent of inventory costs and 10 percent of logistics costs. While the quantity of a certain material an enterprise decides to store in a warehouse depends heavily on supply chain resiliency and transportation system performance, inventory carrying costs change for reasons completely unrelated to transportation. Factors such as economic slowdown and significant changes in business cycle variables result in unexpected increases in inventory carrying costs.

Warehousing is an activity where buildings, equipment, design and continuous planning efforts, and physical and intellectual human resources are pooled together to provide and regulate simultaneous, consistent and continuous flow of the goods, services, and information between the upstream links of the supply chain and the downstream processes of the link that they concern. Well-designed and implemented warehousing, together with an adequate information system (hereafter IT) infrastructure, translates into a substantial competitive advantage.

Since controlling fuel prices, interest rates, investments in other industries and/or competitors, tax system, and insurance costs is impossible, warehousing and obsolescence costs become the most accessible targets for industries in terms of logistic costs. The 17th Annual State of Logistics Report indicates that obsolescence accounts for nearly 40 percent of total inventory carrying costs, thus demonstrating the challenges facing inventory managers in the world of fast cycles and just-in-time procurement. In addition to obsolescence costs, each link pertaining to the supply chain can control warehousing costs as well as immediate internal extensions such as inbound delivery scheduling, inventory planning and analysis, process streamlining, and waste elimination. The aforementioned warehousing cost control challenges encompass public warehouses, plant warehouses, leased warehouses, and private warehouses operated by manufacturing and third or fourth party logistics providers.

Controlling warehousing costs starts with accurate warehouse sizing, adequate floor space allocation, thus accurate inventory allocation, and streamlining the relevant processes which can be translated as waste removal out of the warehousing activities.

Srinivasan (2004) emphasizes that lean thinking must be applied to all the processes in the enterprise to remove waste thoroughly. Otherwise while some waste is removed, creating islands of excellence, some will be queued up elsewhere.

To varying degrees, the logistics function also includes sourcing and procurement of non-core-competency materials and services, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution — strategic, operational, and tactical.

Measuring corresponding costs is not straightforward because logistics management activities involve a substantial amount of in-house operations. In-house operations refer to the business operations that an enterprise conducts to provide services for its own use. In contrast to the services from for-hire operations that are bought and sold in marketplaces, in-house operations are provided and consumed internally without market mediation. Some auxiliary functions which may not be considered within the scope of logistics, such as maintenance and repair of the material handling systems, should also be taken into account because they are the natural and immediate extensions of logistics activities.

Overall in-house logistics operations can be considered as a natural resource acquisition and exploitation activity, depending on the contingent circumstances:

- A portion of the existing floor space in a facility can be dedicated for material handling, storage, staging, replenishment, and/or other relevant non-core-competency activities.
- A new facility offering sufficient floor space can be bought or leased in case existing floor space does not meet the requirements.

- A contract can be negotiated with a 3PL such that logistics operations are managed externally without any in-house floor space requirements.

Similarly, any operation that does not require core-competency of the corresponding enterprise can either be handled in-house or contracted out to effectively utilize the existing floor space depending on the generated value. The fundamental tradeoff is whether or not to allocate all floor space to revenue-generating activities. However sufficient floor space needs to be allocated to the non value-added activities that cannot be outsourced in order to avoid dependencies on third parties. The bottom line is to effectively utilize the existing floor space in order to obtain the greatest return for an investment in order to compete in today's environment.

The fiercest competition today is in the automotive and high technology industries due to globalization, rapid technological improvements, and the need for new energy resources. Original equipment manufacturers (hereafter OEM) in the aforementioned industries exert their power mostly over their first-tier suppliers. Moreover, high market demand volatility, short product life cycles, long design and production lead times, high capital investment requirements, and irreversibility of the investments require extremely intelligent decision making.

Evans, Zhang, Vogt, and Thompson (2004) propose that the most challenging environment described above is that of automotive electronics manufacturing, which has similar manufacturing issues common in all electronics production but has the added difficulty of meeting very stringent quality and reliability requirements in a globally competitive market.

They discuss the fact that electronics manufacturing is a cornerstone of the current global economy and, as such, presents many unique issues and opportunities to manufacturing and investment planners.

Automotive electronics manufacturing involves placing hundreds of tiny components accurately on a minute printed circuit board (hereafter PCB) with high precision, soldering to ensure robust and reliable mechanical and electrical contact, applying a protective coating, and placing the mechanical assembly into a housing designed to operate in harsh conditions such as very cold or hot temperatures, mechanical and thermal shock, vibration, etc.

Figure 1.2 Sample PCB

The need to manufacture complex products in order to survive the competition in the automotive electronics industry requires high volume manufacturing combined with a high level of quality and automation and, more importantly a very low cost. All of the above require carefully engineered logistics, effective material handling, material identification and tracking at individual component levels, if possible, and dedicated and irreversible equipment and tooling investment ranging from $45 million to $60 million per dedicated assembly line depending on the flexibility of the line and floor space, which is ranging from 10,000 sq. ft. to 30,000 sq. ft. for a typical automotive electronics product (Evans, Zhang, Vogt, and Thompson 2004).

Because electronics manufacturing facilities also require specific facility systems like 480-Volt power, nitrogen supply, adequate ventilation, hazardous material storage area, and humidity control, floor space becomes an extremely valuable asset. Effective utilization of this valuable asset results in competitive advantages where intelligent decisions can be made by outsourcing activities that are not included in the core competency list of the enterprise or by keeping them in-house with accurately justified automation investments.

Effective floor space utilization brings in the flexibility to manage the capacity to generate more revenue or more cost savings, hence more contribution to competitive advantage in favor of the subject matter enterprise. Wu, Erkoc and Karabuk (2005) argue that a firm’s ability to manage its capacity is the most critical factor for its long term success. Hence, considering floor space as a primary resource for capacity planning should not be controversial.

Assume a scenario for a first-tier automotive electronics supplier where the quarterly sales forecast of its main customer, an automotive OEM, declines significantly due to globally changing market dynamics, resulting in early contract termination with its suppliers. Collaborative planning, replenishment, and forecasting efforts result in assigning the forecasting task to OEM's in today's automotive industry, thus allowing OEM suppliers not to have to deal with forecasting in order to avoid compounding effect of the amplified forecast errors upstream. However, early contract termination can potentially hurt first-tier suppliers the most due the amount of inventory on-hand beyond the committed order quantity placed by the OEM.

This could potentially generate a ripple effect upstream through the corresponding supply chain if the contracts are negotiated myopically by relying on ample floor space on hand and on naïvely optimistic sales forecasts provided by OEM's. The loss of the first-tier suppliers is the highest because the value of production material at this level is higher before they are converted to finished goods.

Assume another scenario where a decision must be made about whether or not to invest in manufacturing logistics systems in order to save floor space for a new, and state-of-the-art revenue generating manufacturing technology. In this scenario, almost 80 percent of a dedicated assembly line footprint is required in order to erect a hermetically sealed cleanroom for a new flexible manufacturing cell. The tradeoff is between losing an existing business to another facility and making irreversible manufacturing logistics investments to generate the required floorspace for the new business, resulting in significant learning curve challenges and significant changes regarding the way the logistics operations are performed. Generating additional floor space out of an existing layout by means of manufacturing logistics investments could generate additional revenues of $120 million per year, and provide knowledge transfer with state-of-the-art manufacturing technology.

The unpleasant consequences of the aforementioned scenarios range from losing potential business to plant close-out or even bankruptcy due to ineffective floor space utilization. In order to avoid these consequences, better contract management with suppliers and customers, more intelligent warehousing, inventory allocation, and investment decisions are required for first-tier suppliers.

In this way floor space is not underutilized as an idle component of the business for stagnant or obsolete stock keeping units or non-revenue generating activities. In both scenarios floor space value acts as a proxy for valuation to make intelligent decisions.

The largest challenge faced by manufacturing businesses today is the full utilization of an asset by proper valuation and/or finding the real value. Boer (2002) quotes that the greatest challenge facing any organization today is in understanding the huge differential between its balance sheet and market valuation. He argues that as long as most transactions involve physical goods and tangible assets, the accounting approach to valuation works well. However financial statements measure transactions only in a tangible oriented setting where physical assets exist and even the existence of slight uncertainty makes the accuracy of these statements questionable. Moreover, the traditional methods that those financial statements are based on have several drawbacks. They naively assume perfect project cash flows. However future cash flows are barely certain. The discount rate that the traditional methods are utilizing is kept constant all along the project life, where it needs to be adjusted from high to low as the uncertainty resolves representing the risk premium changing based on the arrival of new information. Finally, the traditional methods dictate the decision maker to make "go-or-no-go" or "now-or-never" decisions ignoring the flexibility of switching between alternatives or delaying the decision.

The purpose of this research is to formally investigate the contribution of effective floor space valuation to strategic decision making in the automotive electronics manufacturing industry. This research specifically addresses the value of manufacturing floorspace related to different usage options for the facility.

Currently, finance specialists divide the budget by the total available floor space in order to calculate the floor space value without taking into account the embedded revenue generating potential. However, with ongoing lean initiatives, floorspace is included in waste elimination efforts for manufacturing facilities and considered as an asset. The effective utilization of any asset in manufacturing positively contributes to the financial statements. Generating additional floor space will add additional capacity to the corresponding facility, where future cash flows can be generated. Traditional methods cannot incorporate uncertain future cash flows into associated calculations that financial statements are based on. This research will have specific focus on developing a new financial method, which utilizes a series of both traditional and relatively new techniques addressing the uncertainty aspect of the project cash flows. Considering there are only six first tier automotive electronics facilities in U.S.A., it is crucial to have a better floor space valuation method, especially when the economic circumstances are not favorable, and the aforementioned method will help corporate executives and corporate planners to make better business decisions regarding future product allocations to manufacturing plants based on the floor space value.

CHAPTER 2

VALUE AND FINANCIAL DECISION MAKING

2.1 Value

Valuation is the financial translation of revenue–generating or loss-incurring potential. It is not only important in driving financial transactions, but also in decision making. Boer (2002) defines valuation as assigning a quantitative value, in dollars, for example, to an asset whether that asset is a share of stock, an oil painting, or an invention. He also argues that the economic value is defined as the present value of the future cash flows, and strategic value is defined as the value of unrealized opportunities.

Copeland, Koller, and Murrin (1995) define value as the best metric for performance, and they argue that enterprises that do not perform will find that capital flows toward their competitors. Hence one can conclude that value is an effective key performance indicator where valuation plays a significant role in decision making.

Copeland, Koller, and Murrin (1995) also propose that there is strong correlation between the market value of a company and its discounted cash flows. Valuation is currently being accomplished by using discounted cash flow (hereafter DCF) techniques, where it is assumed that perfect and complete information exists for both future cash flows and risk adjustment of the discount rate. Information is complete when the state of the nature moves first and these moves are known to every player.

Information said to be in perfect order describes a state of complete knowledge about the actions of other players that is instantaneously updated as new information arises when the corresponding information sets are singleton (Rasmusen 1994). However these assumptions about the information seem unrealistic for managing an organization's cash flows, and decision making using perfect and complete information is rarely possible. In most decision problems, the decision maker might chose a "wait and see" approach in order to gather more information by postponing the action rather than immediately adopting it. It is the decision maker's responsibility to evaluate the tradeoff between the cost of postponing the action, thus gathering more information and the value generated thereby. Hence other decision-making techniques sustaining the DCF techniques must be deployed to avoid the aforementioned assumptions and accomplish proper valuation.

This research study is about evaluating options that generate revenue through effective utilization of the floor space dedicated to non-value added activities, with accurately adjusted risk and more realistically projected cash flows using a new method sustaining traditional DCF techniques.

2.2 Financial Decision Making

Where there is no perfect and complete information, there is uncertainty and risk. Consistent decisions under uncertainty can be made by using several different techniques. A decision maker who has a set of alternatives faces uncertain events where there is a payoff or penalty for each alternative and event combination.

The likelihood of occurrence is represented by a probability and, since almost all of the decisions in a manufacturing environment are sequential, a decision tree can be used to structure the decision problem. There are various analytic approaches for decision making including intelligent and formal decision making under uncertainty where tradeoffs between using one or another stem from their limitations.

Expected Monetary Value (hereafter EMV) approach is adequate if the amounts of money involved are small or if the decision is a repetitive one, such as an inventory stocking policy (Bierman, Bonini, and Hausman 1997). However, maximizing the EMV does not seem to generate satisfactory results when risk is involved.

Dominance approach is applied in three different forms. Outcome dominance is the form where the worst benefit of one act is at least as good as the best of another act. Event dominance is the case where the benefit of an act is equal or better than that of another one for each event. Probabilistic or stochastic dominance is the third and final form of dominance criterion where the cumulative probabilities for each outcome of an act outweigh the cumulative probabilities of each outcome of the other act for each value of the outcomes. Based on the sample problem provided by Bierman, Bonini, and Hausman (1997), the conditional benefit table of which is indicated below, act d_1 dominates d_2 by outcome dominance and event dominance, and act d_4 stochastically dominates act d_1. They conclude that, of all the three forms, outcome dominance is the strongest, event dominance is the next strongest, and the stochastic dominance is the weakest.

Table 2.1 Conditional Benefit Table of the Sample Problem

Event	**Probability**	**Acts**			
		d_1	**d_2**	**d_3**	**d_4**
q_1	0.3	2	-1	1	1
q_2	0.2	1	0	0	0
q_3	0.5	0	-1	-1	2

Von Neumann and Morgenstern (1967) argue that decisions are made so as to maximize expected utility rather than EMV. They developed a procedure for quantifying a person’s utility function for commodities or money depending on one’s attitude towards risk. The utility theoretical approach uses lotteries to explain judgments behind decisions. Since the attitude towards risk changes based on the subject matter wealth, the utility function is not always linear. Hence, EMV criterion is only valid when the decision maker is risk neutral. His utility function is then linear over the range of all possible outcomes. This criterion uses a measure called marginal utility: for large benefits the slope of the utility function increases gradually and becomes smaller as smaller additions are contributed. This is also known as the diminishing marginal utility. Bierman, Bonini, and Hausman (1997) explain the utility scale by using a Celcius and Fahrenheit scales analogy: both measure the temperature but have different readings. They discuss that a utility function represents the subjective attitude of a decision maker to risk. Basically, it is a descriptive theory. They also interpret the notion of certainty equivalency used in utility theory as either the maximum insurance that the decision maker is willing to pay to be freed of an undesirable risk or the minimum certain amount that the decision maker is willing to accept for selling a desirable but uncertain set of outcomes.

The above approaches establish the basis for financial decision making. EMV approach is effectively used where there is not any risk involved. Dominance approach fails to select an act in the existence of multiple alternatives that dominate all of the others; however, it sustains EMV criterion in case of risk involvement. Bierman, Bonini, and Hausman (1997) explain that utility analysis does not work effectively since

- It is extremely difficult to estimate the correlation of returns of a decision alternative with others (portfolio effect).
- Decision makers sometimes violate basic assumptions on which the utility analysis is based (Allais paradox).

Decision analytic approaches are not limited to the above. Analytic Hierarchy Process (hereafter AHP) developed by Saaty is a multi-attribute decision analysis approach through ratio scales. AHP requires pairwise comparison judgments which are used to develop overall priorities for ranking the alternatives. It also allows the decision maker(s) to evaluate and improve consistency in ranking the criteria and alternatives within the framework of pairwise comparisons (Saaty and Vargas 2001).

Goal programming, based on linear programming, uses simplex algorithm for multi-attribute decision making which is able to handle conflicting objectives by taking priorities into account (Canada and Sullivan 1989). The most significant limitation of goal programming reported by Canada and Sullivan (1989) is the formulation complexity of a model for real-world problems.

Artificial intelligence techniques like expert systems are powerful tools to solve complex decision problems.

However, these techniques have limitations such as the availability of inference mechanisms, the lack of common sense, and the domain size. The suitability of any artificial intelligence technique should be carefully investigated before deploying (Canada and Sullivan 1989).

Simulation is another descriptive approach to design a model of a real system and to conduct experiments with this model. However, the most significant limitation of this approach is that it is descriptive rather than prescriptive. It provides information for decision making by letting the decision maker know how a system behaves rather than indicating how the system should react to uncertain events.

In addition to these decision analysis methodologies, there are two other methodologies described by Herath and Park (2000): Capital-asset pricing and real options analysis.

Capital asset pricing captures the investor's perspective by measuring the value of an investment decision in terms of its value to the market or its contribution to the investor's wealth. The risk attitude is involved by adding a "market risk premium" to the risk-free discount rate when calculating the risk-adjusted discount rate used to discount the expected future cash flows (Herath and Park 2000).

Real options analysis (hereafter ROA) is based on the opportunity to make a firm decision after observing the events. ROA is a passive methodology using option-pricing theory to evaluate the decisions.

Under ROA framework, decision makers have the right, but not the obligation, to exercise a firm decision such as investment, divestment, expansion, contraction, postponement, or abandonment at a predetermined cost and during the predetermined life of the option. Net present value (hereafter NPV), as a DCF technique, can be interpreted as a special ROA case where the discount rate is constant, the risk is perfectly adjusted, and the expiration date and the future cash flows are known with certainty, which can be considered as an extremely hypothetical situation.

Park and Herath (2000) define ROA as the version of decision analysis that has adopted the market perspective, i.e. the market risk allowing determination of expected values using risk-neutral probabilities and discounting at the risk-free rate. The advantages of ROA are discussed in detail in Appendix A.

Decisions in electronics manufacturing environments require sequential decision making since

- The majority of the decisions involve significant irreversible capital investments.
- Exercising an action takes a significant amount of time.
- Business dynamics such as customer demand, product life cycle, production lead time, technological developments, and acquisitions change fairly frequently and result in significant changes about the contingent circumstances.

The complexity in decision making goes hand in hand with the complexity in the associated manufacturing processes.

Printed circuit boards designed to host up to several hundreds of minuscule electronic components require extreme precision in terms of solder paste dispensing and component placement before they are thermally cured during subassembly process. Final assembly process mainly composed of both manual and automated steps consists of mounting the printed circuit boards into the casings where the finished good product is adapted to its point-of-use environment. For both subassembly and final assembly processes, on-the-go structural, electrical, and functional testing is a strict business requirement, hence a significant capital burden, as well. Therefore heavily automated and expensive equipment is required. Moreover, managers face the challenge of establishing a diverse customer portfolio in order to reduce the business risks associated with global competition stemming from low labor cost pressure and the need for new energy sources. Under the aforementioned circumstances, adapting the electronics manufacturing enterprises to the fast-changing business dynamics is only possible through managerial flexibility in allocating resources. Managerial flexibility to switch between alternatives, to speed up or to slow down a project, and ability to gather additional information contribute more value than is assumed by making use of ROA methodology.

2.3 Research Plan

The research question that will be tackled is indicated as follows: How can the value of the options or unrealized opportunities embedded in the additional floor space be calculated?

Considering the business volume and the associated floor space required by the automotive electronics industry, the primary goal of this research is to formally develop a method to evaluate the value of the additional floor space generated by capital investments. The supporting objectives are to develop the method utilizing traditional DCF analysis, Monte Carlo Simulation (hereafter MCS) analysis, decision tree analysis (hereafter DTA), and ROA, to apply the method to a practical business application using real data, and to compare the resulting decision recommendations.

The research hypothesis is that if a floor space valuation method consists of the aforementioned different financial decision making techniques, then decision makers can value the opportunities embedded in additional floor space by incorporating the probabilistic nature of the input variables and the managerial flexibility.

The scope of this research is limited to plant level capital investment decisions of a global, publicly held high-volume high-mix automotive electronics manufacturer, where the facility in question is located in the United States of America.

It is assumed that macroeconomic parameters are not subject to unexpected changes stemming from regional or global economic and/or geopolitical crises. However the corporation can be exposed to various market and business dynamics such as demand fluctuations, capital cost readjustments, acquisitions, etc.

Chapter 3 presents the review of the relevant literature, where the past research analysis of floor space valuation, option pricing theory, and real options are highlighted. In addition, current application areas and relevant modeling approaches are discussed.

This chapter mainly provides theoretical and practical aspects of ROA based on the past research work in order to establish a basis for using the floor space valuation as a proxy of the overall project valuation.

Chapter 4 presents the methodology and a real-world practical business application concerning a series of capital investment decisions for an automotive electronics manufacturing facility. The projects that are subject to the aforementioned decisions are

- Replacing the existing outdated AS/RS and corresponding WMS with a new AS/RS and WMS to generate floor space and cost savings supported by a throughput analysis through a simulation study.
- Eliminating the existing outdated mini-load AS/RS by switching to a just-in-time delivery system together with three-shift 3PL support and transportation operation.
- Replacing the existing outdated AGV control software and retrofitting the vehicles of the existing AGV system in order to generate floor space by eliminating pick and drop stands and by reducing the aisle space supported by a throughput analysis through a simulation study and to extend the useful life of the mechanical AGV components.
- Replacing the existing outdated AGV system with water spiders utilizing tuggers with associated trailers.

In Chapter 5 traditional valuation models will be discussed with respect to the real-world practical business application presented in Chapter 4.

Then DTA and ROA framework based on floor space valuation will be utilized. In general, an effort will be put forth to strip a layer or two from the surface of the floor space valuation.

In Chapter 6 the conclusions of the conceptual framework that will be provided in Chapter 5 will be explained in order to provide better understanding for the implications of the method. Finally, an outline for future research areas with emphasis upon the results and the contributions associated with this research is discussed.

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

Floor space value has not been studied in detail in the existing body of research, and there are not many publications mentioning floor space utilization. There are two relevant perspectives. The first perspective is that AS/RS requires minimal floor space by utilizing the vertical storage space. These systems are part-to-man systems increasing productivity. Automated storage and retrieval system (hereafter AS/RS) is a dense storage alternative that can be used as a buffer or fast pick area to store and retrieve, replacing the manual picking with automation. The design of such systems can be customized to allow for no interruption in plant production and to minimize installation through timely system implementation. These systems fit within the limited floor space and, therefore, reduce the need for additional non-manufacturing floor space which can be very valuable in case customer demand increases and new manufacturing floor space is needed. Two AS/RS installed within Air Canada's main maintenance base in Montreal are reducing floor space for storing spare parts from 100,000 sq. ft. to 70,000 sq. ft. or less (Rees 1994).

Rees (1994) also emphasizes that the AS/RS equipment and related conveyors, operator workstations, and warehousing software, plus pneumatic tube delivery of small parts to shops and hangars, are boosting productivity and reports that the overall system provided a rapid, 3.5-year investment payback for Air Canada. Other benefits include a major provision in the AS/RS software to provide cycle counting, resulting in a more accurate inventory. Also faster and more certain picking of priority items is possible. To improve the use of available non-manufacturing floor space and to take advantage of material handling technical advances, Air Canada evaluated two storage automation technologies: AS/RS and horizontal carousel equipment, where AS/RS proved to be the most effective system. Ten factors were considered including

- Floor space utilization;
- Picking rate;
- Workstation design;
- Warehousing software;
- Reliability and access during a breakdown, hence robust exception handling;
- Expansion flexibility;
- Maintenance;
- Security;
- Airline industry acceptance for 24-hour, 7-day operations; and
- Price

The second perspective is that of employment densities. Thompson (1997) conducted an empirical study to examine the results of a long-running study of floor space-to-employment ratios for industrial properties in the United Kingdom.

His objectives were to identify the densities generated by a range of industrial building types and to gain a picture of how these densities move over time, in particular relation to economic cycles. According to his research, there are five subtypes of the industrial sector that may behave discretely. These are factories, factory warehouses, warehouses, long-term storage facilities, and workshops. Employees are the main economic influence on each of the sub-sectors with the exception of long-term storage. Thompson (1997) represents employment density by:

$$\frac{Gross\ External\ Area}{Number\ of\ \ Full-Time\ Equivalent\ Employees} \qquad \textbf{(3.1)}$$

By the comparisons existing in the aforementioned study the factory warehouse combination dropped dramatically over the course of the study from 525 sq. ft. per employee to 419 in 1994, and then, in 1996, it rose back to 439. The pattern is difficult to explain. The mean size of building for this property type is much smaller than for the overall sample at just under 3,000 sq. ft. The warehouse returns show densities falling consistently over the five-year period. This is consistent with anecdotal evidence from the market as to the great deal of demand for high-specification distribution centers at the end of 1980's. Since then the recession and slow recovery seems to have been mitigated against rapid growth in this sector. The impact of technology has been particularly fierce in the distribution sector, where high employment densities are often the norm, particularly in the larger, purpose-built facilities.

Although there is no particular bias towards these large, national distribution centers in the sample studied by Thompson (1997), the overall trend serves to raise densities substantially throughout the distribution industry. According to Thompson (1997) the behavior of mixed-use factory/warehouses remains a puzzle.

Another study related to office floor space indicates that as employees become more mobile, companies are realizing that dedicating floor space to the service of a person who is not always there to occupy it is considered a waste of resources. Itinerant members of staff need only as many workstations as there are itinerants actually in the office at any one time. Companies like Ernst & Young, Accenture, and IBM are saving floor space through office hotelling by taking advantage of information technology at the expense of psychological, general privacy, and personal storage arrangement-related concerns (Anonymous, 1995). However office hotelling requires extensive planning and fine-tuned booking procedures so that disastrous effects on efficiency can be averted. The main goal is to adopt more open-plan offices, to reduce individual office sizes, and to move excessive material except work-in-progress out of the prime office space. The space requirement consequently drops even further, while flexibility is increased.

3.2 The DNA of Decision Making: Valuation

Luehrman (1997) defines valuation as the financial analysis skill that general managers want to learn and master more than any other. The value of a business is equal to the present value of its expected cash flows discounted at a predetermined discount rate.

Accurate encoding of the inherited value leads businesses towards the correct direction contributing additional value. Copeland, Koller, and Murrin (1995) propose two frameworks for valuation: Entity DCF model and Economic Profit Model.

The Entity DCF Model values the equity of a company's operations less the value of debt and other investor claims that are superior to common equity. The values of operations and debt are equal to their respective future free cash flows discounted at rates that reflect the riskiness of these cash flows. Free cash flow is equal to the after-tax operating earnings of the company, plus non-cash charges, less investments in operating working capital, property, plant and equipment, and other assets. It does not incorporate any financing-related cash flows such as interest expense or dividends. This framework gives the exact same equity value as if the discounted cash flow to the share holders is directly discounted. According to Copeland, Koller, and Murrin (1995) the discount rate applied to the free cash flow should reflect the opportunity costs to all the capital providers weighted by their relative contribution to the company's total capital, which is also called weighted average cost of capital (hereafter WACC). However the limitation is the selection of the appropriate discount rate to estimate the future free cash flows and to estimate the life of the business. In order to mitigate these limitations and to make the problem mathematically more tractable, they discuss separating the value of the business into two time periods: during and after an explicit forecast period. The present value of the cash flow during an explicit forecast period, and the value of the cash flow after an explicit forecast period, which is referred to as continuing value, can be calculated easily. They argue that the formula below is simple enough to estimate the continuing value without the need to forecast the company's cash flow in detail for an indefinite period.

$$CV = \frac{NOPAT}{WACC} \qquad \textbf{(3.2),}$$

where NOPAT represents the net operating profit after taxes.

Another framework proposed by Copeland, Koller, and Murrin (1995) is the Economic Profit Model, where the value of a company equals the amount of capital invested plus a premium equal to the present value of the value created each year going forward. The advantage of the Economic Profit Model over DCF model is that the economic profit is a useful measure for understanding a company's performance in any single year, while free cash flow is not. The Economic Profit Model measures the value created in a company in a single period of time and is defined as follows:

$$\textit{Economic Profit Model} = \textit{Invested Capital x (ROIC – WACC)} \qquad \textbf{(3.3),}$$

where ROIC represents the return on invested capital calculated by dividing NOPAT by the amount of invested capital.

Both the Entity DCF Model and the Economic Profit Model are incapable of incorporating the value of future opportunities such as growth, expansion, disinvestment or investment, abandonment, and future borrowings together with associated riskiness.

There are other DCF frameworks discussed by Copeland, Koller, and Murrin, (1995) each of which has specific drawbacks and limits to its the practical usefulness.

Direct discounting of equity cash flow is the most straightforward technique that involves discounting the cash flow to equity holders. However this framework is only useful for financial institutions. This technique provides less information about the sources of value creation and is not useful for identifying value creation opportunities.

The increase in dividend of the stock price is projected by assuming that operating performance is constant.

Using real instead of nominal cash flow and discount rates involves projecting cash flow in constant dollars and discounting this cash flow using a real discount rate, which is calculated by subtracting the expected inflation from the nominal rate. Most managers use nominal rates since they are easier to communicate. However for large corporations operating in a geography consisting of countries with both high and low inflation rates, valuation using nominal rates is not mathematically tractable and thus becomes more complicated.

According to Copeland, Koller, and Murrin (1995) discounting pretax cash flow instead of after-tax cash flow involves simple formulation, which is expressed as follows:

$$\text{Value} = \frac{\text{After - tax Cash Flow}}{\text{After - tax discount rate}} \qquad \textbf{(3.4)}$$

$$\text{After - tax Cash Flow} = \text{Pre} - \text{tax Cash Flow} \times (1 - \text{Tax Rate}) \qquad \textbf{(3.5)}$$

$$\text{After - tax Discount Rate} = \text{Pre} - \text{tax Discount Rate} \times (1 - \text{Tax Rate}) \qquad \textbf{(3.6)}$$

$$\text{Value} = \frac{\text{After - tax Cash Flow}}{\text{After - tax discount rate}} = \frac{\text{Pre} - \text{tax Cash Flow} \times (1 - \text{Tax Rate})}{\text{Pre} - \text{tax Discount Rate} \times (1 - \text{Tax Rate})} \qquad \textbf{(3.7)}$$

$$\text{Value} = \frac{\text{Pre} - \text{tax Cash Flow}}{\text{Pre} - \text{tax Discount Rate}} \qquad \textbf{(3.8)}$$

Since taxes are based on accrual accounting, not cash flow, after-tax free cash flow is not simply equal to pretax cash flow multiplied by a tax rate, although the above formulation is logically valid. Hence this approach is not realistic.

Formula-based DCF approach instead of explicit DCF involves a formulation with simplifying assumptions in order to capture the value of the business in a concise formula referred to as the Miller-Modigliani (hereafter MM) formula. It basically values a company as the sum of the value of the cash flow of its assets currently in place and the value of its growth opportunities. The MM formula is defined as follows:

$$Value = \frac{NOPAT}{WACC} + \left(K \times N \times NOPAT \times \left[\frac{ROIC - WACC}{WACC(1 + WACC)} \right] \right) \qquad \textbf{(3.9)},$$

where K is the percentage of NOPAT invested for growth in new projects, and N is the expected number of years that the company will continue to invest in new projects and earn the projected ROIC, also called the interval of competitive advantage. Again, this formulation is based on a single investment period and is not accurate for precise valuation.

Options pricing theory offers particular models based on the variations on standard DCF models. The rationale for these models is the managerial flexibility to modify decisions through multiple periods as more information becomes available in terms of discount rate and future free cash flows. Valuing managerial flexibility such as exploring new opportunities and reevaluating investments that are classified as in-the-money, at-the-money, or out-of-the-money by traditional DCF techniques under changing circumstances is very promising since it avoids undervaluing or overvaluing underlying assets. A detailed review of the traditional DCF techniques is presented in Appendix B at the end of the dissertation.

Copeland, Koller and Murrin (1995) define the valuation process as follows:

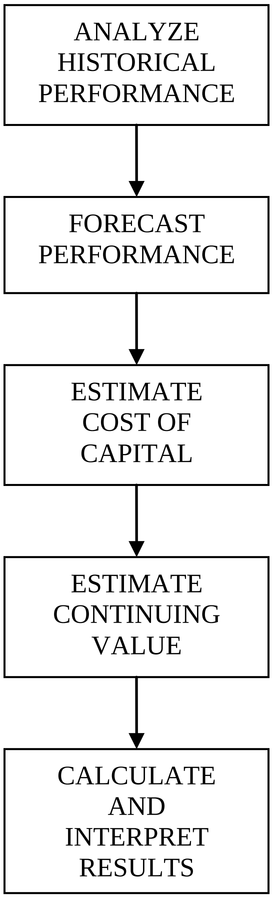

Figure 3.1 Valuation Process

Valuation is the unique communication tool expressing all of the business dynamics to the management by incorporating the financial aspects of the decision alternatives in order to provide a fair comparison of the potential opportunities. Uncertainty requires that decision makers make more intelligent decisions to assess risks. However computational tractability becomes an issue due the existing complexity of decision making under uncertainty in today's business environment, since practical decision making and computational complexity seldom go hand in hand.

Addressing the decision making process is more important than computational refinements for real-world decision-making problems.

The traditional DCF approaches have several drawbacks in terms of uncertainty resolution and, thus, incorporating the valuation of the opportunities embedded in the subject matter capital investment projects.

The first drawback is the selection of a risk-adjusted discount rate. The risk-adjusted discount rate is supposed to reflect the riskiness of the project. In other words, if the riskiness of the project increases, the discount rate increases and vice versa. It is also interpreted as the hurdle rate. If the return on investment or the internal rate of return of the project is below the hurdle rate, then the project is not undertaken. Another interpretation is the cost of capital used in the capital budgeting process, which is the rate of return that could be earned in the capital market on securities of equivalent risk to satisfy shareholders' or investors' expectations. One approach recommended for calculating the risk-adjusted discount rate is the capital asset pricing model (hereafter CAPM). Hull (2006) defines the steps of CAPM as follows:

- Take a sample of companies, whose main line of business is the same as that of the project being contemplated.
- Calculate the betas of the companies and average them to obtain a proxy beta for the project.
- Set the required rate of return equal to the risk-free rate plus the beta times the excess return of the market portfolio over the risk free-rate.

The formulation of CAPM can be represented as follows:

$$r = r_f + \beta\left(MR - r_f\right) \quad \textbf{(3.10)},$$

where r represents the risk adjusted rate, r_f represents the risk free rate, and MR represents market return. Beta measures how closely a security's performance correlates with broader stock market movements (Park, 2002). A Beta value of 1 indicates that the performance of the associated security matches its index.

However, due to the embedded opportunities, companies have options to expand or abandon a project depending on the success of the project. These options exhibit different risk characteristics. In this case using a risk-adjusted discount rate does not allow capturing the value of the corporate management's flexibility to choose either one of the options (Hull, 2006).

The second drawback is that DCF approaches overlook the resolution of uncertainty along the progress of, especially, multi-stage capital investment projects. In that sense the arrival of new information at any stage of the project is not incorporated in the valuation of the project, resulting in either undervaluing or overvaluing of the projects.

The third drawback is that the DCF approaches require either accepting or rejecting the projects if

- The NPV, EVA, AEW, or FW of the project is either positive or negative, respectively;
- The IRR of the project is either above or below the risk-adjusted discount rate, respectively;

- The payback period is above or below the predetermined payback period, respectively;

In that sense the capital investment decisions translate themselves into "now or never" or "go-or-no-go" decisions.

The final drawback is that DCF approaches suggest a "one-size-fits-all" approach in terms of decision timing. Time lag between the decision and the implementation phases of the projects, the delay duration of the project stages, and the time to switch between potential options, are ignored by traditional DCF approaches.

3.3 Options Pricing Theory

Fischer Black, Myron Scholes, and Robert Merton developed a model to price the stock options in the early 1970's, the importance of which was recognized when Myron Scholes and Robert Merton were awarded the Nobel Prize for Economics in 1997 (Hull, 2006). The model is known as Black-Scholes or Black-Scholes-Merton. Stock options are derivatives or, in other words, they are financial instruments, the values of which are derived from the associated stock, i.e., from another asset.

Black-Scholes model is a theoretical valuation formula which is derived for stock options. Black and Scholes (1973) define an option as a security giving the right to buy or sell an asset, subject to certain conditions, within a specified period of time. According to their seminal work an "American option" is one that can be exercised at any time up to the date the option expires, and a "European option" is one that can be exercised only on a specified future date.

The price that is paid for the asset when the option is exercised is called the "exercise price" or "striking price." The last day on which the option may be exercised is called the "expiration date" or "maturity date."

The option that gives the holder the right to buy a single unit of the underlying asset for the exercise price by or at a certain date is referred to as a call option, whereas the option that gives the holder the right to sell a single unit of the underlying asset for the exercise price by or at a certain date is referred to as a put option. These are the simplest kinds of options.

Suppose the stock price of ABC Company is $10 today at the close of trading, and an investor buys one European call option contract having a maturity date three months from today on ABC Company stock with an exercise price of $14 at $1. If the performance of ABC Company is good and the stock price is $17 at the maturity date, then the investor exercises the option, buys one stock at $14, and immediately sells it for $17. As a result, (s)he makes $2 net profit since (s)he already paid $1 for the option contract. On the other hand, if ABC Company does not do well and the stock price is less than $15, then the investor does not exercise the option and loses $1. The contract price paid by the investor is received by another trader who agreed to sell that stock for $14 at the maturity date.

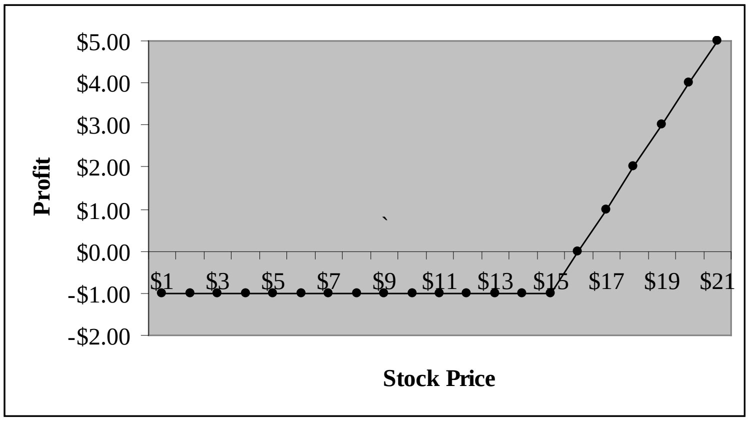

Figure 3.2 **Profit of a Call Option Contract as the Function of the Stock Price**

If the same investor in the above example buys one European put option contract having a maturity date three months from today on ABC Company stock with an exercise price of $14 at $1, and, if the stock price is $11 at the maturity date, then the investor exercises the option and makes $2 net profit since (s)he already paid $1 for the option contract. On the other hand, if ABC Company performs well and the stock price is greater than $14, then the investor loses $1. The contract price paid by the investor is received by another trader who agreed to buy that stock for $14 at the maturity date.

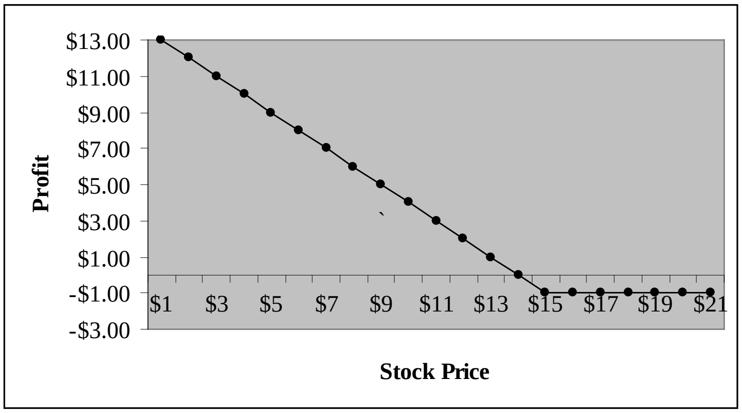

Figure 3.3 **Profit of a Put Option Contract as the Function of the Stock Price**

There are four types of participants and three categories of traders in options market (Hull, 2006).

Participants are classified as follows:

- Buyers of calls
- Sellers of calls
- Buyers of puts
- Sellers of puts

Hull (2006) identifies the broad categories of traders as hedgers, speculators, and arbitrageurs. Hedgers use derivatives to reduce the risk that they face from potential future movements in a market variable. Speculators use them to bet on the future direction of a market variable. Arbitrageurs take offsetting positions in two or more instruments to lock in a profit.

A hedger can be an investor who owns 1 share of ABC Company with $10 price per share and who expects a decline in the near future. Since that investor wants protection, (s)he buys a put option contract on ABC stock at $1 with an exercise price of $9. If the ABC stock price drops to $4, then (s)he exercises the option and makes $8.

A speculator can be an investor who expects an increase in the stock price of ABC Company. Suppose the current stock price of ABC Company is $10, and a call option contract for the same stock is $1 with an exercise price of $12. If the investor has $100 to invest, then there are two different ways to do so. (S)He can buy 10 shares and, if circumstances become favorable and the stock price increases by $5, (s)he makes $50 net profit. Or (s)he can buy 100 call option contracts by paying $100 and, if circumstances become favorable and the stock price increases by $5, (s)he makes $200 net profit instead of $50.

In case the speculator's expectations are not realized, then (s)he loses $100 that (s)he paid for the options contract. Hull (2006) points out that options can give rise to dramatic gains and losses if they are used for speculative purposes.

An arbitrageur can be an investor who wants to obtain risk free profit by trading the same derivative simultaneously in different markets. If the price of the stock that (s)he wants to trade is $4 in New York Stock Exchange, while it is $7 in Istanbul Stock Exchange with a transaction cost of $1, (s)he can make a $2 risk free and instantaneous profit. A detailed review and discussion of the option pricing theory and the associated trading strategies is presented in Appendix C.

3.4 Real Options Analysis

The dilemma of the contemporary corporate planners is the idiosyncrasy of deploying myopic techniques for the valuation of strategic investments with the expectation of long term payoffs under uncertainty. The existing techniques are far from evaluating irreversible strategic investment decisions which may or may not create profitable opportunities in the future.

Kester (1984) argues that a company should not spend time and effort trading off growth with return on investment or market share with profitability in lieu of focusing on the kind of value the investment will create, its durability, and the auxiliary decisions required to protect or enhance it over time.

The real options framework is first coined by Myers (1977) after Black, Scholes, and Merton provided a method to value the options in their seminal work on options pricing in 1973.

Today's research efforts are built upon their seminal work starting with pricing all derivative products. Their work obtained significant acceptance by the creation of Chicago Board of Options Exchange. The aforementioned acceptance exhibits a similar pattern as the traditional DCF techniques did earlier. Miller and Park (2002) argue that academia usually identifies evaluation techniques that are in-line with theory, and it takes many years for practitioners to adopt such ideas. DCF tools first identified in the 1950's did not replace payback period until the 1980's. ROA, which was first identified 20 years ago, has begun its acceptance for corporate decision-making process in a similar fashion.

Luehrman (1997) discusses that understanding valuation has become a prerequisite for meaningful participation in a company's resource allocation decisions. The key to valuing a corporate investment opportunity as an option is the ability to discern a simple correspondence between project characteristics and option characteristics. The potential investment to be made corresponds to an option's exercise price. The operating assets the company would own, assuming it made the investment, are like the stock one would own after exercising a call option. The length of time the company can wait before it has to decide is like the call option's time to expiration. Uncertainty about the future value of the operating assets is captured by the variance of returns on them; this is analogous to the variance of stock returns for call options. The analytical tactic here is to perform this mapping between the real project and a simple option. Luehrman (1997) proposes that a pragmatic way to use option pricing is as a supplement, not a replacement, for the valuation methodology already in use.

Trigeorgis (1993) provides a comprehensive overview of the existing real options literature and applications.

He presents practical principles for quantifying the value of various real options and takes a first step towards extending the real options literature to recognize interactions with financial flexibility. He suggests that management's flexibility to adapt its future actions in response to altered future market conditions expands an investment opportunity's value by improving its upside potential while limiting downside losses relative to management's initial expectations under passive management. Trigeorgis (1993) proposes that the resulting asymmetry caused by managerial adaptability calls for an "expanded NPV" rule, reflecting both value components: the traditional (static or passive) NPV of direct cash flows and the option value of operating and strategic adaptability. This does not mean that the traditional NPV should be scrapped, but rather should be seen as a crucial and necessary input to an options-based, expanded NPV analysis.

Dixit and Pindyck (1994) support Luehrman (1997) and agree that irreversibility, uncertainty, and the choice of timing alter the investment decision in critical ways. They discuss that conventional approaches to decision making have shortcomings where two basic issues need to be addressed. First, how to determine the expected stream of profits that the proposed project will generate and the expected stream of costs required to implement the project; and, second, how to choose the discount rate for the purpose of calculating net present value. Their research is based on an important analogy with financial options. A company with an opportunity to invest is holding something much like a financial call option; it has the right, but not the obligation to buy an asset at a future time of its choosing.

By deciding to go ahead with expenditure, the company gives up the possibility of waiting for new information that might affect the desirability or timing of the investment.

It cannot disinvest should market conditions change adversely. The lost option value is an opportunity cost that must be included as part of the cost of investment. Thus the simple NPV rule needs to be modified. Instead of just being positive, the present value of the expected stream of cash from a project must exceed the cost of the project by an amount equal to the value of keeping the investment option alive. Investment expenditures are irreversible when they are specific to a company or to an industry. They are sunk costs. Even investments that are not company or industry specific are partially irreversible (the average value of used equipment, vehicles, etc.).

When a company makes irreversible investment expenditures, it "exercises", in effect, its call option. Uncertainty plays a crucial role in the timing of capital investment decisions and in recognizing an investment opportunity like a financial call option. It is considered that the more volatile the price of the stock on which the option is written, the more valuable the option and the greater the incentive to wait and keep the option alive rather than exercise it. Economies of scale can be an important source of cost savings for companies. Dixit and Pindyck (1995) support their argument with the example of building one large plant instead of two or three smaller ones, so that companies might be able to reduce their average unit cost while increasing profitability. When the growth of demand is uncertain, there is a trade-off between the scale of economies and the flexibility gained by investing more frequently in small additions to capacity as they are needed. Hence they suggest that irreversibility, uncertainty, and the choice of timing alter the investment decision in critical ways.

Miller and Park (2002) identify and systematize the current body of research and discuss a concise summary of modeling concerns, applications, and a roadmap for future modeling efforts. Their argument is that the DCF techniques ignore the flexibility to modify decisions along the value chain as new information arrives. NPV is a passive method that works well in deterministic situations, but under conditions of uncertainty it has limited capability. ROA is a promising tool for strategic investment decisions whereby projects are viewed as real options that can be valued using financial option pricing techniques. Technically, ROA enables managers to bundle a number of possible mutually exclusive outcomes into a single investment. Under ROA, any corporate decision to invest or divest in real assets is simply an option.

Copeland and Antikarov (2003) explain ROA by using the turnpike theorem analogy. It is preferable to deviate from your present direction to take advantage of higher speed paths until something unexpected such as a traffic jam or an unplanned detour occurs. However investing in a more detailed map, a global positioning system and satellite radio that broadcasts frequent traffic updates allows you to detect the unexpected events so that you can dynamically plan your itinerary by taking advantage of shortcuts. In this way, you are investing in flexibility in order to increase the resolution of potential uncertainties. ROA behaves more realistically than the traditional DCF techniques to capture the value of the flexibility, and it is an insurance against under or over valuation risk of the investment decisions.

Hence real options can be defined as the right, but not the obligation to make further investments in order to increase the throughput of a project, to defer a project, to extend the useful life of a project, to reduce the scale of a project, to switch between strategies, to invest contingently, or to terminate a project using intelligent timing decisions.

Assume Company ABC is a software provider, and the senior management is considering investing \$5 million in a new state-of-the art ERP system development. The estimated net cash inflow per year is \$1 million during the project life of five years. Since the demand to ERP systems is volatile due to the global knowledge transfer, the cash volatility is estimated as 40 percent. The risk-free interest rate is 6 percent, and the ABC Company's MARR is 8 percent. Even though there is volatility in cash inflows, the senior management has an option to delay this project for two years with an estimated initial investment increase of 15 percent per year. The chief financial officer of Company ABC recommends not investing since the NPV of the project is

$$NPV(8\%) = -\$5M + \$1M(P/A,8\%,5) = -\$1.01$$

However if the investment is made two years from today the estimated project value is V_2=\$3.99 million with today's value of V_0=\$3.42 million. Valuing this investment using the Black-Scholes-Merton model, Company ABC realizes that the delay option is worth \$455,000. Thus Company ABC decides to invest in this project two years from now instead of making a "now or never" decision today made through underestimation of the flexibility stemming from traditional DCF techniques.

3.5 Modeling Approaches

Miller and Park (2002) identify and systematize the current body of ROA research and classify the current modeling approaches as discrete time and continuous time models.

Continuous time modeling consists of closed-form equations, stochastic differential equations, and MCS. Black and Scholes (1973) developed the first closed-form equation for option and warrant valuation. Their research is the backbone of today's option pricing technique. Margrabe (1978) developed a closed-form equation for the valuation of an option where one asset is exchanged for another. Margrabe (1978) assumes that the exercise price is a stochastic variable, where the Black and Scholes model treats the exercise price as a deterministic variable. Fischer (1978) also developed a closed-form equation with exercise price as a stochastic variable, while Geske (1979) used deterministic exercise prices for compound option valuation in his closed-form equation. Later Carr (1988) treated the exercise prices as stochastic variables for the sequential investment decisions discussed in Geske (1979). Kumar (1996) presents a theoretical analysis of the variation of option values with project risk and a comparison of Black-Sholes and Margrabe models, where he examines the relationship between project risk and option values of investments in new information technologies and illustrates how this relationship is significantly different from well-known results in the case of financial option pricing. Taudes (1998) proposes using option pricing formulas, which consist of closed-form equations to obtain the estimate value of flexibility of an information system platform.

He also discusses the various assumptions of the option pricing models and the limitations of the real options approach in the context of information system investments by introducing option pricing formulas for the valuation of various types of software growth options.

The derivation of the closed-form equations is performed through the solution of stochastic differential equations. The solutions to the stochastic differential equations do not always exist and partial differential equations must be solved either using finite-difference methods or MCS (Miller and Park, 2002). Kulatilaka (1993) develops a flexibility model using continuous time dynamics of a state variable that is computationally simple and is more amenable to empirical implementation than those that rely on analytical solutions. The model is applied to the case of an industrial steam boiler that can switch between using residual fuel oil and natural gas. Cortazar and Schwartz (1993) develop a continuous time model for valuing a copper mine that has a production bottleneck and for determining its optimal output rate and capacity using stochastic differential equations under boundary conditions. Their objective is to extend the real option approach by modeling the firm as a two-stage process with bounded output rates, in which the output of the first stage may be held as work-in-process inventory, where the underlying asset is a compound option, which, if exercised, has an option to finish the work-in-process inventory and sell the output as its payoff.

Mauer and Ott (1995) analyze the determinants of sequential replacement investment decisions in a contingent claims model with maintenance and operation cost uncertainty and realistic tax effects by deriving a closed-form solution through solving partial differential equations. Hull (2006) provides an overview of MCS together with finite difference methods.

Assume that a portfolio consists of a long position in Δ shares and a short position in one call option. The number of shares that generates a riskless portfolio is calculated as follows using the formulation given in Hull (2006):

$$\Delta = \frac{f_u - f_d}{S_0 u - S_0 d} \qquad \textbf{(3.11)},$$

where S_0 is the stock price, f_u is the option price if the stock price moves up to S_0u, f_d is the option price if the stock price moves down to S_0d, u is the up movement coefficient, where u>1 and u-1 is the percentage increase in the stock price S_0, and d is the down movement coefficient, where d<1 and 1-d is the percentage decrease in the stock price S_0.

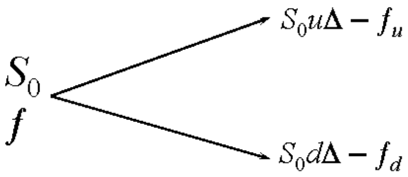

Figure 3.4 One-Step Binomial Tree (Hull 2006)

In the above one-step binomial tree the portfolio is valued using the risk-free rate. Since the option is not exercised if the stock price goes down, the present value of the portfolio is calculated as follows using the formulas given in Hull (2006):

$$S_0\Delta - f = \left(S_0 u\Delta - f_u\right)e^{-rT} \qquad \mathbf{(3.12)}$$

or

$$f = S_0\Delta\left(1 - ue^{-rT}\right) + f_u e^{-rT} \qquad \mathbf{(3.13)}$$

Substituting Equation (3.11) in Equation (3.13):

$$f = e^{-rT}\left[pf_u + \left(1-p\right)f_d\right] \qquad \mathbf{(3.14)},$$

where

$$p = \frac{e^{rT} - d}{u - d} \qquad \mathbf{(3.15)}$$

The lattice approach assumes the underlying asset follows a discrete, multinomial, multiplicative stochastic process through time to form some form of tree, where the option value is solved recursively from the end nodes of the tree (Miller and Park, 2002). Cox, Ross and Rubinstein (1979) developed the standard binomial approach. Rendleman and Barter (1979) present an elemental two-state option pricing model, which is mathematically simple, yet can be used to solve many complex option pricing problems. In contrast to widely accepted option pricing models which require solutions to stochastic differential equations, their model is derived algebraically by using a binomial lattice approach since solving continuous time option pricing problems using closed form solutions is unattainable. Boyle (1988) developed an extension of the Cox, Ross, Rubinstein binomial lattice algorithm to handle the situation in which the payoff from the option depends on more than one state variable. His modification to the Cox, Ross, Rubinstein algorithm consists of replacing the two-jump process with a five-jump process. Madan, Milne, and Shefrin (1989) derived a multinomial option pricing formula where they generalized the Cox, Ross, Rubinstein binomial model to multinomial case.

Tian (1993) developed a modified approach to the selection of lattice parameters including probabilities and jumps by conducting numerical simulations to investigate the comparative accuracy of the approach with that of the Cox, Ross, Rubinstein and Boyle trinomial procedures. Tian (1993) found that all trinomial approaches are more accurate than binomial procedures. Detemple and Sunderesan (1999) provide a simple framework to value derivative assets subject to trading decisions using a computationally tractable and easy to implement binomial model. Herath and Park (2002) present a lattice approach to value a compound real option. Miller and Park (2002) summarize the modeling approaches for option calculation as follows:

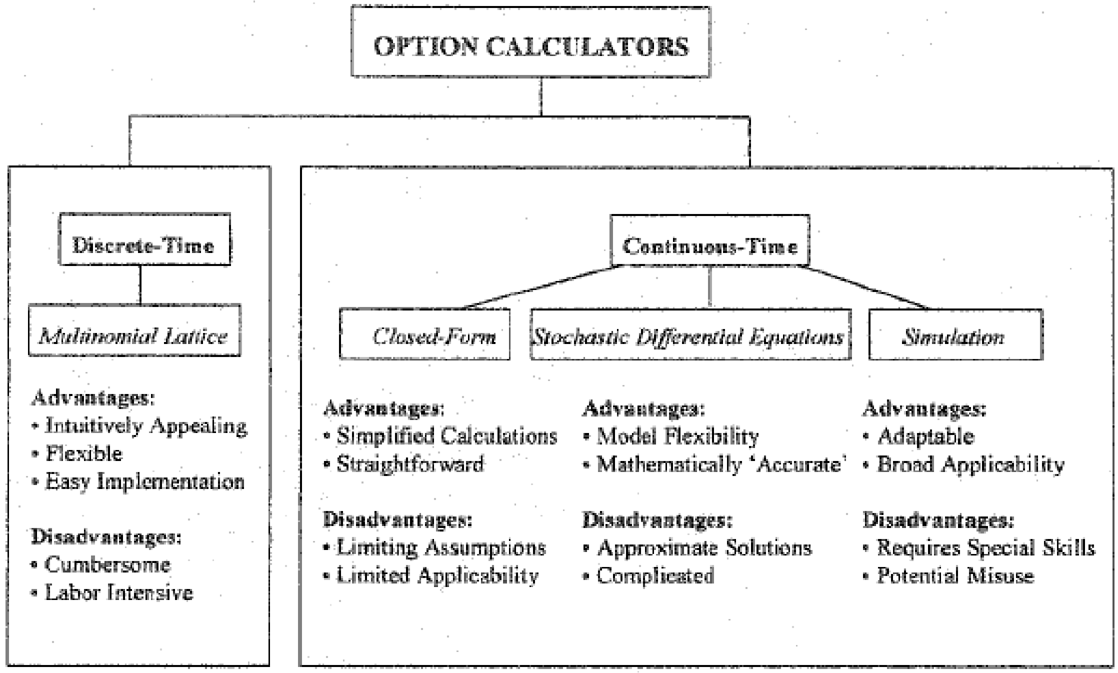

Figure 3.5 Numerous ROA Modeling Approaches for Option Calculation

3.6 ROA Application Areas

The adoption of ROA into practice, like the adoption of the net present value and cost of capital techniques, is slow.

Miller (2004) reports that the use of net present value and cost of capital techniques, which was first identified in the 1950's, did not replace payback period until the 1980's. Considering the aforementioned 30-year adoption period, expecting an increasing trend of ROA adoption for decision making in the offing must not be considered as ambitious. However, it should be noted that DCF tools are still required for utilizing ROA.

The ROA application areas where the majority of publications have been made within the last decade are stock valuation, natural resource valuation, research and development project valuation, manufacturing and inventory decisions, strategic decision making, technology selection and deployment, and biotechnology (Miller, 2004).

Based on his research into the investment and capital budgeting decisions of companies, Kester (1984) thinks of future investment opportunities as analogous to ordinary call options on securities.

The design of an optimal mesh of contingent claims with purchasing commitments that will best meet the risk-reward preferences of the decision maker can be viewed in Ritchken and Tapiero (1986). Under risk preferences, their study examines conditions under which option contracts serve as superior or complementary strategies to inventory building.

Chung (1990) utilizes the option pricing model for the evaluation of the firm's output decision under uncertainty. He presents a contingent claim analysis of output decisions for the firm facing uncertain demand and uncertain technology.

McLaughlin and Taggart (1992) evaluate capital budgeting problems that arise when a new project proposal calls for the use of existing, but currently idle, equipment or facilities. Basically they discuss a new framework for capacity planning.

The essence of their option framework is as follows: capacity in place gives the firm an option to produce. Thus, if a firm diverts capacity from Product A to Product B, it forgoes the option to produce Product A immediately, but it acquires an option to replace the diverted capacity.

Pickles and Smith (1993) attempt to explain in a simple, tutorial way the application of developments in the theory of finance to the valuation of certain types of petroleum property and investment. Specifically, they are concerned with the valuation of discovered but undeveloped oil and gas reserves, which then leads to the valuation of an exploration lease where some amount is to be spent for a chance at finding reserves which could subsequently be developed.

Kemna (1993) suggests that the main contribution of options pricing theory in capital budgeting is twofold. First, it helps management to structure the investment opportunity by defining the different investment alternatives with their underlying uncertainties and their embedded options. Second, options pricing theory can handle flexibilities within the project more easily than the traditional DCF analysis.

Cortazar and Schwartz (1993) extend the real option approach by modeling the firm as a two-stage process with bounded output rates, in which the output of the first stage may be held as work-in-process. They consider the asset as a compound option, which, if exercised, has an option to finish the work-in-process and sell the output as its payoff. They discuss that the existence of intermediate inventories may arise, not only because of inefficiencies in the production system, but also as an optimal investment strategy for exploiting possible future price increases.

They provide analytical expressions for valuing a firm that has a production bottleneck and for determining its optimal output rate and capacity.

A general model of flexible manufacturing that is computationally simple and is more amenable to empirical implementation than those that rely on analytical solutions can be found in Kulatilaka (1993). The model is applied to the case of an industrial steam boiler that can switch between using residual fuel oil and natural gas.

Kogut and Kulatilaka (1994) analyze the platform investments, and are engaged in developing heuristics to aid the understanding of how capabilities must be built in anticipation of the future. They argue that the world is witnessing a new era of competition with the development of new principles of organizing work, radical technologies, and globalization. They propose that there have been two streams of thought aimed at correcting this bias. The first theory is to formulate the strategic investments as real options, and the second idea consists of recent work on organizational capabilities and core competencies (e.g., quality programs, kanban systems, value-based activity analysis, etc.).

Smith and Nau (1995) analyze a simple two-period capital budgeting problem. They first employ the naïve DTA fundamental idea of discounted cash flow approach, where the problem is that the appropriate discount rate is unknown. Then, they employ options pricing technique seeking a portfolio of securities that exactly replicates the project's payoffs. Next, they approach the problem with full DTA by using subjective probabilities instead of risk-adjusted or risk-neutral probabilities to capture time and risk preferences using its utility function. The result obtained by the latter is exactly the same as the one obtained by options pricing analysis.

Finally they utilize an integrated approach using both DTA and options pricing technique by decomposing project cash flows into its market and private components. They conclude that option pricing and decision analysis methods are fully compatible and can be profitably integrated by separating market and private risks.

Mauer and Ott (1995) analyze the determinants of sequential replacement investment decisions in a contingent claims model with maintenance and operation cost uncertainty and realistic tax effects. The optimal replacement policy is characterized by a critical level of maintenance and operation cost, which is the replacement barrier at which the firm should replace an existing asset with another stochastically equivalent asset.

Stowe and Su (1997) present a contingent-claims approach to inventory-stocking decision. Their approach incorporates the economic principles of asset-pricing models, such as the Black-Scholes option pricing model, to replace the expected profit maximization logic of the conventional approach.

Brown and Davis (1998) examine a situation, in which an organization is faced with making a mutually exclusive choice between two projects with unequal lives. Their objective is to illustrate the impacts of the ignored existence of options that can occur as a result, using a simple example of choice between mutually exclusive projects. They demonstrate that the standard techniques can lead to errors in a stochastic environment assuming interest rate uncertainty.

As noted in Chen, Kensinger, and Conover (1998), option pricing methods can be applied to evaluate capital budgeting of equipment, such as computer-controlled machine tools, that convert a generic input into any of a variety of different machined parts.

Option pricing models offer the possibility of improving the decision makers' ability to analyze investments in computer integrated manufacturing (hereafter CIM) systems.

Kelly (1998) applies a binomial approach to the investment timing option. His approach relies on data that is readily available from published sources such as futures and spot markets. Although the method eliminates the need to estimate both future cash flows over the life of the project and risk-adjusted discount rates, it requires the existence of a futures market in the underlying asset.

Ottoo (1998) models an internal growth option for a biotechnology firm, which gains access to productive technology by successfully completing a research and development project before its competitors and introducing a new product to the market. In a competitive market marked by rapid change and uncertainty, very little is known about valuing opportunities, especially for startup and emerging firms.

The analysis of multi-stage or compound real options that involve a staged capital commitment and offer the right to make future follow-on investments under favorable developments can be found in Panayi and Trigeorgis (1998). Such growth option investments may have negative net present values when considered in isolation, but can add strategic value to a firm by serving as the first stage necessary to generate profitable follow-on investment opportunities in the future. They analyze the actual case of an information-technology infrastructure investment decision faced by a state telecommunications authority. They then examine the option facing a bank to expand its operations into another country as part of multi-nationalizing its operations. In both cases, by making a costly first-stage investment, the firm involved essentially acquires a foothold on future investment opportunities.

Such multi-stage options are of strategic import to the firms that invest to acquire, nurture, develop further, and optimally exercise or abandon them over time, based on future market developments. They develop an expanded or strategic NPV criterion reflecting both the traditional NPV and the value of managerial flexibility, or, in other words, value of option flexibility given by the following Equation (3.16):

$$\textit{Expanded (Strategic) NPV} = \textit{Traditional NPV} + \textit{Value of option flexibility} \qquad \textbf{(3.16)}$$

Bollen (1999) develops a real option valuation framework that explicitly incorporates a stochastic product life cycle. The product life cycle is represented using a regime-switching process. The cycle begins in a growth regime, characterized by increasing demand, and switches stochastically to a decay regime, in which demand generally falls. The option to change a project's capacity is valued, and it is shown that option values consistent with a product life cycle are significantly different than those from a standard model that makes simplifying assumptions about the demand process.

Park and Herath (2000) develop a single-period binomial lattice approach to price a call option and risk-free arbitrage principle of valuation. Their basic idea is to develop a hedge portfolio to replicate the future returns on the call. They conceptualize how the financial options approach can be used to value flexibility associated with a real investment opportunity. They formulize the value of this flexibility or the real options premium by the following Equation (3.17):

$$\textit{ROP} = \textit{SNPV} - \textit{Conventional NPV} \qquad \textbf{(3.17)},$$

where ROP represents the value of the real options premium or the value of the flexibility and SNPV represents the strategic NPV.

As noted in Childs and Triantis (1999), the multinomial lattice approach can also be used to develop a trinomial lattice approach to value research and development case studies.

Lint and Pennings (2001) consider the product development process as a series of real options for reducing uncertainty over time. They develop criteria to decide whether to speed up or delay the development process for Philips Electronics. Any particular project can be assigned within a two-by-two matrix of uncertainty versus research and development option value. The matrices support portfolio management throughout the different phases of development and enable management to decide on an appropriate point at which to abandon individual projects.

Nembhard, Shi, and Aktan (2005) develop a supply chain model, in which a manufacturing firm can have the flexibility to select different suppliers, plant locations, and market regions considering that there can be an implementation time lag for the supply chain operations. The main purposes of their study were to place the difference between immediate implementation and the time lag into this framework and then to analyze the effect on the outcome and hence the managerial course of action. They use a real options approach to estimate the value of flexibility and to determine the optimum strategy to manage the flexibility under uncertainty in the currency exchange rate.

Burnetas and Ritchken (2005) investigate real option contracts in a supply chain contract when the demand curve is downward sloping. They consider call (put) options that provide the retailer with the right to reorder (return) goods at a fixed price, where goods have long lead times, short selling seasons, and high demand uncertainties. They argue that these options are not zero-sum games.

Cucchiella and Gastaldi (2006) study a supply chain strategy for limiting the damages that can be stemming from the sources of uncertainty recoverable inside a supply chain. Firstly, a set of sources of uncertainty have been selected; subsequently the risks connected with each sources have been defined. They study and simulate the ability of the outsource option to cover, at the same time, the risks of production capacity and price fluctuations of a high technology company that produces medical devices.

It should be noted that the real option approach has also some disadvantages with respect to traditional discounted cash flow methodologies, since it requires more data on the variability of considered parameters as well as models that well match the project under examination, it could be seen as a black box not so easily understood and utilized. Finally, the analysis is more complex and needs ad hoc computer programs to solve the real option algorithm.

CHAPTER 4

PRACTICAL BUSINESS APPLICATION

4.1 Introduction

This chapter presents a real-world business application concerning a series of capital investment decisions for an automotive electronics manufacturing facility. Data availability has not been a challenge; financial and operational data have been available on a daily basis through the associated databases of the subject matter facility since October 2006. The valuation of the aforementioned series of capital investments is performed through discounted cash flow techniques, MCS, DTA, and real options analysis in Chapter 5. The results obtained in Chapter 5 are interpreted in Chapter 6. Hence a combination of both quantitative and experimental research methodologies is utilized.

The practical business application is about a series of capital investment decisions that will allow the facility management to generate additional floor space to accommodate additional assembly lines, cleanrooms, and manufacturing cells for potential future business opportunities.

4.2 Facility Overview

Huntsville Electronics operations began business in 1952 when Chrysler arrived in Huntsville to provide support and engineering services to Dr. Werner Von Braun's Mercury rocket team. Chrysler engineers supported breadboard operations such as cathode ray and vacuum tubes, pre-electrical devices and electrical configurations.

The company grew in the 1960's to over 4,000 people as a prime contractor on Redstone, Mercury, and Saturn 1 rocket programs. The original 65,000 sq. ft. Wynn Drive Plant (hereafter Plant II), built in 1965 to support the Saturn/Apollo space projects, was expanded to 100,000 sq. ft. in 1972 for car radio manufacturing, with approximately 70 people making the first inroads to automotive electronics with the electronically tuned radio.

In 1974, another 120,000 sq. ft. expansion allowed the manufacture of electronic ignition control units for all Chrysler Motors passenger cars. In July 1977, the Huntsville Division completed an additional 200,000 sq. ft. manufacturing plant across the road from Plant II in response to the expanding electronics market and electronic content in vehicles, such as the "learn burn" engine controllers, radios, pressure units, and other products. From the 1970's through the 1980's, Chrysler Huntsville was one of the fastest growing high-tech automotive electronics engineering and manufacturing operations in the southeast.

In 1988, Acustar Inc., Chrysler's wholly owned parts subsidiary, formally opened its $170 million Huntsville Electronics Complex with a ribbon-cutting ceremony at the Huntsville plant (hereafter Plant I).

Acustar's Huntsville Electronics Division developed and produced automotive electronic systems and components, including radios; sound systems; electronic and electromechanical gauges and instrument panel clusters; driver information and trip computers; fuel injection control systems; spark control computers and speedometers; odometers; engine oil pressure sensors; and pressure switches. By 1988, the Huntsville Electronics Division of Acustar produced thousands of electronic components and systems daily. Plant I became a DaimlerChrysler operation on November 11, 1998, when two OEM's merged. Later it became an integrated part of Siemens VDO Automotive Corporation from April 2, 2004 until December 3, 2007, when Continental AG acquired Siemens VDO Automotive Corporation.

The facility has been serving the community and the industry as a leading first-tier automotive electronics supplier. With the compounding effects of globalization and improvements in technology, the competition is not between individual business entities anymore. Collaborative planning, replenishment, and forecasting synergy generated by supply chains carried the competition up to the supply chain level. Continental AG has strengthened its market position in the NAFTA region by acquiring the second of the six first-tier automotive electronics manufacturing facilities located in the U.S.A. In addition to Chrysler, GM, Ford, VW, and BMW, more OEM's need to be added to the customer portfolio of Plant I in order to hedge against the variability in automotive sales due to fairly frequent changes market dynamics of the automotive industry.

Plant I is a $1 billion annual sales automotive electronics manufacturing facility. After Plant II was shut down at the end of fiscal year 2007, instrument panel cluster manufacturing operations were transferred to the Guadalajara facility in Mexico, leaving additional floor space for revenue generating purposes. Plant I is one of the six first-tier automotive electronics manufacturing facilities located in the U.S.A., with a total facility area of 816,299 sq. ft. The breakdown of the total area is as follows: The engineering and administration building area is 239,915 sq. ft., the manufacturing building area is 564,286 sq. ft., the waste and chemical storage building area is 10,984 sq. ft., and the area for pump houses is 1,114 sq. ft. The following Figure 4.1 indicates the overall area distribution of Plant I.

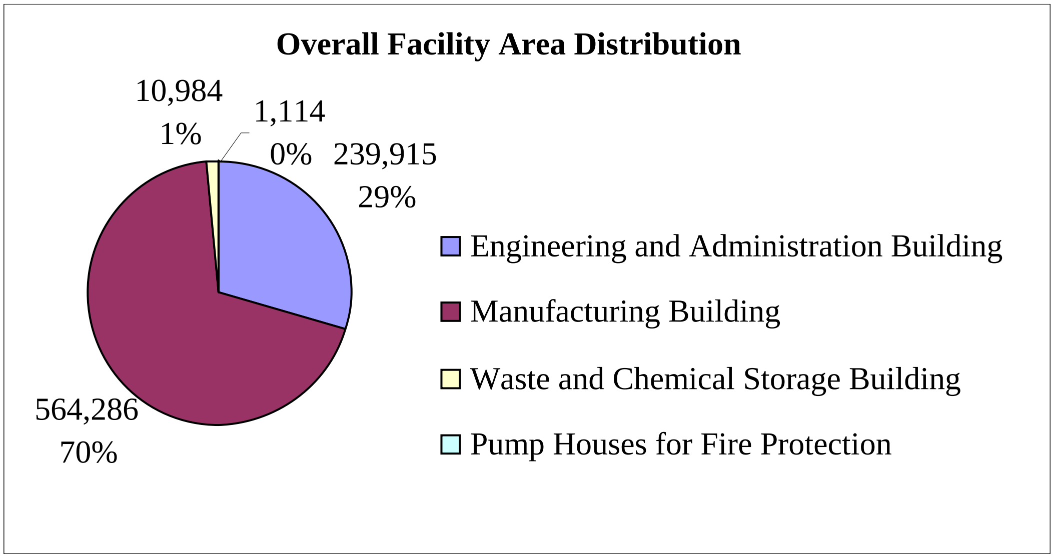

Figure 4.1 Overall Facility Area Distribution

The manufacturing building has an aspect ratio of 1.2:1 and houses 15 assembly lines measuring 600 feet long by 25 feet wide, which are laid out in a north-south orientation and have a total area of 308,400 sq. ft., the distribution center located in the North Dock with a total area of 50,385 sq. ft., while the finished goods warehouse is located in the South Dock with a total area of 26,952 sq. ft. Finally the administrative, social, quality control, and facilities systems related area consists of 178,550 total sq. ft.

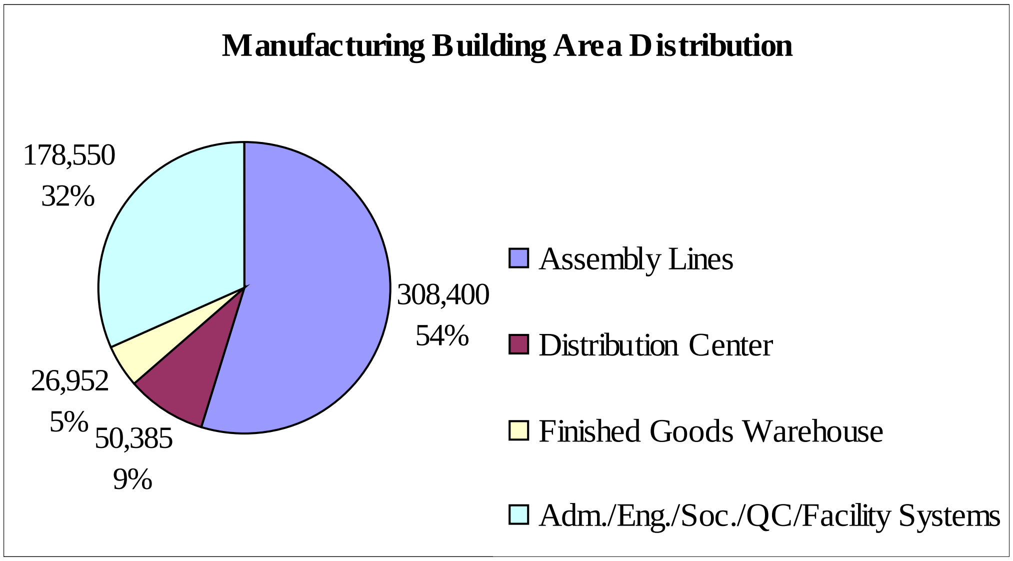

Figure 4.2 Manufacturing Building Area Distribution

4.3 Practical Business Application

Fierce competition in the automotive electronics industry is forcing corporations that are operating in the U.S.A. to develop innovative technologies that will provide them with a competitive advantage and/or to generate significant cost savings by moving their operations to other countries, where the labor cost is relatively low.

Since moving operations to other countries results in loss of domestic expertise, increased transportation costs, and decreased supply chain resiliency, corporations investigate opportunities that will allow them to generate additional revenues to compensate for the high labor costs. Capacity plays an important role in additional revenue generation since floor space is a significant component.

Plant I management started to evaluate a replacement/retrofitting project for the existing, but outdated mini-load AS/RS and the AGV system in January 2005 which offered opportunities for increasing the overall throughput capacity with additional floor space generation totaling up to approximately 70,000 sq. ft. The management's primary objective was to diversify the customer portfolio for hedging against the variability in domestic automotive sales while also keeping the existing customer portfolio. Thus, they need additional floor space to achieve their objective.

Considering the aforementioned circumstances, facility officials were diligently investigating the floor space availability that involves minimum capital investment. Although the average floor space requirement for an assembly line is approximately 15,000 sq. ft., utilizing a floor space of 5,000 sq. ft. is becoming a common practice for manufacturing high value-low volume products. This practice is made possible by utilizing such technologies as chip-and-wire, tape-automated bonding, flip-chip, and multi-chip module through Class-One cleanroom applications or by deploying manufacturing cells rather than conventional I-shape assembly lines.

However, according to Plant I management, there are two major sources of uncertainty:

- The volatility of the OEM demand.
- The corporate marketing performance that realizes as additional business volume, i.e., additional market share.

As of January 2005, there is not any available floor space for additional potential business opportunities. Therefore the facility management is analyzing the utilization of the current floor space dedicated to such non-value added activities as logistics and maintenance.

The decision portfolio is composed of the following options that are embedded in the practical business application:

- Replacing the existing outdated AS/RS and corresponding WMS with a new AS/RS and WMS to generate floor space and cost savings, which is supported by a throughput analysis through a simulation study.
- Eliminating the existing outdated mini-load AS/RS by switching to a just-in-time delivery system together with three-shift 3PL support and transportation operation.
- Replacing the existing outdated AGV control software and retrofitting the vehicles of the existing AGV system in order to generate floor space by eliminating pick and drop stands and by reducing the aisle space supported by a throughput analysis through a simulation study and extends, which is the useful life of the mechanical AGV components.

- Replacing the existing outdated AGV system with water spiders utilizing tuggers with associated trailers.

The Plant I distribution center operates three shifts per day and houses five different types of storage: Mini-load AS/RS storage, static rack storage, non-production material crib, launch crib, and refrigerated storage.

The mini-load AS/RS storage consists of a six-aisle mini-load AS/RS that was commissioned in 1987 and manufactured by Litton Industrial Automation Systems, Inc. It features a 6,691.2 sq. ft. footprint laid out in an east-west orientation. The 80-foot long and 14.5-foot high aisles of the mini-load AS/RS were designed to hold relatively small electronic components for sub-assembly processes randomly assigned to 9,000 storage locations.

Inbound bulk production material, the demand for which is a full pallet load, are stored in single deep selective and three-high static racks with a net total footprint of 3,667.3 sq. ft. and 564 storage locations. The static racks that are located on the east and north side of the mini-load AS/RS are referred to as "East Rack," and the static racks that are located on the west side of the mini-load AS/RS are referred to as "West Rack." Racks are laid out in a north-south orientation, where the associated layout is provided in Appendix D.

The non-production material crib is used for one-time purchase order material storage, receiving expedited and/or rush package deliveries, and storage of non-production material like cleaners, gloves, and tapes. The total storage area is 7,073 sq. ft.

The launch crib is a caged set of rack locations where pilot or launch parts are stored. These parts are used in assembly prototyping for a product that will be launched in the future. The total storage area is 552 sq. ft.

Chemical production materials such as solder paste, adhesives, and flux are stored in the refrigerated storage area for longer shelf life. The total storage area is 260 sq. ft.

Inbound production material delivery to assembly lines, finished goods delivery to the finished goods warehouse, empty dunnage delivery to the dunnage return station located in the distribution center, and line-to-line movements are performed by AGV's. There are 24 AGV's in the distribution center and eight AGV's in the finished goods warehouse, which were manufactured by Egemin Automation, Inc. and deployed in 1987. There are 370 pick and drop stands, together with ergonomic lifts, located on the manufacturing floor which occupy approximately 8000 sq. ft.

Plant I performs scheduled receiving functions by using a pre-receiving tool: Electronic data interchange (hereafter EDI). The receiving function is performed in the North Dock of the facility (see Appendix D for the layout of the North Dock). Plant I has been using SAP R/3 as the enterprise resource planning (hereafter ERP) host system since April 2, 2004. Mini-load AS/RS is managed and controlled by a legacy proprietary material handling control software (hereafter MHCS), whereas static rack storage is deprived of the handling unit management (hereafter HUM) module of SAP R/3 between the ERP host system and physical receiving at the operational level. There are three on-campus 3PL's: J.I.T. Services Inc., Mtronics.com, and Span Ltd. 3PL's provide vendor managed inventory (hereafter VMI) service to the majority of international/domestic suppliers.

In addition to 3PL's, there are six direct-shipping local domestic suppliers, and the "Span Triana" facility that provides a reusable container management service in close proximity of Plant I.

Inbound production material is delivered by a dedicated regional less-than-truckload trucking company called AAA Cooper Transportation. There are nine scheduled inbound deliveries per day during the first and second shift operations. However, depending on spontaneous daily changes in the production schedule, expedited deliveries might occur, either through the transportation company or by using company-owned vehicles.

4.4 Mini-Load AS/RS and MHCS

The mini-Load AS/RS consists of a six-aisle, mini-load AS/RS that was commissioned in 1987 and manufactured by Litton Industrial Automation Systems, Inc. It features a 6,691.2 sq. ft. footprint laid out in an east-west orientation. It was designed for a service life of 15 years and is fully depreciated. The 80-foot long and 14.5-foot high aisles of the mini-load were designed to hold relatively small electronic components for sub-assembly processes that are randomly assigned to storage locations. The parts are ordered by assembly lines in quantities less than a whole pallet-load and are stored in plastic returnable totes or recyclable cardboard boxes placed in metal pans that are accessible by mini-load AS/RS cranes. Each storage location has a 26-inch by 51-inch pan that is able to hold loads up to 500 lbs. Pans are stored in slots located on the left and right sides of the aisles. Each side has 25 bays of 10 tiers of slots.

The first three tiers from the top in each aisle, i.e., tiers 8, 9, and 10, are sized for large totes. The slot heights by tier are given in Table 4.1 below:

Table 4.1 Slot Heights by Tier

Tier Number	Slot Height (inches)
1	11
2	11
3	11
4	13
5	11
6	13
7	11
8	21
9	19
10	21

Figure 4.3 Mini-Load AS/RS Aisle

The total storage capacity is designed to be 9,000 tote storage locations; however the total number of the net available tote storage locations was reported to be 8,814 by the plant engineering department.

Some slots and/or tote storage locations in slots are reported to be unavailable for storage due to monuments like columns, pipes, and conduits, while some are unavailable due to software problems. With ongoing efforts toward resolving software problems, the number of available storage locations is shifted back up to 8,868.

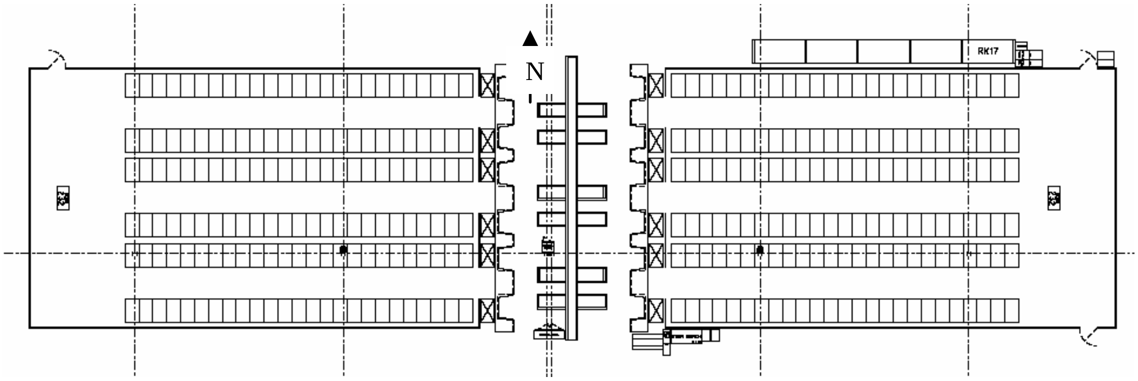

Figure 4.4 Mini-Load AS/RS Layout

Mini-load parts are received in totes and cardboard boxes with three different sizes shipped on 40-inch by 48-inch plastic pallets. Size specifications of the returnable totes are given in Table 4.2 below:

Table 4.2 Tote Size Specifications

Tote Size	Dimensions (Length x Width x Height) (inches)
Half-Size	12 x 16 x 9
Small	24 x 16 x 8
Large	24 x 16 x 15

MHCS was originally designed to store six half-size and three small and/or large size totes in a mini-load AS/RS pan. However, currently only three half-size totes can be stored in each mini-load pan, just as if they were the small size. Totes are tracked by one-dimensional bar-coded unique identification tags.

Each unique identification tag consists of six numerical digits indicating the size and whether it is a plastic returnable tote or a recyclable cardboard box. Table 4.3 below indicates the identification number block allocations:

Table 4.3 Identification Number Block Allocations

Identification Number	Container Type	Container Size
100000-199999	Plastic Reusable Tote	Half-Size
200000-299999	Cardboard Box	Half-Size
300000-399999	Plastic Reusable Tote	Large
400000-499999	Cardboard Box	Large
500000-899999	Plastic Reusable Tote	Small
900000-999999	Cardboard Box	Small

Each storage location in the mini-load is assigned a unique name of the form "MLAANNN," where ML represents mini-load AS/RS storage, AA represents an aisle number ranging from 01 to 06, and NNN represents a slot number ranging from 001 to 500 starting from the left-hand side bottom slot. The original design allows zoning, where fast moving items can be stored in slots which the crane takes the least amount of time to access from the end-of-aisle starting position. However random storage policy is being used in consideration of the following reliability concern: Zoning is believed to cause over-utilization of the equipment, i.e., brakes and rails, functioning within the fast-pick zone, which results in increased machine downtime due to increased non-uniform wear and tear.

There are frequent mechanical and electrical failures together with communication breakdowns between the Multi-Crane Interface (hereafter MCI) and cranes.

MCI refers to the mini-load AS/RS controller system with a backup option to communicate directly with the cranes. Cranes can be operated manually; however it is not efficient to do so in terms of throughput and human resource considerations. The cranes and MHCS communicate through MCI sustained by hard wire, where excessive communication failures are being experienced. Equipment downtime significantly increased due to normal wear and tear. Moreover, since the equipment manufacturer does not exist anymore, spare part availability is becoming a serious maintenance challenge.

MHCS interfaces with SAP, which is an enterprise wide multi-module information system operating on a centralized database server located in Wetzlar, Germany. SAP is used to conduct the direct information interchange and establish integration between suppliers, customers, and corresponding internal entities locally and/or globally by means of a network infrastructure. MHCS refers to the VAX 6410 computer and all controls for peripheral systems such as AGV's, workstations, RF terminals, mini-load AS/RS cranes, communication media, and programmable logic controllers (hereafter PLC).

The VAX 6410 was designed to operate for 10 years when it was introduced in 1987 and is fairly fragile after almost 20 years of service. One of the significant limitations of the current system is that MHCS must be shut down between 02:30 a.m. and 03:15 a.m. every day for "housekeeping" purposes like data cleaning and database refreshment. During the shut down period, mini-load AS/RS and AGV system are not operational. The manufacturing company Digital was subsequently purchased by Compaq, and Compaq was subsequently purchased by Hewlett-Packard, making spare parts challenging to procure.

Cooling and reheating old electronic components is estimated as the most common cause of failures. Furthermore, the existing source code to run MHCS was written in FORTRAN IV, a procedural programming language that is outdated for MHCS purposes. It is not a high-level object oriented programming language and limits the extent of modifications to the existing configuration by in-house personnel. Severe database corruption problems necessitate contracting with the original developer, who currently resides in San Diego, California. The source code for the SiGEN database is not available since it is proprietary in nature. Thus managing and maintaining the database, especially in case of database corruptions, is very troublesome.

Since overall system reliability and throughput is severely jeopardized, necessitating immediate retrofitting and/or replacement of the existing systems in order to sustain manufacturing operations, Plant I management has decided to first launch an analysis effort in January 2005 in collaboration with the Auburn University Industrial and Systems Engineering Department. The effort involves activity profiling and throughput analysis.

Plant I management set the on-hand inventory target as two days for approximately 3,500 mini-load AS/RS part numbers. Scheduled requirements are adjusted daily based on the customers' weekly production schedule utilizing MRP II methodology. There is not enough computational capability to make Pareto analysis of the on-hand inventory on a daily basis. Therefore detailed inventory activity profiling at part number level based on on-hand inventory is extremely challenging. Hence inventory activity profiling is performed based on the storage period of the parts packaged in totes.

It has been discovered that mini-load AS/RS storage is not being utilized as a fast pick area. Almost 20 percent of the totes stored at mini-load AS/RS consists of service parts consumed by one of the 15 assembly lines, the demand for which is extremely low for mini-load AS/RS storage. Similarly, obsolete parts occupy approximately 10 percent of the storage locations. Further investigation also indicated that, when the acquisition took place in April 2004, transition from one ERP system to the other was not planned effectively enough, resulting in a lack of operational data visibility, invalid obsolete inventory elimination process, and misinterpretation of float, i.e., the amount of stock placed between two manufacturing operations, safety stock, and safety time calculations. Figure 4.5 below summarizes the inventory activity profiling.

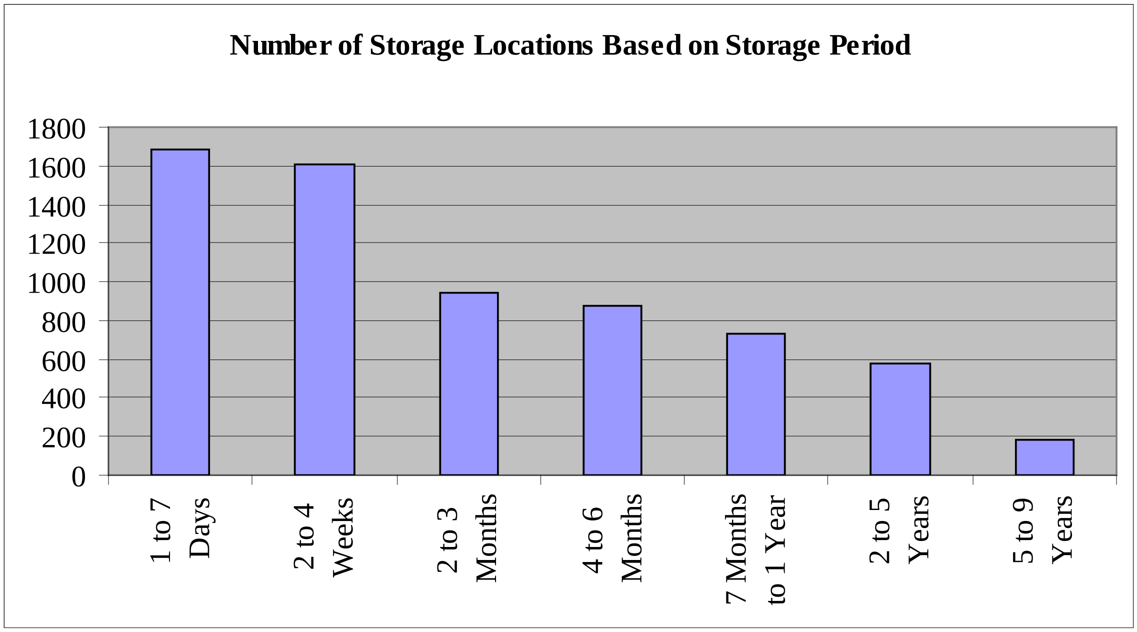

Figure 4.5 Inventory Activity Profiling

Order activity profiling revealed that on average 1,600 pick and 750 store transactions are performed per day. The inbound transportation is built around a two-shift production/operation schedule of the 3PL's and direct shipping domestic suppliers. Together with the assembly line operators' traditional behavior of ordering more parts during shift change, the aforementioned inbound transportation schedule triggers an hourly average peak of 125 pick and 75 store transactions around 3:00 p.m. In addition, inbound production material pack sizes, order quantities, and tote sizes have not been revisited since the acquisition. Therefore almost 800 part numbers are partially picked from the inbound totes by the crane operators resulting in excessive material handling and deployment of an additional mechanical system called the "chair lift system," which is designed to feed internally circulated 500 pick-to totes to crane operators.

Figure 4.6 Chair Lift System for Partial Picks

System throughput is defined as the number of storage or retrieval transactions per unit time; the rate at which the storage system receives and stores loads and retrieves and delivers loads to the output station is the main performance measure (Heragu, 1997).

In addition to the system throughput, utilization is defined as the proportion of time that the system is actually up and running for its original design purposes to its total available time and availability, i.e., the ratio of time that the system is ready for operation to total scheduled time, are other relevant performance measures. Groover (2001) utilizes the method recommended by the Material Handling Institute of America. According to that method, it is assumed that randomized storage of loads is used, storage compartments are of equal size, the pick and drop station is located at the base and end of the aisle, horizontal and vertical speeds of storage and retrieval equipment are constant, and horizontal and vertical travels are simultaneous. The equations associated with the method are provided by Groover (2001) and are indicated below. The single command cycle time is expressed as

$$T_{cs} = 2\,Max\left\{\frac{0.5L}{v_y}, \frac{0.5H}{v_z}\right\} + 2T_{pd} \qquad \textbf{(4.1)},$$

where L is the length of the AS/RS rack structure, v_y is the velocity of the crane along the length of the aisle, H is the height of the rack structure, v_z is the vertical velocity of the crane, and T_{pd} is the pickup and deposit time. The dual command cycle time is expressed as

$$T_{cd} = 2\,Max\left\{\frac{0.75L}{v_y}, \frac{0.75H}{v_z}\right\} + 4T_{pd} \quad \textbf{(4.2)}$$

The relative number of single and dual command cycles performed by the system defines the system throughput, and the amount of time spent in performing single and dual command cycles each hour is formulated as

$$R_{cs}T_{cs}+R_{cd}T_{cd} = 60U \quad \textbf{(4.3)},$$

where U is the system utilization, R_{cs} is the number of single command cycles performed per hour, and R_{cd} is the number of dual command cycles per hour. It should be noted that the relative proportions of R_{cs} and R_{cd} must be determined, or assumptions must be made.

The total hourly cycle rate is given by

$$R_c = R_{cs} + R_{cd} \quad \textbf{(4.4)}$$

The total number of transactions performed per hour is given as:

$$R_t = R_{cs} + 2R_{cd} \qquad \textbf{(4.5)}$$

The length, L, and the height, H, of the mini-load AS/RS rack structure used in Plant I is 702 inches and 121 inches, respectively. Although there is not any specific zoning for high turnover items since the first top three tiers of the bays are reserved for large totes, it is assumed that there is spontaneous zoning depicted as in Figure 4.7 below.

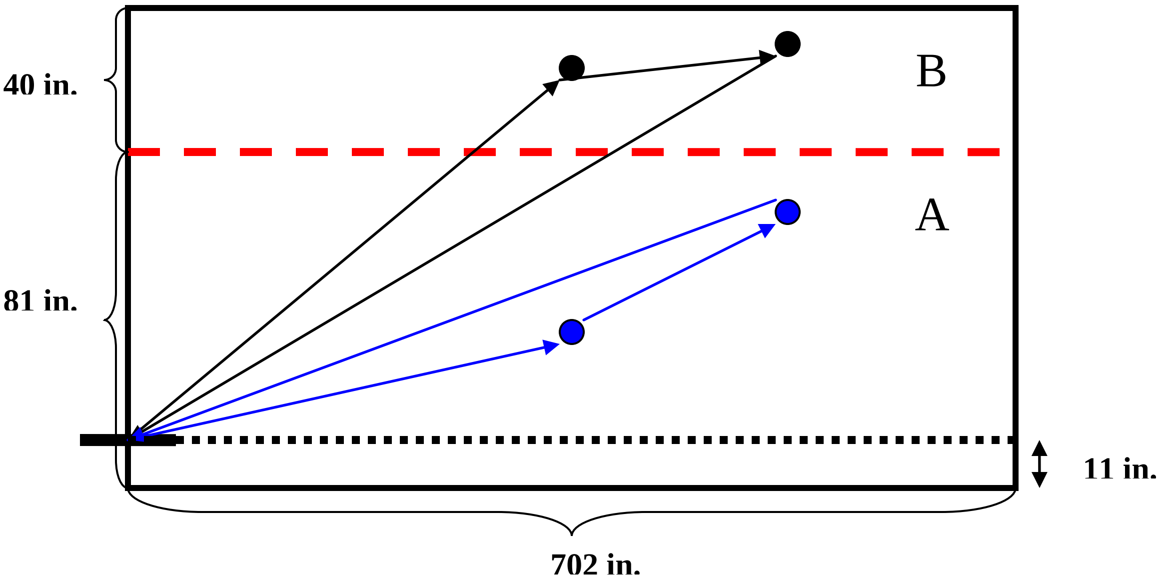

Figure 4.7 Travel Trajectory for Mini-Load AS/RS Cranes

Together with the aforementioned zoning and the slight vertical location shift of the pick and drop station, the single and dual cycle time for both the A and B zone is formulated as follows:

$$T_{csA} = 2\,Max\left\{\frac{0.5\times 702}{v_y}, \frac{(0.5\times 81)-11}{v_z}\right\} + 2T_{pd} \qquad \textbf{(4.6)}$$

$$T_{cdA} = 2\,Max\left\{\frac{0.75\times 702}{v_y}, \frac{(0.75\times 81)-11}{v_z}\right\} + 4T_{pd} \qquad \textbf{(4.7)}$$

$$T_{csB} = 2\,Max\left\{\frac{0.5\times 702}{v_y}, \frac{70+(0.5\times 40)}{v_z}\right\} + 2T_{pd} \qquad \textbf{(4.8)}$$

$$T_{cdB} = 2\,Max\left\{\frac{0.75\times 702}{v_y}, \frac{70+(0.75\times 40)}{v_z}\right\} + 4T_{pd} \qquad \textbf{(4.9)}$$

The equation for how each aisle spends its time during one hour is given as

$$R_{csA}T_{csA} + R_{cdA}T_{cdA} + R_{csB}T_{csB} + R_{cdB}T_{cdB} = 60U \qquad \textbf{(4.10)}$$

Based on the information gathered from the transaction logs generated by SiGEN database, it is observed that the number of single command cycles is approximately five times as many as the number of dual command cycles ($R_{cs} = 5\ R_{cd}$) and that the transactions in A zone account for 75 percent of the total transactions, while the transactions in B zone account for the remaining 25 percent.

The pick and deposit time for the storage and retrieval equipment is 7 seconds. The vertical velocity of the cranes is 60 ft/min or 12 in/sec. The horizontal velocity of each crane is indicated in Table 4.4 below.

Table 4.4 Horizontal Velocity of Mini-Load AS/RS Cranes

Crane Number	Horizontal Velocity (feet per minute/inches per second)
1	180/36
2	180/36
3	180/36
4	180/36
5	250/50
6	200/40

The crane utilization, based on the collected data and calculations using the formulation mentioned above, is summarized in Table 4.5 below.

Table 4.5 Mini-Load AS/RS Crane Utilization

	Crane-1	Crane-2	Crane-3	Crane-4	Crane-5	Crane-6
Total Transactions/Day	394	409	394	239	414	372
Single Command Cycles/Day	280	290	280	175	294	256
Dual Command Cycles/Day	57	59	57	32	60	58
A Zone Transactions/Day	100	110	100	46	119	102
B Zone Transactions/Day	294	299	294	193	295	270
T_{csA} (seconds)	33.5	33.5	33.5	33.5	28.04	31.55
T_{csB} (seconds)	33.5	33.5	33.5	33.5	29	31.55
T_{cdA} (seconds)	57.25	57.25	57.25	57.25	49.06	54.325
T_{cdB} (seconds)	57.25	57.25	57.25	57.25	49.06	54.325
R_{csA} (transactions/hour)	9	9	9	6	10	8
R_{csB} (transactions/hour)	3	3	3	2	3	3
R_{cdA} (transactions/hour)	2	2	2	1	2	2
R_{cdB} (transactions/hour)	1	1	1	0	1	1
Total transactions per hour	17	17	17	10	18	16
Utilization	15.45%	15.83%	15.29%	9.29%	13.58%	13.58%

The findings indicated in Table 4.5 are confirmed by the Plant I maintenance team since they spend more time in repair on Crane-4, Crane-5, and Crane-6.

The dedicated manpower of the existing mini-load AS/RS is indicated in Table 4.6.

Table 4.6 Dedicated Manpower of The Mini-Load AS/RS

	Shift		
Workstation	**1**	**2**	**3**
Buy-in	2	2	0
Cranes	4	4	2
AGV Accumulation Stands	3	2	1
Maintenance and Repair	2	2	1
Total	**11**	**10**	**4**

4.5 AGV System

AGV's are driverless industrial trucks utilized for material handling purposes within the facility. They are remotely controllable, wheeled vehicles driven by electric motors using storage batteries, and they follow a magnetic path along aisles. Plant I deployed 32 inertial-guided shuttle arm AGV's manufactured by Egemin Automation, Inc. in 1987. There are 24 AGV's in the distribution center and eight AGV's in the finished goods warehouse. AGV availability is 60 minutes per hour with the use of a second set of batteries. The nominal velocity of each AGV is 110 ft/min, but it decreases to 60 ft/min in curves and turns. The maximum weight capacity is 1,000 lbs, and the maximum dunnage height is 54 inches.

Figure 4.8 AGV

Distribution center AGV's pick parts from 12 accumulation stands in order to deliver production material from mini-load AS/RS storage and static rack storage to assembly lines. They also return empty dunnage from assembly lines to the dunnage return station located in the distribution center.

The average round trip for distribution center AGV's takes approximately 30 minutes. It should be noted that inbound bulk production material is delivered to the drop stands located along the southern half of the assembly lines that are, in average, 500 feet away from the distribution center.

Finished goods warehouse AGV's deliver finished goods packaging material, referred to as replenishment dunnage, from the finished goods warehouse to assembly lines. They also deliver finished goods from assembly lines to the finished goods warehouse whenever a pick-up order is placed for finished goods. Thus the efficiency of the finished goods warehouse AGV's is increased by eliminating deadheading. In addition, finished goods warehouse AGV's are also deployed for:

- Line to line subassembly transfer from Line 14, which is manufacturing car radio keyboards to the southern half of Line 5, which is dedicated to final assembly of the car radios.
- Empty container transfer from the southern half of Line 5 to Line 14.
- Finished goods transfer from a third party quality control unit that is called 3PVA to the banding equipment for the final functionality test of car radios within the finished goods warehouse.

The average round trip for finished goods warehouse AGV's takes approximately 20 minutes.

Figure 4.9 Mini-Load AS/RS Accumulation Stands

The inbound production material deliveries and empty dunnage returns are made to and from approximately 370 pick and drop stands throughout the facility that are located alongside the assembly lines. The number and location of pick and drop stands is dynamically changing due to frequent changes in assembly line layouts.

Figure 4.10 Pick and Drop Stand

The existing AGV system is operating under two independent control systems: External Control System–1 (hereafter ECS-1) controls the eight S700 type AGV's assigned to the finished goods warehouse, and External Control System–2 (hereafter ECS-2) controls 24 S700 type AGV's assigned to the distribution center. Changing AGV assignment between the finished goods warehouse and the distribution center is extremely labor intensive and cumbersome due to the existing control structure. The AGV system uses using a wireless communication system operating on 2.4GHz frequency that is also referred to as 802.11b. Both the software and the hardware of the aforementioned control systems are outdated and fully depreciated. Hence the deployment of a new WMS also requires the deployment of a new control system called E'tricc, which is provided by Egemin Automation, Inc. E'tricc consolidates existing ECS-1 and ECS-2 and is expected to provide a more efficient AGV utilization by pooling all of the vehicles under a single control system. It also allows for the elimination of the pick and drop stands and mono-directional aisle traffic. However, since the AGV's have not had preventive maintenance in the last three years, 80 percent of the AGV's experience severe mechanical failures and spare part availability is extremely challenging.

The inbound production material delivery transfer is handled by 24 AGV’s assigned to the distribution center. AGV’s make three different types of trips:

- Drop: AGV’s leave the distribution center loaded with inbound production material destined for assembly lines and then return empty.
- Single Dunnage Trip: AGV’s leave the distribution center empty and bring back empty dunnage, or they leave the distribution center full and come back empty.

- Dual Dunnage Trip: AGV’s leave the distribution center loaded with inbound production material destined for assembly lines and bring back dunnage return, i.e., reusable containers, from assembly lines.

Since overall system reliability and throughput is severely jeopardized, necessitating immediate replacement of the existing system in order to sustain manufacturing operations, Plant I management decided to first launch an analysis effort in January 2005 in collaboration with the Auburn University Industrial and Systems Engineering Department.

The average number of trips per day performed by distribution center AGV's based on the data provided by MHCS over 82 consecutive days is indicated in Table 4.7.

Table 4.7 Average Number of Distribution Center AGV Trips

Trip Type	Average Number of Trips per Day
Drop from Mini-Load AS/RS	452
Drop from Static Racks	259
Total Drops	711
Single Dunnage Trips	137
Dual Dunnage Trips	372
Total Dunnage Trips	508
Uncompleted Drops	64
Total Trips	912

Table 4.8 below indicates the daily average number of trips per AGV, assuming that trips are uniformly distributed to AGV's.

Table 4.8 Daily Average Number of Trips Per Distribution Center AGV

Trip Type	Daily Average Number of Trips per AGV
Drop from Mini-Load AS/RS	19
Drop from Static Racks	11
Total Drops	30
Single Dunnage Trips	6
Dual Dunnage Trips	16
Total Dunnage Trips	22
Uncompleted Drops	3
Total Trips	39

Approximately 65 percent of the total completed drops are made from mini-load AS/RS, while 35 percent are made from static racks. The reason for the higher number of AGV trips is considered to stem from the relatively large number of partial picks from mini-load AS/RS storage. Single dunnage, which is referred to as deadheading, has negative impact on AGV system utilization; therefore minimizing or eliminating single dunnage trips will increase the efficiency.

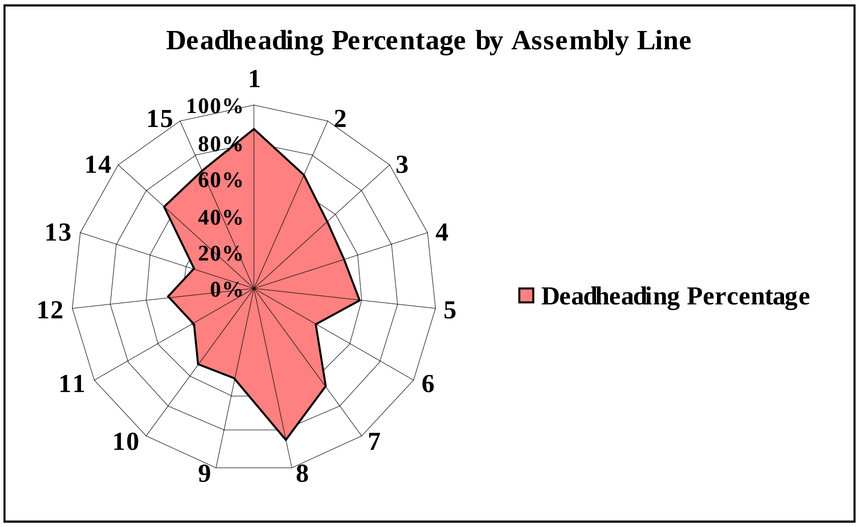

Figure 4.11 Deadheading Analysis of the AGV System

Another source of waste in the AGV system are uncompleted drops. Approximately 10 percent of the attempted drops are wasted. They are considered to be caused by the following reasons:

- The line of sight between the AGV sensor and the diagonal reflector on the drop stand is blocked because the material handler assigned to the destined assembly line does not pick up the inbound production material from the drop stands or the diagonal reflector is disoriented.
- The line of sight between the AGV sensor and the diagonal reflector on the drop stand is blocked because the AGV sensor is malfunctioning.
- The centrally located and vertically oriented reflector on the drop stand is not aligned with the AGV sensor.

In case the diagonal reflector is blocked, the AGV generates a sound signal until the material handler of the destined assembly line shifts the AGV to "Manual" mode, then back to "Auto" mode. Then, depending on whether the inbound production material is manually loaded to the drop stand or not by the corresponding material handler, the AGV returns to the distribution center either empty or full, respectively. Upon returning to the distribution center, the AGV enters the buffer, where it waits for the next assignment. If it is still loaded, it will not be able to pick up the next load and will block the accumulation stand until it is taken care of.

In case the centrally located and vertically oriented reflector is not aligned with the AGV sensor, the AGV makes two more drop attempts and then returns to the AGV buffer located in the distribution center.

Upon returning to the distribution center, the AGV control system generates a "purge request" for the corresponding AGV. The AGV enters the buffer in the south portion of the east mini-load AS/RS and blocks the buffer lane until the purge request is taken care of, while any the other AGV's waiting behind are blocked. Then the ECS operator directs the AGV to the dunnage return station, where the subject matter load is repositioned on an AGV pick stand and reassigned for delivery. However currently there is not a designated ECS operator, and this task is being performed randomly by either a mini-load AS/RS crane operator or an AGV accumulation stand operator. Moreover it has also been reported that there have been occurrences where the ECS operator directs the AGV to an irrelevant AGV drop stand on the manufacturing floor and the associated parts become obsolete as they are staged somewhere on the manufacturing floor.

The average number of trips per day performed by AGV's that are assigned to the finished goods warehouse based on the data provided by MHCS over 82 days is indicated in Table 4.9.

Table 4.9 Average Number of Finished Goods Warehouse AGV Trips

Trip Type	Average Number of Trips per Day
From Warehouse to Assembly Lines	100
From Assembly Lines to Warehouse	120
Line to Line	6
From 3PVA to Banding Equipment	6
Total Trips	232

Table 4.10 below indicates the daily average number of trips per AGV, assuming that trips are uniformly distributed to AGV's.

Table 4.10 Daily Average Number of Trips Per Finished Goods AGV

Trip Type	Average Number of Trips per Day
From Warehouse to Assembly Lines	13
From Assembly Lines to Warehouse	15
Line to Line	1
From 3PVA to Banding Equipment	1
Total Trips	30

The mechanical retrofitting of the AGV's requires upgrading of the following components:

- The main board of the AGV's on-board micro computer called "NT Box"
- The gear box assembly called "Hurth Drive" and wheels
- The shuttle arm assembly

The maintenance and in-house repair operations are performed by one electrician per shift for three shifts a day in the AGV shop located on the east side of the manufacturing building, the floor space of which is 3800 sq. ft. There are two battery charge areas located in the distribution center and the finished goods warehouse; the floor space of each is 660 sq. ft. and 2000 sq. ft., respectively.

CHAPTER 5

FLOOR SPACE VALUATION METHOD

5.1 Introduction

This chapter presents the valuation of the capital investment decision alternatives together with the floor space associated with each alternative. Plant I management started to evaluate a decision portfolio in order to replace and/or to retrofit the existing, but outdated mini-load AS/RS and the AGV system in January 2005. The portfolio consists of four decision alternatives, which are evaluated in two groups: the alternatives related to the mini-load AS/RS and the ones related to the AGV system. Although the decisions are made utilizing NPV criterion, the floor space value perspective is also included in the decision making process in order to emphasize and communicate its significance.

5.1.1 Mini-Load AS/RS Related Alternatives (Group-1)

The alternatives included in this group are considered as mutually exclusive, and they need to be implemented within the next two years.

5.1.1.1 Mini-Load AS/RS and WMS Replacement (Alternative-1)

This alternative consists of replacing the existing outdated mini-load AS/RS and the associated WMS with a new mini-load AS/RS and a proprietary WMS.

Based on the activity profiling and the throughput analysis of the simulation study performed by the Auburn University Industrial and Systems Engineering Department, it is recommended to initially phase out Crane-4, Crane-5, and Crane-6, to reduce the mini-load AS/RS inventory by 50 percent, and to deploy a new four-aisle mini-load AS/RS, together with a new WMS. In order to justify the investment through labor cost savings, it is also recommended to deploy two palletizing robots for the order picking process and an RFID system for the receiving process. The implementation of this alternative is estimated to take 12 months, while the warehouse operations are maintained by Crane-1, Crane-2, and Crane-3 and supported by the existing WMS during the implementation period. As soon as the implementation is accomplished Crane-1, Crane-2, and Crane-3 will be phased out. The required investment for this alternative is $2.7 million with a five-year useful project life. The annual preventive maintenance cost is estimated as $30,000. The estimated labor cost savings and inventory holding cost savings are $1 million and $200,000 per year, respectively. Finally, the estimated floor space savings are 5,000 sq. ft. through additional facility layout modifications, which involve moving the AGV repair shop and AGV battery charge areas to the distribution center.

5.1.1.2 Just-in-Time Delivery (Alternative-2)

This alternative consists of eliminating the mini-load AS/RS and the associated WMS and requires third-shift 3PL support and transportation operations, together with J.I.T. delivery efforts. It is recommended to first phase out Crane-4, Crane-5, and Crane-6, and then to employ a flow-through conveyor system equipped with diverters that has a capacity of a full truck load of totes as well as a handling unit management system.

In order to sustain J.I.T. delivery, it is imperative to use an electronic Kanban system between Plant I and the 3PL's. Direct shipping suppliers are required to ship the raw material to the 3PL's for storage and staging purposes. In order to justify the investment through labor cost savings, it is also recommended to deploy two palletizing robots for the order picking process and an RFID system for the receiving process. The implementation of this alternative is estimated to take nine months, while the warehouse operations are maintained by Crane-1, Crane-2, and Crane-3 and supported by the existing WMS during the implementation period. As soon as the implementation is accomplished Crane-1, Crane-2, and Crane-3 will be phased out. The required investment is $1 million with a five-year useful project life. The annual preventive maintenance cost is estimated as $20,000. The annual 3PL and transportation costs in order to support third-shift operations are estimated as $600,000. The estimated labor cost savings and inventory holding cost savings are $700,000 and $400,000 per year, respectively. The estimated floor space savings are 10,000 sq. ft. through additional facility layout modifications, which include moving the AGV repair shop, AGV battery charge areas, and machine shop to the distribution center. This alternative is mutually exclusive to Alternative-1.

5.1.2. AGV System Related Alternatives (Group-2)

The alternatives included in this group are considered to be mutually exclusive and they need to be implemented within the next four years.

5.1.2.1 AGV Control Software Replacement and Mechanical Component Retrofitting (Alternative-3)

This alternative requires the replacement of the existing outdated AGV control software with the new version, where ECS-1 and ECS-2 are consolidated and the mechanical AGV components are retrofitted.

The new version of the control software allows all of the vehicles to be pooled under a single control system and also permits dynamic task allocation by eliminating fixed task allocation windows and brings in the flexibility of

- Eliminating pick and drop stands
- Switching to mono-directional AGV traffic through bi-directional shuttle arm motion

The current reliability of the mechanical AGV components is defined as being as low as 70 percent. Based on the throughput analysis through the simulation study performed by the Auburn University Industrial and Systems Engineering Department, it is recommended to reduce the number of AGV's by 37.5 percent (i.e. 12 vehicles) after mechanical retrofitting, which requires upgrading the following components:

- The main board of the AGV's on-board micro computer called "NT Box"
- The gear box assembly called "Hurth Drive" and wheels
- The shuttle arm assembly

The implementation of this alternative is estimated to take eight months assuming that the purchase order is issued. The required investment for this alternative is $1.15 million with a five-year useful project life.

The estimated maintenance and repair cost savings are estimated as $350,000 per year, while the estimated floor space savings through pick and drop stand elimination and a switch to mono-directional aisle traffic is estimated as 45,000 sq. ft. through additional facility layout modifications. However, either Alternative-1 or Alternative-2 must precede or be simultaneously implemented with this alternative.

5.1.2.2 Water Spider Deployment (Alternative-4)

This alternative requires replacing the AGV system with water spiders equipped with tugger vehicles and associated trailers. The water spider is a lean manufacturing term representing a material handler who is more involved in the process or cell (s)he supports than just a pick-up and drop-off material handler. In this type of material handling system, the material handler performs a standard route through a facility at precisely determined time intervals such as every 20 minutes. The amount of material moved each time may vary, but the time interval is exact. During this interval, the material handler follows a predetermined, standard route, picking up kanban cards, signaling what materials to deliver next, and delivering the materials to production locations. This system often is coupled with a heijunka box in which the withdrawal intervals in the columns of the box correspond to the time required for the standard material handling route. This type of system often is employed in assembly operations where a large number of components need to be delivered to many points along a line. It is also called mizusumashi or waterspider conveyance.

The implementation of this alternative is estimated to take two months. The required investment for this alternative is $1 million with a five-year useful project life.

It is estimated that there will be an additional labor cost of $200,000 since Plant I management is considering employing additional material handlers and training them as water spiders. The estimated maintenance and repair cost savings due to the elimination of the AGV system are estimated as $350,000 per year. The estimated floor space savings are estimated as 60,000 sq. ft. since Plant I management is considering switching to a more flexible cellular manufacturing layout by avoiding the aisle requirement due to the elimination of the AGV system. This alternative is mutually exclusive to Alternative-3 while either Alternative-1 or Alternative-2 must precede or be simultaneously implemented with this alternative.

Each decision alternative from Group-1 is combined with decision alternatives from Group-2 to form all possible options indicated in the following Table 5.1.

Table 5.1 Decision Alternative Combinations

Decision Alternative Combination	Option
Alternative-1 and Alternative-3	Option-1
Alternative-1 and Alternative-4	Option-2
Alternative-2 and Alternative-3	Option-3
Alternative-2 and Alternative-4	Option-4

The second section presents the valuation of the decision portfolio through discounted cash flow techniques and the associated sensitivity and scenario analysis based on the decision criterion adopted by the corporate management of the subject matter business application. The third section presents the MCS model of the decision portfolio, taking into account the variability of the input parameters with and without the financial impact of the free cash flows that can potentially be generated by the additional floor space.

The fourth section presents DTA of the decision portfolio utilizing the average WACC and the risk-free interest rate. The fifth section presents the real options analysis of the decision portfolio through the combination of DTA and a binomial lattice, where the volatility factor is estimated using the logarithmic cash flow returns method and MCS.

In order to reduce the complexity of the calculations and to be able to narrow down the scope of the analysis in the aforementioned sections, the following assumptions are made:

- Lost sales are not taken into account since the demand that cannot be met by Plant I can be satisfied by another plant of the corporation as it actually is.
- Opportunity cost stemming from the implementation delay of the alternatives is not taken into account since different interpretations of the opportunity cost can significantly impact the results of the analysis in each section.
- Implementation start time lag for the alternatives is not taken into account because the required resolution negatively impacts the mathematical tractability.
- A new contract requires deployment of the dedicated floor space as long as the useful project life once it is negotiated with the customer.

The quality of the valuation process depends on the validity of different valuation techniques together with the effectiveness of the associated free cash flow streams, discount rate, and contingent alternatives. In a very broad sense, the value of any alternative is the difference between the revenues and the costs through the overall life cycle.

The objective of the valuation is to evaluate an alternative from both project NPV and floor space value perspective, to compare it against others competing for the same investment pool, and also to decide the changes on the course of the alternative, together with the associated timing scheme.

5.2 Discounted Cash Flow Approach

This section presents the valuation of each option utilizing DCF techniques including sensitivity and scenario analysis. The decision criterion adopted by the corporate management is the NPV. Any alternative is considered acceptable if it has a positive NPV. It should be noted that the corporate finance department is utilizing the straight-line depreciation method.

5.2.1 Alternative-1

The implementation of this alternative is estimated to take 12 months. The required investment is $2.7 million with a five-year useful project life. The annual preventive maintenance cost is estimated as $30,000. The estimated labor cost savings and inventory holding cost savings are $1 million and $200,000 per year, respectively, while the estimated floor space savings are 5,000 sq. ft. through additional facility layout modifications, which include moving the AGV repair shop and the AGV battery charge areas to the distribution center. The WACC and the tax rate are defined as seven percent and 30 percent, respectively. The DCF analysis of Alternative-1 is given in Table 5.2 below.

Table 5.2 DCF Analysis of Alternative-1 (In Thousands of US Dollars)

Year	**0**	**1**	**2**	**3**	**4**	**5**
Income Statement						
Revenues						
Labor Cost Savings		$1,000	$1,000	$1,000	$1,000	$1,000
Inventory Holding Cost Savings		$200	$200	$200	$200	$200
Expenses						
O & M		$30	$30	$30	$30	$30
Depreciation		$540	$540	$540	$540	$540
Taxable Income		$630	$630	$630	$630	$630
Income Taxes (30%)		$189	$189	$189	$189	$189
Net Income		$441	$441	$441	$441	$441
Cash Flow Statement						
Cash from Operation						
Net Income		$441	$441	$441	$441	$441
Depreciation		$540	$540	$540	$540	$540
Investment	($2,700)					
Net Cash Flow	($2,700)	$981	$981	$981	$981	$981
NPV (7%)	$1,322.3					

5.2.2 Alternative-2

The implementation of this alternative is estimated to take nine months. The required investment is $1 million with a five-year useful project life. The annual preventive maintenance cost is estimated as $20,000. The annual 3PL and transportation costs in order to support third-shift operations are estimated as $600,000. The estimated labor cost savings and inventory holding cost savings are $700,000 and $400,000 per year, respectively, while the estimated floor space savings are 10,000 sq. ft. through additional facility layout modifications, which include moving the AGV repair shop, AGV battery charge areas, and machine shop to the distribution center. The WACC and the tax rate are defined as seven percent and 30 percent respectively. The DCF analysis of Alternative-2 is given in Table 5.3 below.

Table 5.3 DCF Analysis of Alternative-2 (In Thousands of US Dollars)

Year	**0**	**1**	**2**	**3**	**4**	**5**
Income Statement						
Revenues						
Labor Cost Savings		$700	$700	$700	$700	$700
Inventory Holding Cost Savings		$400	$400	$400	$400	$400
Expenses						
O & M		$20	$20	$20	$20	$20
Depreciation		$200	$200	$200	$200	$200
3PL & Transportation		$600	$600	$600	$600	$600
Taxable Income		$280	$280	$280	$280	$280
Income Taxes (30%)		$84	$84	$84	$84	$84
Net Income		$196	$196	$196	$196	$196
Cash Flow Statement						
Cash from Operation						
Net Income		$196	$196	$196	$196	$196
Depreciation		$200	$200	$200	$200	$200
Investment	($1,000)					
Net Cash Flow	($1,000)	$396	$396	$396	$396	$396
NPV (7%)	$623.68					

5.2.3 Alternative-3

The implementation of this alternative is estimated to take eight months, assuming that the purchase order is issued. The required investment is $1.15 million with a five-year useful project life. The estimated maintenance and repair cost savings are estimated as $350,000 per year, while the estimated floor space savings through pick and drop stand elimination and a switch to mono-directional aisle traffic are estimated as 45,000 sq. ft. through additional facility layout modifications. However, either Alternative-1 or Alternative-2 must precede or be simultaneously implemented with this alternative. The WACC and the tax rate are defined as seven percent and 30 percent, respectively. The DCF analysis of Alternative-3 is given in Table 5.4 below.

Table 5.4 DCF Analysis of Alternative-3 (In Thousands of US Dollars)

Year	**0**	**1**	**2**	**3**	**4**	**5**
Income Statement						
Revenues						
O & M Cost Savings		$350	$350	$350	$350	$350
Expenses						
Depreciation		$230	$230	$230	$230	$230
Taxable Income		$120	$120	$120	$120	$120
Income Taxes (30%)		$36	$36	$36	$36	$36
Net Income		$84	$84	$84	$84	$84
Cash Flow Statement						
Cash from Operation						
Net Income		$84	$84	$84	$84	$84
Depreciation		$230	$230	$230	$230	$230
Investment	($1,150)					
Net Cash Flow	($1,150)	$314	$314	$314	$314	$314
NPV (7%)	$137.46					

5.2.4 Alternative-4

The implementation of this alternative is estimated to take two months. The required investment is $1 million with a five-year useful project life. It is estimated that there will be an additional labor cost of $200,000 since Plant I management is considering employing water spiders. The estimated maintenance and repair cost savings due to the elimination of the AGV system are estimated as $350,000 per year. The estimated floor space savings is estimated as 60,000 sq. ft. since Plant I management is considering switching to a more flexible cellular manufacturing layout by avoiding the aisle requirement due to the elimination of the AGV system. However, either Alternative-1 or Alternative-2 must precede or be simultaneously implemented with this alternative. The WACC and the tax rate are defined as seven percent and 30 percent, respectively. The DCF analysis of Alternative-4 is given in Table 5.5 below.

Table 5.5 DCF Analysis of Alternative-4 (In Thousands of US Dollars)

Year	**0**	**1**	**2**	**3**	**4**	**5**
Income Statement						
Revenues						
O & M Cost Savings		$350	$350	$350	$350	$350
Expenses						
Labor		$200	$200	$200	$200	$200
Depreciation		$200	$200	$200	$200	$200
Taxable Income		($50)	($50)	($50)	($50)	($50)
Income Taxes (30%)		($15)	($15)	($15)	($15)	($15)
Net Income		($35)	($35)	($35)	($35)	($35)
Cash Flow Statement						
Cash from Operation						
Net Income		($35)	($35)	($35)	($35)	($35)
Depreciation		$200	$200	$200	$200	$200
Investment	($1,000)					
Net Cash Flow	($1,000)	$165	$165	$165	$165	$165
NPV (7%)	($323.47)					

5.2.5 Combinations of the Options Based on Implementation Start Time

Since both Group-1 and Group-2 alternatives need to be implemented within the next two and four years, respectively, eight combinations are formed for each option in accordance with the implementation start time of each alternative. The implementation start time combination of each option is numbered such that the first digit represents the Group-1 decision alternative, the second digit represents the implementation start time of the aforementioned Group-1 decision alternative as Year 0 or Year 1, the third digit represents the Group-2 decision alternative, and the fourth digit represents the implementation start time of the aforementioned Group-2 decision alternative as Year 0, Year 1, Year 2, or Year 3. The DCF analysis of all possible implementation start time combinations for each option is given in Table 5.6 below.

Table 5.6 DCF Analysis of All Possible Option Combinations

Option	Generated Floor Space (in sq. ft.)	Implementation Start Time Combination	NPV	NPV per sq. ft.
Option-1	50,000	1030	**$1,459,756**	**$29.20**
		1031	$1,450,763	$29.02
		1032	$1,442,358	$28.85
		1033	$1,434,504	$28.69
		1130	$1,373,250	$27.47
		1131	$1,364,258	$27.29
		1132	$1,355,853	$27.12
		1133	$1,347,998	$26.96
Option-2	65,000	1040	$998,826	$15.37
		1041	$1,019,988	$15.69
		1042	$1,039,765	$16.00
		1043	**$1,058,248**	**$16.28**
		1140	$912,321	$14.04
		1141	$933,482	$14.36
		1142	$953,260	$14.67
		1143	$971,743	$14.95
Option-3	55,000	2030	**$761,140**	**$13.84**
		2031	$752,147	$13.68
		2032	$743,743	$13.52
		2033	$735,888	$13.38
		2130	$720,339	$13.10
		2131	$711,346	$12.93
		2132	$702,941	$12.78
		2133	$695,087	$12.64
Option-4	70,000	2040	$300,211	$4.29
		2041	$321,372	$4.59
		2042	$341,149	$4.87
		2043	**$359,632**	**$5.14**
		2140	$259,409	$3.71
		2141	$280,571	$4.01
		2142	$300,348	$4.29
		2143	$318,831	$4.55

Based on the most likely static inputs, DCF analysis of all possible combinations indicates that the best course of action is Option-1 by investing in both Alternative-1 and Alternative-3 at Year 0 with respect to the NPV and NPV per square foot.

5.2.6 Sensitivity and Scenario Analysis

The DCF techniques presented in the previous sections utilize the most likely values for such inputs as WACC, labor cost savings, inventory holding cost savings, O&M cost savings, labor costs, O&M costs, and 3PL and transportation costs. However, it is not realistic to assume one set of deterministic values for the inputs. Thus sensitivity analysis is used to analyze the impact of the variations of the input variables on the decision criterion. The input variations identified by the management are presented in the following Table 5.7.

Table 5.7 Input Variations

Input	Variation from the Base-Case
WACC	6% to 12%
Labor Cost Savings	± 10%
Inventory Holding Cost Savings	± 30%
O & M Cost Savings	± 10%
Labor Costs	± 10%
3PL & Transportation Costs	± 25%
O & M Costs	± 10%

WACC is the input that has the most impact on the NPV of Alternative-1. The variation in WACC stems from the different target capital structures of the corporations involved in the acquisition of Plant I. Detailed graphical data are provided in Figure 5.1.

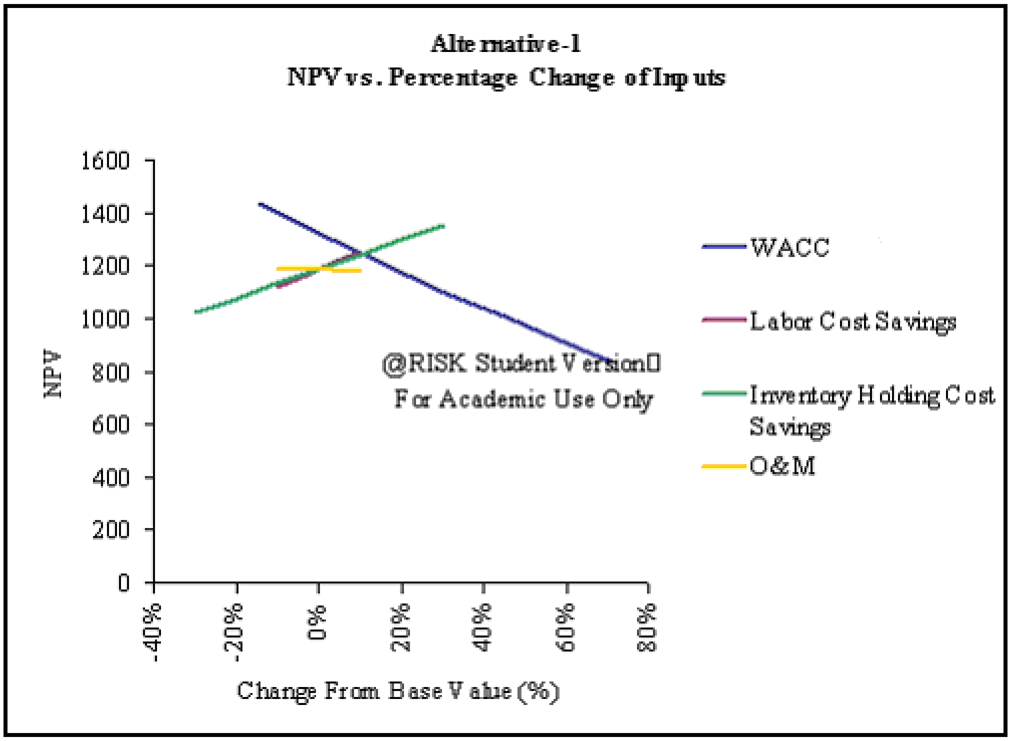

Figure 5.1 Alternative-1 NPV vs. Percentage Change of Inputs

3PL and transportation costs is the input that has the most impact on the NPV of Alternative-2, where the variation stems from the variability of the fuel price and the price changes that may potentially be imposed by 3PL's. Detailed graphical data are provided in Figure 5.2.

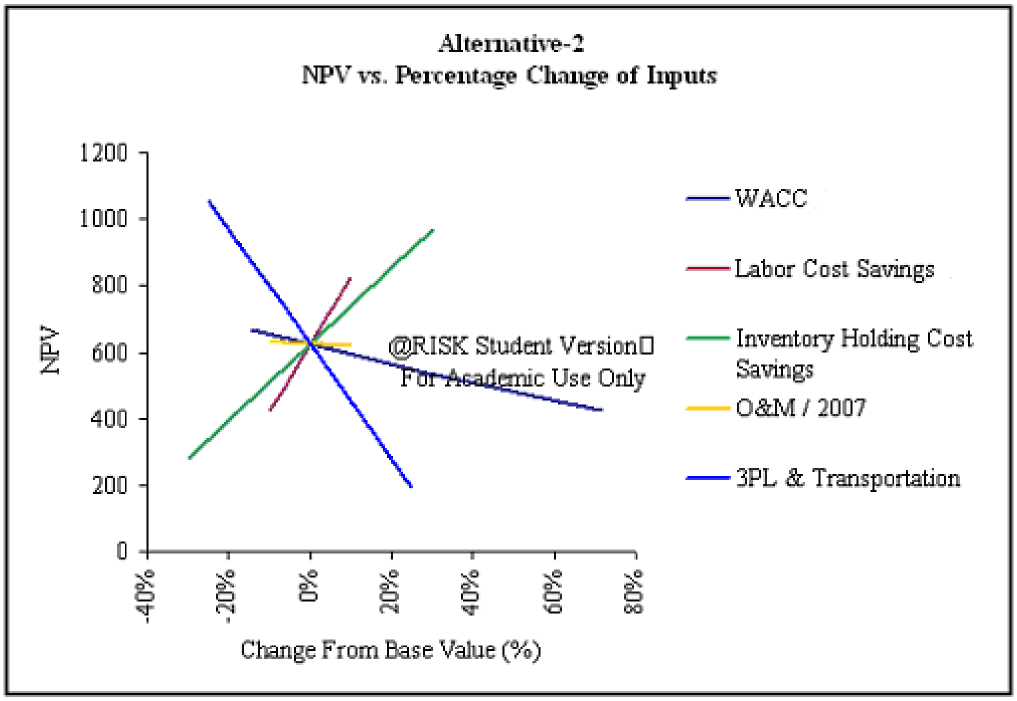

Figure 5.2 Alternative-2 NPV vs. Percentage Change of Inputs

Operations and maintenance cost savings has the most impact on the NPV of Alternative-3. The variation in operations and maintenance cost savings stems from the total price of the spare parts, depending upon the magnitude of the failure and the variability of the labor category utilized for repair. Detailed graphical data are provided in Figure 5.3.

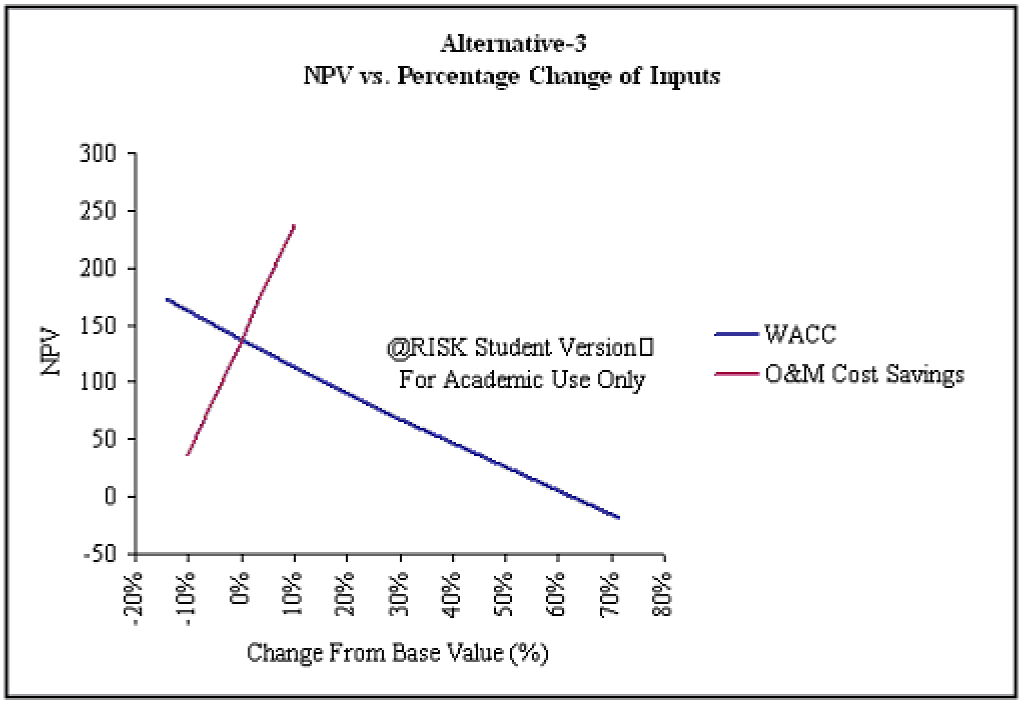

Figure 5.3 Alternative-3 NPV vs. Percentage Change of Inputs

Operations and maintenance cost savings has the most impact on the NPV of Alternative-4. The variation in operations and maintenance cost savings stems from the total price of the spare parts depending upon the magnitude of the failure and the variability of the labor category utilized for repair. Detailed graphical data are provided in Figure 5.4.

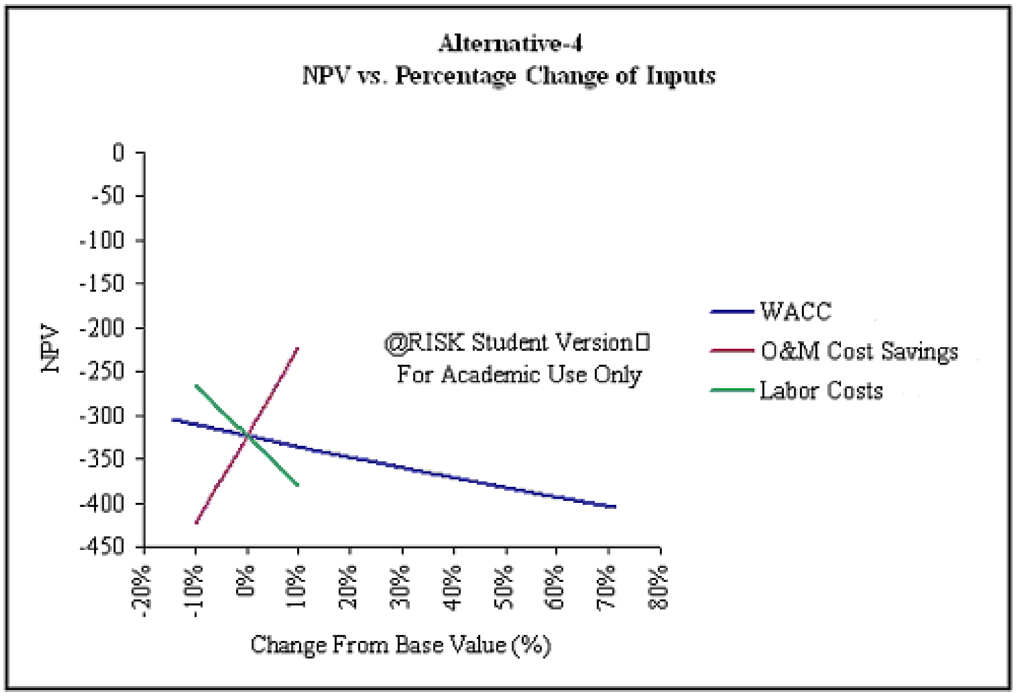

Figure 5.4 Alternative-4 NPV vs. Percentage Change of Inputs

Sensitivity analysis is not able to specify the interdependencies among the input variables, since it only allows holding one input variable constant at a time. However, input variables do not behave in that manner. Thus, analyzing the sensitivity of the decision criterion to the movement of one variable is not realistic. Scenario analysis is a technique that allows for the consideration of extreme values of the input variables simultaneously. Although scenario analysis provides the range of the possible values that the decision criterion can take considering the extreme values of the input variables, the likelihoods and the risks are not known to the decision maker. The scenario analysis for the NPV, considering input variations indicated in Table 5.7, is summarized in the following Table 5.8, Table 5.9, and Table 5.10.

Table 5.8 Scenario Analysis for NPV of Each Alternative

Criterion: NPV	**Best Case**	**Base Case**	**Worst Case**
Alternative-1	$1,912,959.58	$1,322,293.68	$424,980.49
Alternative-2	$1,676,535.95	$623,678.18	($435,492.05)
Alternative-3	$275,885.14	$137,461.99	($106,417.29)
Alternative-4	($142,783.97)	($323,467.42)	($543,995.81)

Table 5.9 Best Case DCF Analysis for All Possible Option Combinations

Option	**Generated Floor Space (in sq. ft.)**	**Implementation Start Time Combination**	**Best Case NPV**	**Best Case NPV per sq. ft.**
Option-1	50,000	1030	**$2,188,845**	**$43.78**
		1031	$2,173,229	$43.46
		1032	$2,158,496	$43.17
		1033	$2,144,598	$42.89
		1130	$2,080,564	$41.61
		1131	$2,064,948	$41.30
		1132	$2,050,216	$41.00
		1133	$2,036,317	$40.73
Option-2	65,000	1040	$1,770,176	$27.23
		1041	$1,778,258	$27.36
		1042	$1,785,882	$27.48
		1043	**$1,793,075**	**$27.59**
		1140	$1,661,895	$25.57
		1141	$1,669,977	$25.69
		1142	$1,677,602	$25.81
		1143	$1,684,795	$25.92
Option-3	55,000	2030	**$1,952,421**	**$35.50**
		2031	$1,936,805	$35.21
		2032	$1,922,073	$34.95
		2033	$1,908,174	$34.69
		2130	$1,857,523	$33.77
		2131	$1,841,907	$33.49
		2132	$1,827,174	$33.22
		2133	$1,813,276	$32.97
Option-4	70,000	2040	$1,533,752	$21.91
		2041	$1,541,834	$22.03
		2042	$1,549,459	$22.14
		2043	**$1,556,652**	**$22.24**
		2141	$1,438,854	$20.56
		2142	$1,446,936	$20.67
		2143	$1,454,560	$20.78
		2144	$1,461,754	$20.88

Table 5.10 Worst Case DCF Analysis for All Possible Option Combinations

Option	Generated Floor Space (in sq. ft.)	Implementation Start Time Combination	Worst Case NPV	Worst Case NPV per sq. ft.
Option-1	50,000	1030	$318,563	$6.37
		1031	$329,965	$6.60
		1032	$340,145	$6.80
		1033	**$349,235**	**$6.98**
		1130	$273,030	$5.46
		1131	$284,431	$5.69
		1132	$294,612	$5.89
		1133	$303,701	$6.07
Option-2	65,000	1040	($119,015)	($1.83)
		1041	($60,730)	($0.93)
		1042	($8,690)	($0.13)
		1043	**$37,775**	**$0.58**
		1140	($164,549)	($2.53)
		1141	($106,264)	($1.63)
		1142	($54,223)	($0.83)
		1143	($7,759)	($0.12)
Option-3	55,000	2030	($541,909)	($9.85)
		2031	($530,507)	($9.65)
		2032	($520,327)	($9.46)
		2033	($511,238)	($9.30)
		2130	($495,249)	($9.00)
		2131	($483,848)	($8.80)
		2132	($473,667)	($8.61)
		2133	**($464,578)**	**($8.45)**
Option-4	70,000	2040	($979,488)	($13.99)
		2041	($921,203)	($13.16)
		2042	($869,162)	($12.42)
		2043	($822,698)	($11.75)
		2141	($932,828)	($13.33)
		2142	($874,543)	($12.49)
		2143	($822,502)	($11.75)
		2144	**($776,038)**	**($11.09)**

Scenario analysis supported by sensitivity analysis indicates that the best course of action is Option-1 by investing in Alternative-1 and Alternative-3 at Year 0 for the best case, and in Alternative-1 at year 0 and Alternative-3 at Year 3 for the worst case, respectively.

5.3 Monte Carlo Simulation Approach

DCF techniques involve the use of only one set of input variables; therefore it is a deterministic approach. However, the input variables exhibit probabilistic behavior. The impact of the aforementioned probabilistic behavior is explored by conducting sensitivity and scenario analysis on a limited basis. One limitation is that sensitivity analysis does not investigate the interactions among the input variables and the probability of the deviations from the base-case. It is assumed that the outcome has a fixed path while contingent decisions generating different outcomes than the expected are ignored. The other limitation is that only the downside risk is accounted for by DCF techniques since the higher the risk is, the higher is the added risk premium, with no consideration for the upside potential. In other words, as the discount rate is increased with an increase in risk, the reward potential is ignored.

MCS is an extension to DCF techniques, which calculates the outputs for as many times as the number of simulation runs by varying the input variables in accordance with their associated probability distributions. MCS generates the outputs in the form of probability distribution. As an extension to DCF techniques MCS has the same drawback; the management's flexibility to change the course and the timing of the decision alternative are not taken into account.

MCS analysis is performed for the NPV utilizing the student version of @Risk Software with 10,000 iterations in each run, for which Monte Carlo sampling is used instead of Latin Hypercube. Although Latin Hypercube is a specialized method that helps insure that the entire range of random variate is adequately covered and reduces the number of replications required to obtain a representative sample, Monte Carlo sampling is easier than using Latin Hypercube. Also fixed initial random number seed is utilized in order to reduce the variance between the simulation runs of each option and to have more control on the simulation runs.

MCS is applied to the practical business application in three phases. The first phase involves scenarios generated by using random values for each one of the input variables indicated in Table 5.7. Since there is no historical data for the input variables utilized in Section 5.2.6, parameters such as mean, standard deviation, and optimistic and pessimistic estimates are provided based on management's judgment. The second phase assumes that the additional floor space generated by each option is fully utilized and the associated demand generates free cash flows that are directly proportional to the historical cash flows generated by the existing manufacturing floor space. The third phase involves the additional free cash flows that can potentially be generated by the new business associated with the additional floor space, which is contributed by each respective option under the impact of the two major sources of uncertainty mentioned in Section 3.3:

- The volatility of the OEM demand.
- The corporate marketing performance that realizes as additional business volume, i.e., additional market share.

5.3.1 First Phase

The probability distribution and the associated parameters for each input variable are provided based on management's judgment. Table 5.11 summarizes the probability distribution and the associated parameters for each input variable utilized in the DCF analysis of each option.

Table 5.11 Input Variable Distribution Summary

Input	Probability Distribution	Variation from the Base-Case
WACC	Triangular (Most likely value is 7%)	6% to 12%
Labor Cost Savings	Uniform	± 10%
Inventory Holding Cost Savings	Uniform	± 30%
O & M Cost Savings	Uniform	± 10%
Labor Costs	Uniform	± 10%
3PL & Transportation Costs	Normal N(600,60)	± 25%
O & M Costs	Uniform	± 10%

The MCS analysis results for the NPV are indicated in Table 5.12 below, which presents all of the implementation start time combinations of each option. The results are in parallel with the results of the DCF techniques used in the former sections. Option-1 is still the best course of action by investing in Alternative-1 and Alternative-3 at Year 0. The reason that the mean NPV for each option and its associated combinations is relatively less than the NPV calculated using DCF techniques is the combined stochastic behavior of the input variables.

Table 5.12 Phase-1 MCS Analysis

Option	Generated Floor Space (in sq. ft.)	Implementation Start Time Combination	Mean NPV	Standard Deviation	Mean NPV per sq. ft.
Option-1	50,000	1030	**$1,278,744.47**	**$196,947.52**	**$25.57**
		1031	$1,274,207.83	$189,823.38	$25.48
		1032	$1,268,898.65	$190,985.59	$25.38
		1033	$1,263,615.89	$188,105.70	$25.27
		1130	$1,190,539.33	$195,239.25	$23.81
		1131	$1,186,069.67	$190,453.77	$23.72
		1132	$1,181,138.87	$188,025.11	$23.62
		1133	$1,170,323.13	$187,095.88	$23.41
Option-2	65,000	1040	$840,004.69	$178,615.40	$12.92
		1041	$866,848.96	$173,562.87	$13.34
		1042	$891,501.95	$167,731.41	$13.72
		1043	**$914,277.30**	**$165,040.37**	**$14.07**
		1140	$750,364.99	$178,062.60	$11.54
		1141	$777,210.17	$172,248.46	$11.96
		1142	$801,924.56	$167,524.02	$12.34
		1143	$824,634.00	$162,947.12	$12.69
Option-3	55,000	2030	**$662,711.55**	**$160,243.76**	**$12.05**
		2031	$656,016.92	$157,494.88	$11.93
		2032	$649,729.91	$156,063.64	$11.81
		2033	$643,926.75	$153,928.84	$11.71
		2130	$619,664.47	$153,050.62	$11.27
		2131	$612,953.13	$154,268.41	$11.14
		2132	$606,662.01	$149,630.15	$11.03
		2133	$600,844.26	$147,682.88	$10.92
Option-4	70,000	2040	$222,484.26	$149,964.95	$3.18
		2041	$249,285.38	$146,558.56	$3.56
		2042	$273,998.84	$142,496.50	$3.91
		2043	**$296,773.80**	**$140,336.69**	**$4.24**
		2141	$179,328.81	$142,336.29	$2.56
		2142	$206,208.63	$138,805.50	$2.95
		2143	$230,887.43	$135,012.43	$3.30
		2144	$253,730.18	$134,038.69	$3.62

The detailed graphical results for Option-1 are represented in Figure 5.5 and Figure 5.6 in the form of a probability density function and cumulative distribution function respectively. The probability of Option-1 the NPV being negative is .0. Therefore it is considered as a risk-free option for Plant I management.

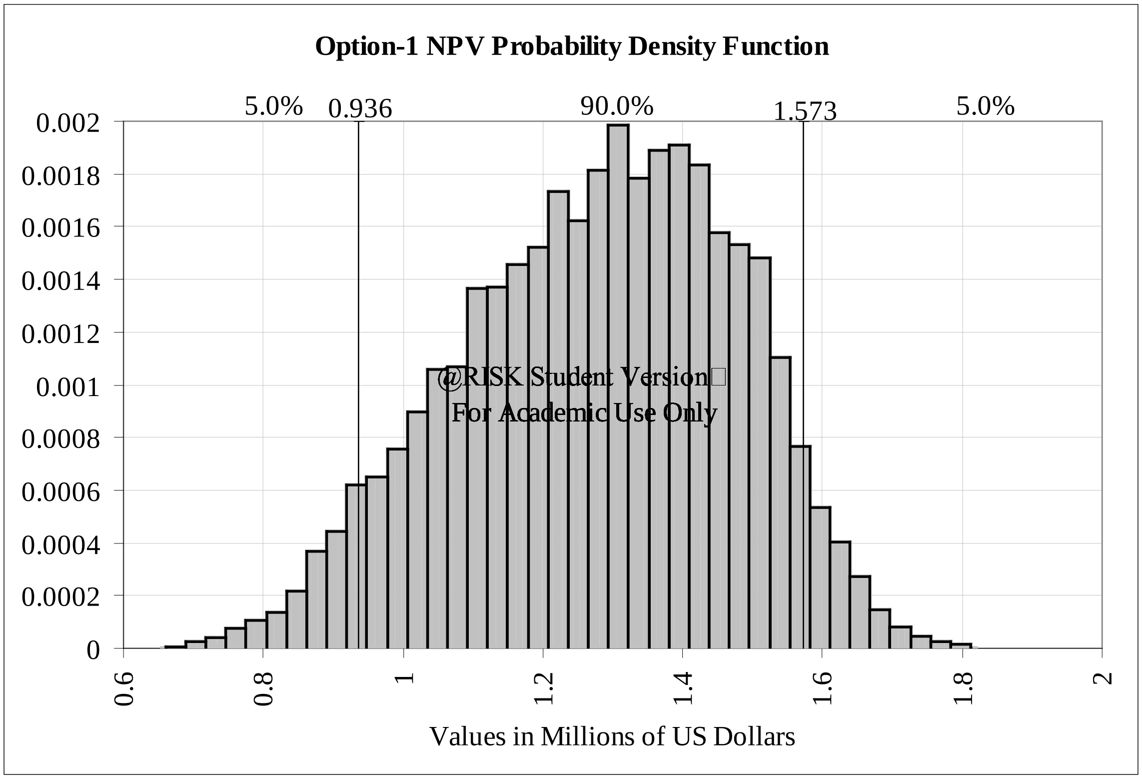

Figure 5.5 Option-1 NPV Probability Density Function

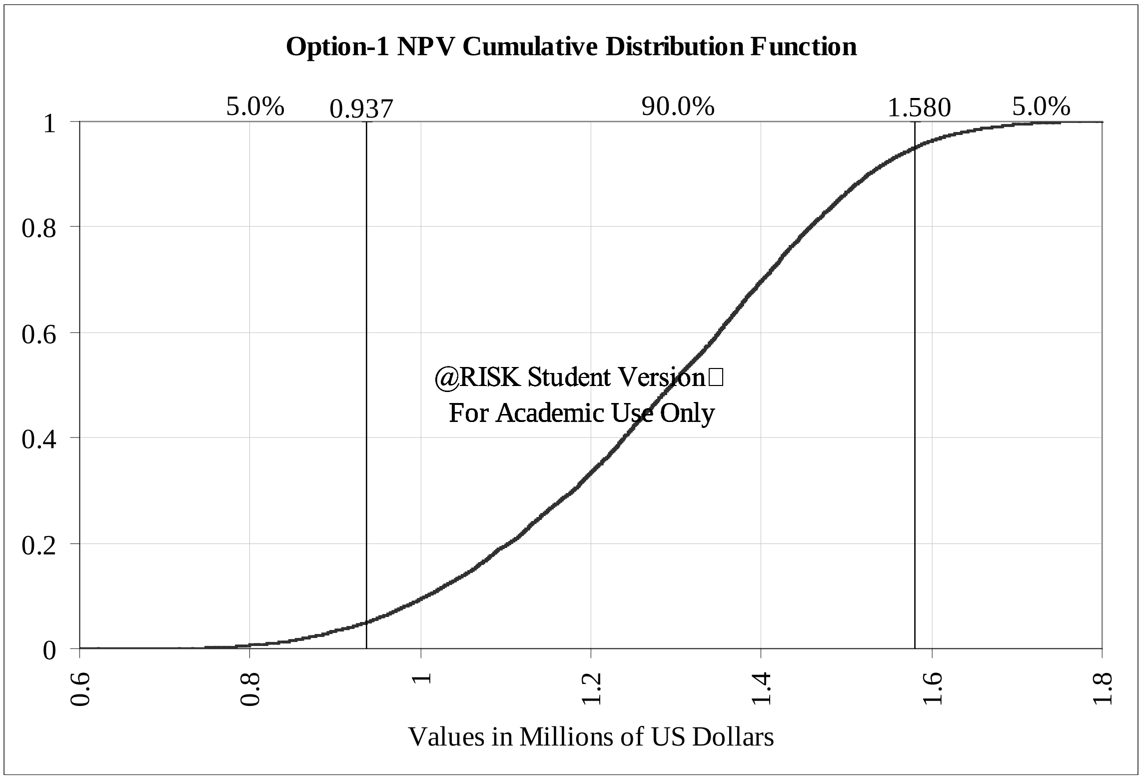

Figure 5.6 Option-1 NPV Cumulative Distribution Function

5.3.2 Second Phase

It is assumed that the additional floor space contributed by each option is fully utilized and the associated demand generates free cash flows that are directly proportional to the historical cash flows generated by the existing manufacturing floor space. In other words, the second phase can be considered as the best case MCS analysis, where additional floor space is fully utilized. The aforementioned strong assumption requires the following data:

- The historical data including the automotive electronics demand of the OEM's, Plant I revenues, and associated cash outflows.

- The capital investment amount required in order to productively utilize each additional floor space option.

The distribution into which the historical data are fit is investigated using two different statistical software packages: BestFit 4.5 and Minitab 15. The Anderson-Darling statistic is utilized to measure how well the data follow a particular distribution and to compare the fit of several distributions to see which one is the best or to test whether a sample of data comes from a population with a specified distribution. The better the distribution fits the data, the smaller this statistic will be. The primary purpose of using the Anderson-Darling statistic is to verify whether the data meets the assumption of normality for hypothesis testing.

The hypotheses for the Anderson-Darling test are

H_0: The data follow a specified distribution

H_1: The data do not follow a specified distribution

If the p-value for the Anderson-Darling test is available and lower than the chosen significance level, then it can be concluded that the data do not follow the specified distribution. Minitab 15 does not always display a p-value for the Anderson-Darling test because it does not mathematically exist for certain cases. It should be noted that, in order to determine which distribution the data follow when using multiple Anderson-Darling statistics, it is generally correct to compare them. The distribution with the smallest Anderson-Darling statistic has the closest fit to the data. If distributions have similar Anderson-Darling statistics, then the one based on practical knowledge must be chosen. The results of the test conducted for the Plant I monthly demand are indicated in the following Table 5.13.

Table 5.13 Fitted Distributions for Plant I Monthly Demand

Distribution	Anderson-Darling Statistic	P-Value
Logistic	0.7507	0.027
Normal	0.7083	0.065
Triangular	0.4598	N/A
Uniform	0.7895	N/A
Weibull	0.6053	0.090

Although the Plant I monthly demand data fit best with Triangular (930292,1800232,2059000) distribution, the normality assumption is utilized in order to be able to perform parametric statistical tests and for statistical tractability considerations. Hence, the Plant I monthly demand is concluded to fit with Normal (1577178,264406) distribution through the aforementioned Anderson-Darling test. The graphical results of the aforementioned distribution are represented in the following Figure 5.7.

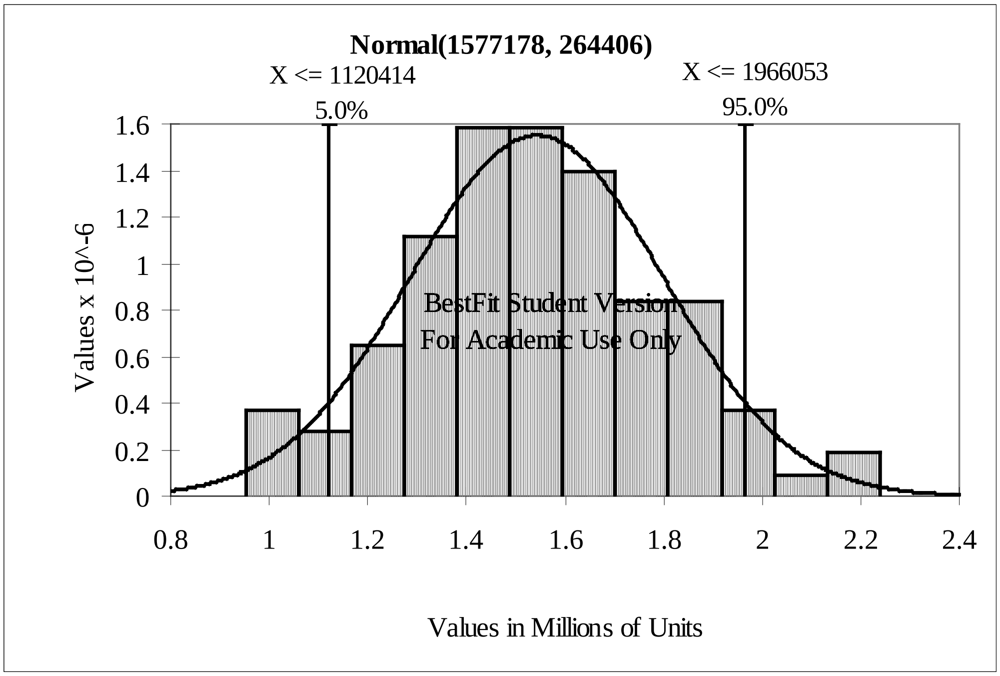

Figure 5.7 Plant I Monthly Demand Distribution

Although the Plant I monthly revenues fit best with Logistic (87523893,9173440) distribution, the normality assumption is utilized in order to be able to perform parametric statistical tests and for statistical tractability considerations. Hence, the Plant I monthly revenues are concluded to fit with Normal (87618597,16523385) distribution through the aforementioned Anderson-Darling test. The tabular and graphical results of the conducted test are indicated in the following Table 5.14 and Figure 5.8, respectively.

Table 5.14 Fitted Distributions for Plant I Monthly Revenues

Distribution	Anderson-Darling Statistic	P-Value
Beta General	0.1999	N/A
Logistic	0.1640	>0.250
Normal	0.1900	0.890
Triangular	0.3192	N/A
Weibull	0.2980	>0.250

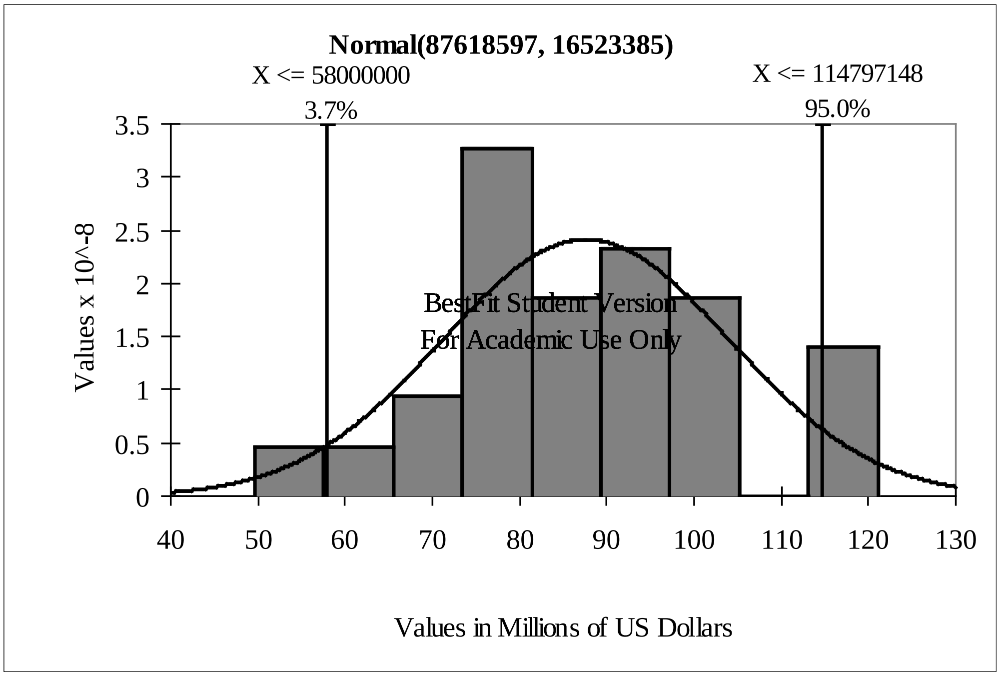

Figure 5.8 Monthly Plant I Revenue Distribution

Monthly demand and revenue distributions are converted to annual distributions to be able to replicate the simulation effort presented in the previous section. Hence annual demand and revenue distributions are estimated as Normal (18926136,915929.25) and Normal (1051423164,57238684.7), respectively. The demand and revenue estimations for each option are presented in the following Table 5.15 and Table 5.16.

Table 5.15 Annual Demand Estimation with Direct Proportionality

Floor Space (In Thousands of sq. ft.)	Demand (In Units)
225	Normal (18926136,915929.25)
5 (Alternative-1)	Normal (420580.8,20353.98)
10 (Alternative-2)	Normal (841161.6,40707.96)
45 (Alternative-3)	Normal (3785227.2,183185.82)
60 (Alternative-4)	Normal (5046969.6,244247.76)
50 (Option-1)	Normal (4205808,203539.83)
65 (Option-2)	Normal (5467550.4,264601.783)
55 (Option-3)	Normal (4626388.8,223893.817)
70 (Option-4)	Normal (5888131.2,284955.76)

Table 5.16 Annual Revenue Estimation with Direct Proportionality

Floor Space (In Thousands of sq. ft.)	Revenue (In US Dollars)
225	Normal (1051423164,57238684.7)
5 (Alternative-1)	Normal (23364959.2,1271970.771)
10 (Alternative-2)	Normal (46729918.4,2543941.542)
45 (Alternative-3)	Normal (210284632.8,11447736.94)
60 (Alternative-4)	Normal (280379510.4,15263649.25)
50 (Option-1)	Normal (233649592,12719707.71)
65 (Option-2)	Normal (303744469.6,16535620.02)
55 (Option-3)	Normal (257014551.2,13991678.48)
70 (Option-4)	Normal (327109428.8,17807590.8)

The distribution of the capital investment amount required to productively utilize each floor space option is estimated by Plant I management. The aforementioned distribution is specified as PERT distribution, which is a special form of a scaled Beta distribution. It is a pragmatic and readily understandable distribution.

It can generally be considered as superior to the Triangular distribution when the parameters result in a skewed distribution, as the smooth shape of the curve places less emphasis in the direction of the skew. Hence capturing tail or extreme events increases the emphasis in the direction of the skew. PERT distribution is considered to be more suited to model the capital investment. Table 5.17 below indicates the capital investment distribution for each floor space alternative and option.

Table 5.17 Distributions of the Required Capital Investment

Floor Space (In Thousands of sq. ft.)	Capital Investment (US Dollars)
5 (Alternative-1)	PERT (5000000,7000000,10000000)
10 (Alternative-2)	PERT (10000000,14000000,20000000)
45 (Alternative-3)	PERT (75000000,120000000,150000000)
60 (Alternative-4)	PERT (100000000,160000000,200000000)
50 (Option-1)	PERT (80000000,127000000,160000000)
65 (Option-2)	PERT (105000000,167000000,210000000)
55 (Option-3)	PERT (85000000,134000000,170000000)
70 (Option-4)	PERT (110000000,174000000,220000000)

Although the salvage value of the storage and material handling equipment utilized for each decision alternative is assumed negligible, capital equipment used for value-adding purposes is assumed to have a salvage that is equivalent to 10 percent of its associated initial investment amount.

The MCS analysis results for the NPV are indicated in Table 5.18 below for all of the implementation start time combinations of each option. The results reveal that the full utilization of the additional floor space leads Plant I management to pick Option-4 as the best course of action by investing in Alternative-2 and Alternative-4 at Year 0, while delaying Alternative-4 by one year can be considered as the second best course of action.

It is very intuitive that the value of the generated floor space significantly increases by when utilized it for value-adding purposes.

Table 5.18 Phase-2 MCS Analysis

Option	**Generated Floor Space (in sq. ft.)**	**Implementation Start Time Combination**	**Mean NPV**	**Standard Deviation**	**Mean NPV per sq. ft.**
Option-1	50,000	1030	**$56,046,933**	**$20,549,318**	**$1,121**
		1031	$52,385,389	$18,971,941	$1,048
		1032	$48,998,115	$17,425,771	$980
		1033	$45,880,170	$16,196,346	$918
		1130	$55,469,776	$20,032,884	$1,109
		1131	$51,800,227	$19,192,760	$1,036
		1132	$48,437,621	$17,748,640	$969
		1133	$45,312,213	$16,527,359	$906
Option-2	65,000	1040	**$71,741,674**	**$26,840,510**	**$1,104**
		1041	$66,924,890	$24,661,410	$1,030
		1042	$62,424,039	$23,024,597	$960
		1043	$58,291,138	$21,077,303	$897
		1140	$71,161,885	$26,425,955	$1,095
		1141	$66,335,786	$24,961,521	$1,020
		1142	$61,839,682	$23,018,182	$951
		1143	$57,754,165	$21,502,648	$888
Option-3	55,000	2030	**$61,757,833**	**$22,556,165**	**$1,123**
		2031	$58,065,949	$20,800,446	$1,056
		2032	$54,714,175	$18,838,594	$995
		2033	$51,591,286	$17,125,022	$938
		2130	$60,738,487	$21,658,883	$1,104
		2131	$57,079,874	$21,048,928	$1,038
		2132	$53,710,745	$19,281,875	$977
		2133	$50,557,879	$17,624,876	$919
Option-4	70,000	2040	**$77,460,233**	**$28,605,133**	**$1,107**
		2041	$72,636,938	$26,637,473	$1,038
		2042	$68,140,403	$24,067,039	$973
		2043	$63,990,098	$22,270,709	$914
		2140	$76,028,124	$27,723,528	$1,086
		2141	$71,613,985	$27,052,597	$1,023
		2142	$67,148,002	$24,481,239	$959
		2143	$62,992,094	$22,484,083	$900

The detailed graphical results for Option-4 are represented in Figure 5.9 and Figure 5.10 in the form of a probability density function and cumulative distribution function, respectively. The probability of the Option-4 NPV being negative is .003. Therefore it is considered as an attractive option for Plant I management due to the risk associated with it.

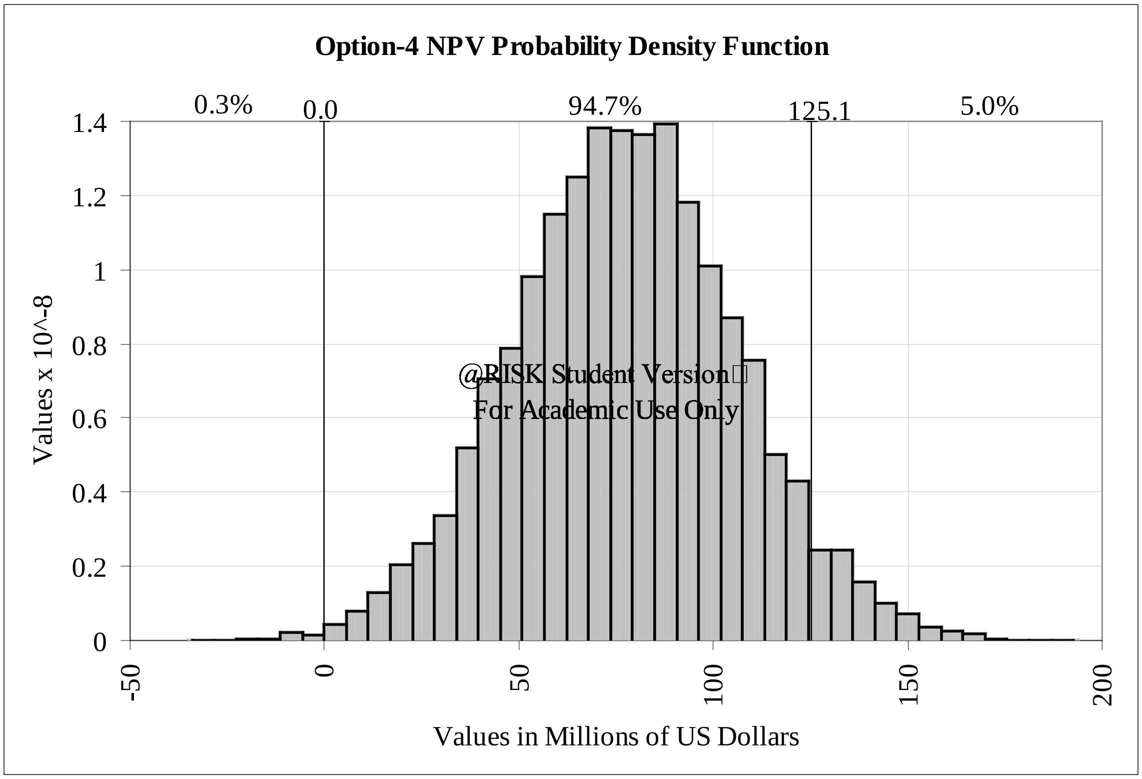

Figure 5.9 Option-4 NPV Probability Density Function

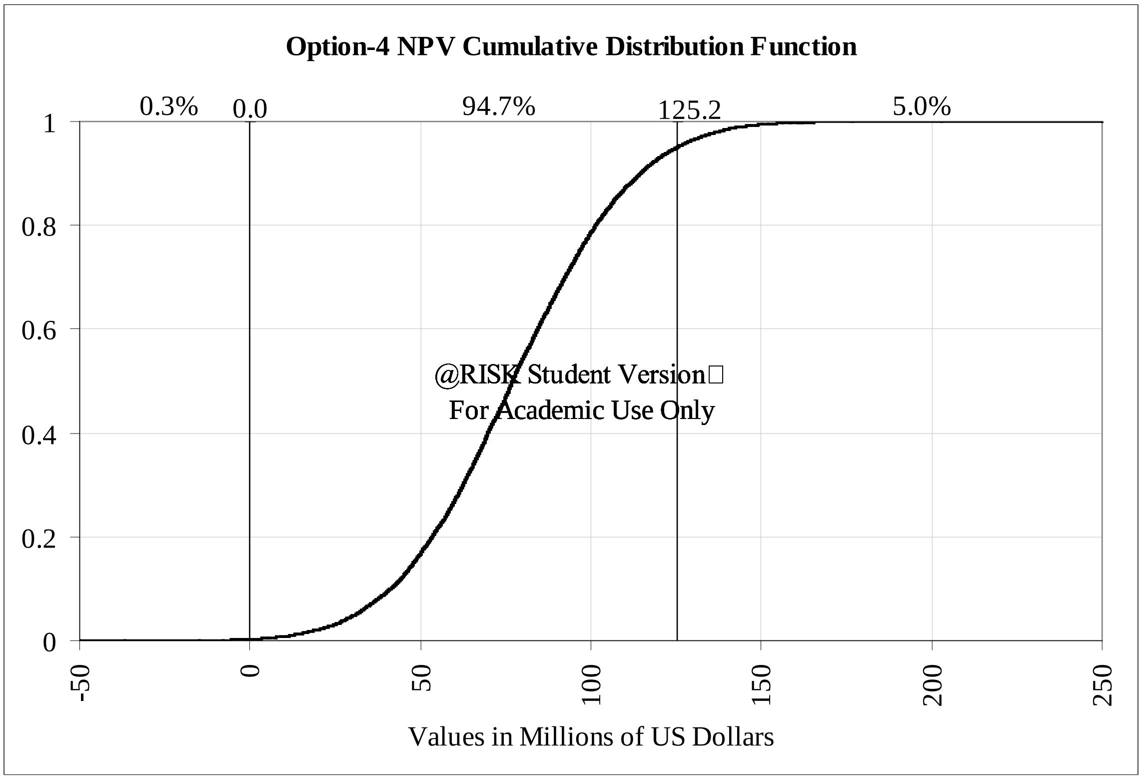

Figure 5.10 Option-4 NPV Cumulative Distribution Function

5.3.3. Third Phase

Since the demand for automotive OEM's is volatile and the corporate marketing performance is variable, Plant I management is expecting a fluctuating automotive electronics demand pattern for the five-year planning horizon. Since Plant I is serving NAFTA automotive OEM's, they use historical demand data to estimate the NAFTA automotive electronics sales. The annual demand distribution for automotive electronics products in NAFTA region that are not manufactured by Plant I is estimated as Normal (171769069,6952221) in number of units. Plant I management is estimating the corporate marketing performance in terms of the additional market share distribution for Plant I as PERT (1%,2%,5%).

Hence the average additional business volume in number of units and average additional revenue in US dollars for Plant I are estimated to be distributed as Normal (4007944.94,162218.49) and Normal (222686883.05,10137434.74), respectively. However, not every alternative and not every option is capable of meeting the aforementioned demand. Thus the additional revenue that can be generated by each alternative and each option is calculated using their associated demand meeting probabilities and then represented in Table 5.19 below.

Table 5.19 Revenue Distributions for Additional Market Share

Floor Space (In Thousands of sq. ft.)	Mean	Standard Deviation
5 (Alternative-1)	$23,364,959.20	$1,271,970.77
10 (Alternative-2)	$46,729,918.40	$2,543,941.54
45 (Alternative-3)	$152,969,148.62	$6,962,390.18
60 (Alternative-4)	$206,000,532.26	$9,376,113.39
50 (Option-1)	$174,363,829.42	$7,937,611.40
65 (Option-2)	$215,048,722.96	$9,789,720.73
55 (Option-3)	$193,334,230.32	$8,803,348.33
70 (Option-4)	$219,373,740.32	$9,990,441.94

The MCS analysis results for the NPV are indicated in Table 5.20 below for all of the implementation start time combinations of each option using the revenue distributions indicated in Table 5.19. The results reveal that the full utilization of the additional floor space encourages Plant I management to pick Option-4 as the best course of action by investing in Alternative-2 at Year 1 and Alternative-4 at Year 0, while Option-2 is considered as the second best course of action by investing in Alternative-1 at Year 1 and Alternative-4 at Year 0.

Table 5.20 Phase-3 MCS Analysis

Option	Generated Floor Space in sq. ft.	Implementation Start Time Combination	Mean NPV	Standard Deviation	Mean NPV per sq. ft.
Option-1	50,000	1030	**$35,039,738**	**$22,763,463**	**$701**
		1031	$33,030,016	$20,849,567	$661
		1032	$31,168,912	$18,990,327	$623
		1033	$29,467,615	$17,155,507	$589
		1130	$34,539,794	$22,171,267	$691
		1131	$32,414,520	$21,227,519	$648
		1132	$30,594,430	$19,344,003	$612
		1133	$28,832,263	$17,520,711	$576
Option-2	65,000	1040	$42,915,520	$29,440,298	$660
		1041	$40,969,968	$26,766,391	$630
		1042	$39,204,587	$24,982,108	$603
		1043	$37,590,731	$22,785,665	$578
		1140	**$43,369,219**	**$28,872,918**	**$667**
		1141	$39,708,758	$27,110,446	$611
		1142	$37,914,521	$25,009,103	$583
		1143	$36,291,364	$23,146,027	$558
Option-3	55,000	2030	**$40,549,984**	**$25,350,016**	**$737**
		2031	$38,755,125	$23,065,785	$704
		2032	$36,990,148	$20,811,394	$672
		2033	$35,397,437	$18,657,814	$644
		2130	$39,862,193	$24,522,684	$725
		2131	$37,655,337	$24,016,822	$685
		2132	$35,851,063	$21,572,734	$652
		2133	$34,267,364	$19,287,375	$623
Option-4	70,000	2040	$42,423,074	$29,786,091	$606
		2041	$41,968,813	$27,156,999	$600
		2042	$41,537,244	$25,103,356	$593
		2043	$41,141,104	$23,309,210	$588
		2140	**$44,061,720**	**$29,492,982**	**$629**
		2141	$39,244,253	$27,385,026	$561
		2142	$38,878,737	$25,562,328	$555
		2143	$38,442,482	$23,415,930	$549

The detailed graphical results for Option-4 are represented in Figure 5.11 and Figure 5.12 in the form of a probability density function and cumulative distribution function, respectively. The probability of the Option-4 NPV being negative is .031.

Therefore it is considered as a slightly risky option for Plant I management due to the risk associated with it.

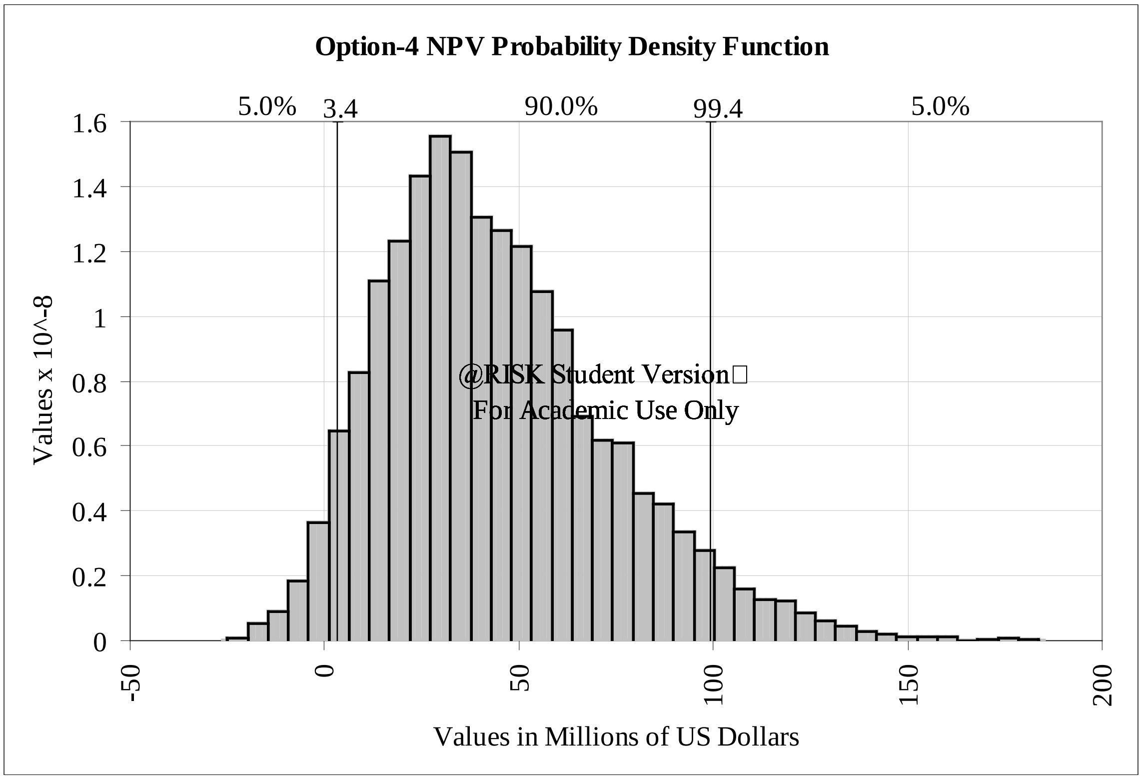

Figure 5.11 Option-4 NPV Probability Density Function

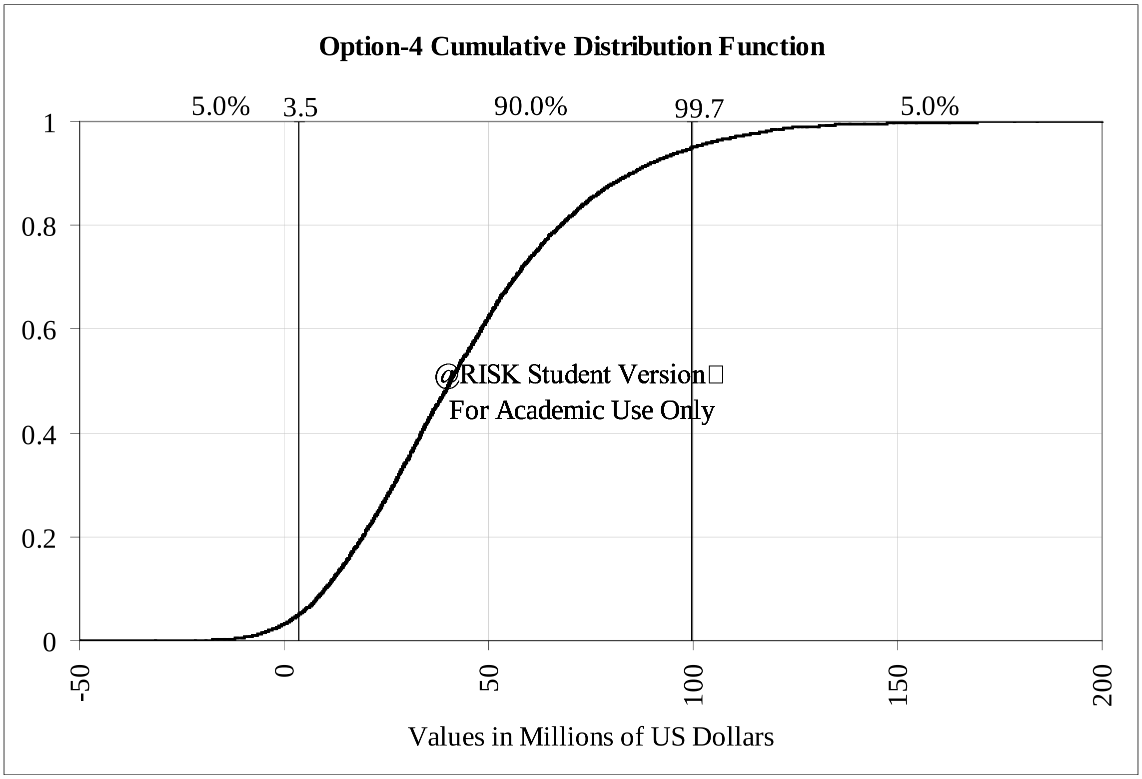

Figure 5.12 Option-2 NPV Cumulative Distribution Function

5.4 Decision-Tree Analysis

Plant I management estimates the probabilities of low, high, and medium marketing performance levels as 55 percent, 5 percent, and 40 percent, respectively, due to increasing oil prices and therefore expected future decrease in automotive OEM sales. The corresponding revenues that are generated by each alternative and option are indicated in the following Table 5.21, Table 5.22, and Table 5.23.

Table 5.21 Revenue Distributions for Low Marketing Performance

Floor Space (In Thousands of sq. ft).	Mean	Standard Deviation
5 (Alternative-1)	$23,364,959.20	$1,271,970.77
10 (Alternative-2)	$46,729,918.40	$2,543,941.54
45 (Alternative-3)	$95,424,734.23	$4,344,614.89
60 (Alternative-4)	$95,424,734.23	$4,344,614.89
50 (Option-1)	$95,424,734.23	$4,344,614.89
65 (Option-2)	$95,424,734.23	$4,344,614.89
55 (Option-3)	$95,424,734.23	$4,344,614.89
70 (Option-4)	$95,424,734.23	$4,344,614.89

Table 5.22 Revenue Distributions for Medium Marketing Performance

Floor Space (In Thousands of sq. ft.)	Mean	Standard Deviation
5 (Alternative-1)	$23,364,959.20	$1,271,970.77
10 (Alternative-2)	$46,729,918.40	$2,543,941.54
45 (Alternative-3)	$190,849,214.87	$8,689,229.78
60 (Alternative-4)	$190,849,214.87	$8,689,229.78
50 (Option-1)	$190,849,214.87	$8,689,229.78
65 (Option-2)	$190,849,214.87	$8,689,229.78
55 (Option-3)	$190,849,214.87	$8,689,229.78
70 (Option-4)	$190,849,214.87	$8,689,229.78

Table 5.23 Revenue Distributions for High Marketing Performance

Floor Space (In Thousands of sq. ft.)	Mean	Standard Deviation
5 (Alternative-1)	$23,364,959.20	$1,271,970.77
10 (Alternative-2)	$46,729,918.40	$2,543,941.54
45 (Alternative-3)	$210,284,632.80	$11,447,736.94
60 (Alternative-4)	$280,379,510.40	$15,263,649.25
50 (Option-1)	$233,649,592.00	$12,719,707.71
65 (Option-2)	$303,744,469.60	$16,535,620.02
55 (Option-3)	$257,014,551.20	$13,991,678.48
70 (Option-4)	$327,109,428.80	$17,807,590.80

The decision tree consists of four tiers, and the tier structure for the action nodes is represented in Figure 5.13 below.

All three branches of the chance nodes, which represent low, high, and medium marketing performance levels with 55 percent, 5 percent, and 40 percent probability, respectively, are located at the origin of each branch stemming from the action nodes called "Group-1 Alternatives" and "Options".

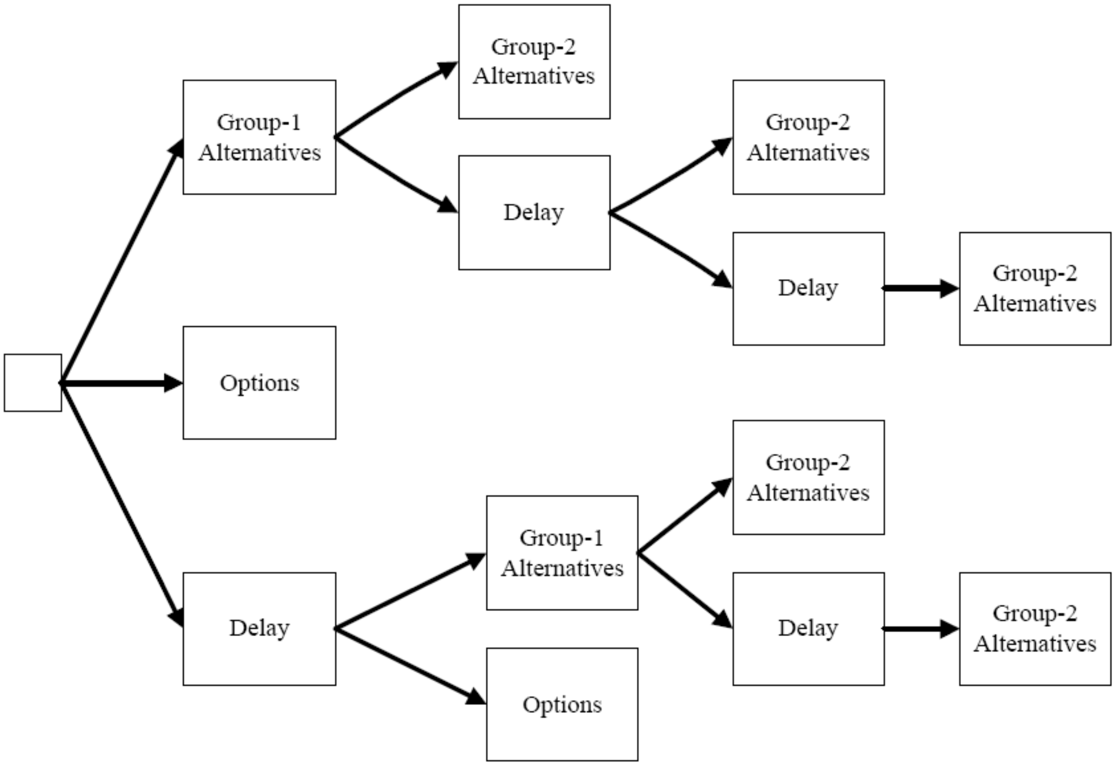

Figure 5.13 Action Node Structure for DTA

Precision Tree 1.0 for MS Excel is used to make the DTA as described above, which, together with the simulated cash flow inputs and the suggested policy, is indicated in Figure 5.14 below.

The recommended solution for Plant I management is to pick Alternative-3 at Year 0 for all marketing performance levels, Alternative-2 at Year 1 in case the marketing performance turns out to be high, and Alternative-1 at Year 1 in case the marketing performance turns out to be low and medium. The mean and the standard deviation of the NPV that is calculated through DTA are $28,225,882 and $12,854,312, respectively, utilizing the average WACC of 8.33 percent. The floor space value per square foot for each branch of the chance node is calculated as $1,103.97, $868.06, and $257.08 for high, medium, and low marketing performance levels, respectively, where the weighted average floor space value per square foot is calculated as $543.81.

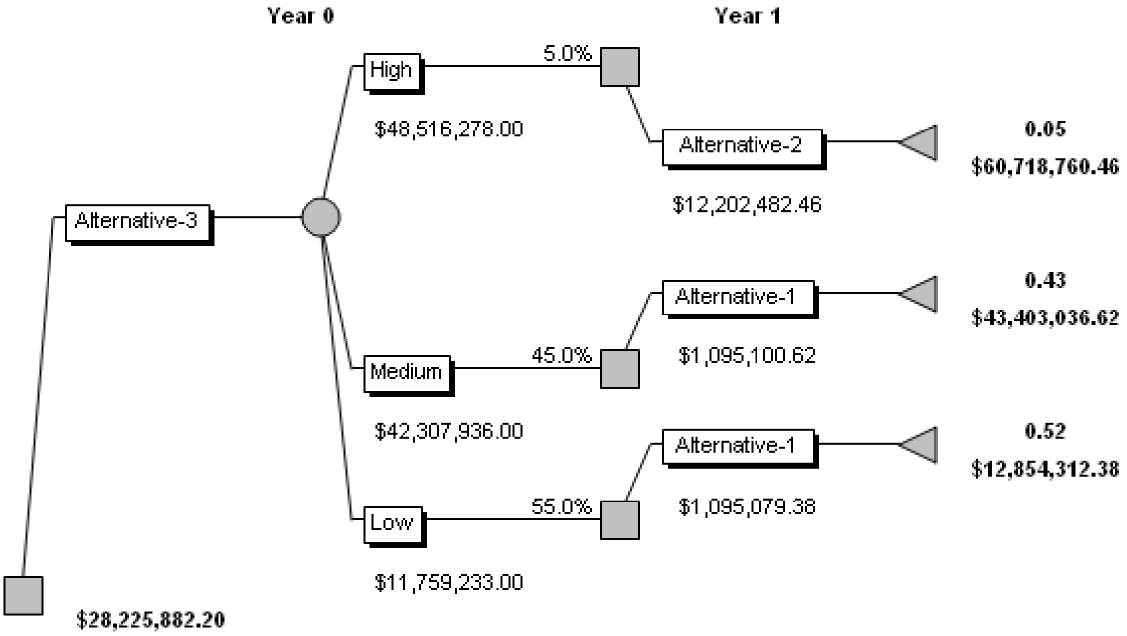

Figure 5.14 Decision-Tree Diagram of the Suggested Policy

Since there is no consensus in the financial community on what is the most appropriate discount rate utilized inside the decision tree and since it is not clear whether it is the private risk that dominates the cash flows inside the decision tree, DTA is replicated using a risk-free rate of 5 percent. The mean and the standard deviation of the NPV that is calculated through DTA are $28,277,438 and $12,889,077, respectively, where the suggested policy scheme is the same as depicted in Figure 5.14 above. The floor space value per square foot for each branch of the chance node is calculated as $1,111.02, $868.75, and $257.78 for high, medium, and low marketing performance levels, respectively, where the weighted average floor space value per square foot is calculated as $544.83.

5.5 Real Options Analysis

Since the Black and Scholes equation promotes a black box approach, where the mathematical complexity might risk the management buy-in and since it does not allow more than one strike price, which does not conform to this practical business application, a binomial lattice approach is utilized. The main advantage of the binomial lattice model over the Black and Scholes equation is the transparency and simplicity of the underlying framework, although the calculated option value is a close approximation to the one calculated through the Black and Scholes equation.

A six-step process described in Kodukula and Papudesu (2006) is used to perform the analysis, where the steps are

- Frame the application
- Identify the input parameters

- Calculate the option parameters
- Build the binomial tree and calculate the asset values at each node of the tree
- Calculate the option values at each node of the tree by backward induction
- Analyze the results

The challenge in the real options analysis is the identification of such parameters as the underlying asset value and the volatility of the underlying asset value. As mentioned in the previous chapter, there are two sources of volatility pertaining to this practical business application:

- The volatility of the OEM demand interpreted as the market risk
- The corporate marketing performance interpreted as the private risk

This practical business application consists of multiple options combined in a parallel compound option structure since the Group-2 alternatives can be implemented simultaneously or after the Group-1 alternatives, where the option life for Group-2 is longer than Group-1. The options consist of all possible implementation start time combinations of the Group-1 alternatives (Alternative-1 and Alternative-2) with the Group-2 alternatives (Alternative-3 and Alternative-4):

- Alternative-1 with manufacturing equipment: Introduce a new mini-load AS/RS, expand floor space by 5,000 sq. ft., and use capital equipment for manufacturing.
- Alternative-1 without manufacturing equipment: Introduce a new mini-load AS/RS and expand floor space by 5,000 sq. ft. without using any capital equipment for manufacturing.

- Alternative-2 with manufacturing equipment: Deploy J.I.T. deliveries, expand floor space by 10,000 sq. ft., and use capital equipment for manufacturing.
- Alternative-2 without manufacturing equipment: Deploy J.I.T. deliveries and expand floor space by 10,000 sq. ft. without using any capital equipment for manufacturing.
- Alternative-3 with manufacturing equipment: Replace AGV control software, retrofit mechanical AGV components, expand floor space by 45,000 sq. ft., and use capital equipment for manufacturing.
- Alternative-3 without manufacturing equipment: Replace AGV control software, retrofit mechanical AGV components, expand floor space by 45,000 sq. ft. without using capital equipment for manufacturing.
- Alternative-4 with manufacturing equipment: Utilize water spiders, expand floor space by 60,000 sq. ft., and use capital equipment for manufacturing.
- Alternative-4 without manufacturing equipment: Utilize water spiders and expand floor space by 60,000 sq. ft. without using capital equipment for manufacturing.

In order to be able to reduce the complexity of the model, the private risk is incorporated in the form of a decision-tree model as represented in Figure 5.15 below.

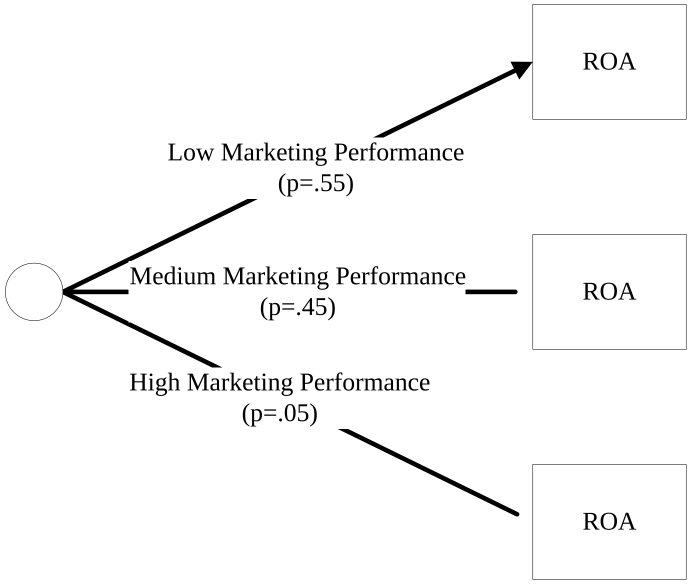

Figure 5.15 ROA Model Framework

The underlying asset value for this practical business application is estimated as the NPV of all the revenue streams for every level of the marketing performance, regardless of the capability of each option to meet the demand. The logic behind the aforementioned setting is a simple analogy: The additional revenue for each marketing performance level can be compared to an oil reserve under the ground waiting to be extracted. The amount and the value of the extracted oil depend on the magnitude of the extraction investment and hence the quality of the corresponding extraction equipment in addition to all other market variables.

Thus, the underlying asset value for low, medium, and high marketing performance levels at Year 0 is defined as $375,049,491.55, $750,098,955.39, and $1,875,247,588.60, respectively.

The option life is given as two and four years for Group-1 and Group-2 options, respectively, where the exercise price for each level of the marketing performance is estimated by the following equation:

$$X_i = \text{NPV Revenues}_{\text{j}} - \text{NPV Free Cash Flows of the Option}_{\text{i}} \qquad \textbf{(5.1)},$$

where i = Alternative-1 and Alternative-2 with and without manufacturing equipment for Group-1 and Alternative-3 and Alternative-4 with and without manufacturing equipment for Group-2 and j = low, medium, and high marketing performance levels.

The volatility is estimated through the logarithmic cash flow returns method by utilizing numerous simulated cash flow profiles (Kodukula and Papudesu, 2006). The method consists of calculating the relative returns of each interval starting with the second period by dividing the current cash flow (CF_t) by the preceding one (CF_{t-1}), which is described in the following equation.

$$R_t = \frac{CF_t}{CF_{t-1}} \qquad \textbf{(5.2)}$$

Then the standard deviation of the natural logarithms of the relative returns (R_t) becomes the volatility factor of the underlying revenue streams that is estimated by the following equation 5.3 (Kodukula and Papudesu, 2006). The resulting volatility is estimated as 6.45 percent.

$$\sigma = \sqrt{\frac{\sum_{t=1}^{n}\left(\ln R_t - \frac{\sum_{t=1}^{n}\ln R_t}{n}\right)^2}{n-1}} \qquad \textbf{(5.3)}$$

The risk-neutral probability approach is used instead of the replicating portfolio approach due to its mathematical convenience in terms of adjusting the cash flows so that they may be discounted at a risk-free rate. It is also difficult to find a twin security with perfectly correlated cash flows. Thus the discount rate becomes consistent and stays constant along the lattice. The up and down movement factors are calculated as 1.066 and 0.937 using the following equations 5.4 and 5.5, respectively, where $\delta \text{t} = 1$.

$$u = \exp\left(\sigma\sqrt{\delta \text{t}}\right) \qquad \textbf{(5.4)}$$

$$d = 1/u \qquad \textbf{(5.5)}$$

The risk-neutral probability, p, is calculated as 88.1 percent through the following equation 5.6, where r is the risk-free interest rate defined as 5 percent:

$$p = \frac{\exp(r\delta \text{t}) - d}{u - d} \qquad \textbf{(5.6)}$$

The asset values for the longest option group, which, in this case, becomes Group-2, are calculated at each node of the lattice over the life of the option starting with the underlying asset value (S_0). The underlying asset value at time 0 is multiplied by the up and down movement factors *u* and *d*, respectively, for the next year. Then the binomial underlying asset valuation lattice is completed by moving right and continuing in the same fashion for every node until the last time step. The option values are then calculated by backward induction for the longest option starting from the rightmost nodes. The discounting between time intervals is performed by utilizing the risk neutral probabilities and the continuous risk-free interest rate. The binomial option valuation lattice of the longest option becomes the underlying asset valuation tree of the shortest option group, which, in this case, becomes Group-1.

The process described above is replicated for the Group-1 options, as well. The aforementioned binomial lattice logic is represented in the following Figure 5.16 and the corresponding equations 5.7 through 5.16.

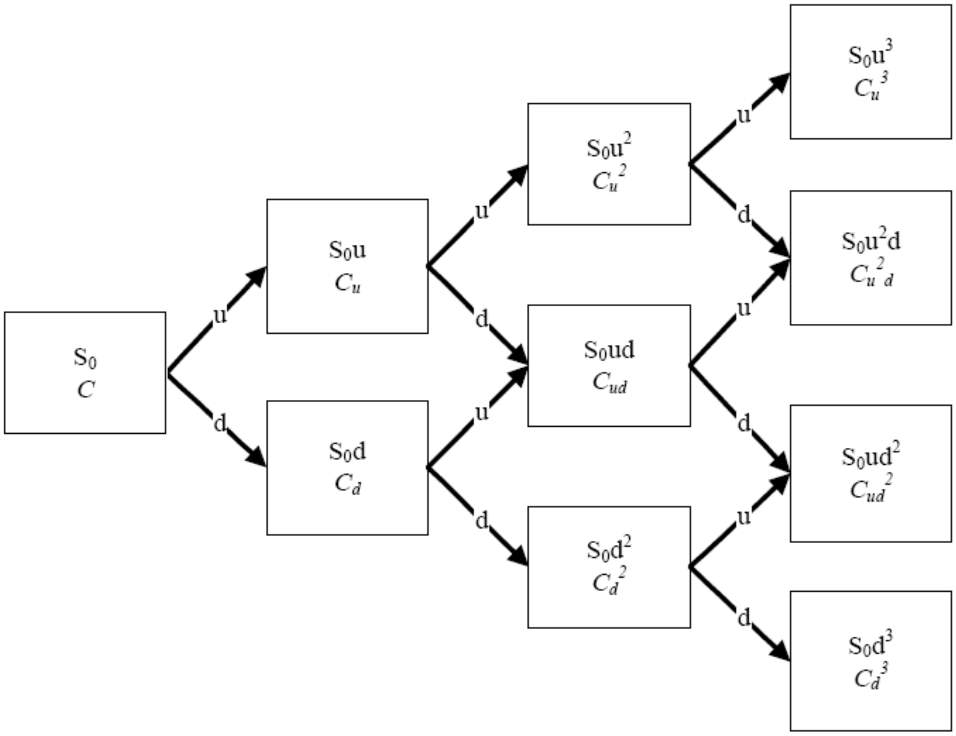

Figure 5.16 Binomial Lattice Logic

$$C_u{}^3=\text{Max}[S_0u^3-X_i,\ I_k]\ \textbf{(5.7)}$$

$$C_u{}^2{}_d=\text{Max}[S_0u^2d-X_i,\ I_k] \qquad \textbf{(5.8)}$$

$$C_{ud}{}^2=\text{Max}[S_0ud^2-X_i,\ I_k] \qquad \textbf{(5.9)}$$

$$C_d{}^3=\text{Max}[S_0d^3-X_i,\ I_k] \qquad \textbf{(5.10)}$$

$$C_u{}^2=\text{Max}[S_0u^2-X_i,\ ((p*\ C_u{}^3)+(1-p)*\ C_u{}^2{}_d)*e^{-r\delta t},\ I_k]\ \textbf{(5.11)}$$

$$C_{ud}=\text{Max}[S_0ud-X_i,\ ((p*\ C_u{}^2{}_d)+(1-p)*\ C_{ud}{}^2)*e^{-r\delta t},\ I_k] \qquad \textbf{(5.12)}$$

$$C_d^2 = \mathrm{Max}[S_0 d^2 - X_i, ((p* C_{ud}^2)+(1-p)* C_d^3)*e^{-r\delta t}, I_k] \quad \textbf{(5.13)}$$

$$C_u = \mathrm{Max}[S_0 u - X_i, ((p* C_u^2)+(1-p)* C_{ud})*e^{-r\delta t}, I_k] \quad \textbf{(5.14)}$$

$$C_d = \mathrm{Max}[S_0 d - X_i, ((p* C_{ud})+(1-p)* C_d^2)*e^{-r\delta t}, I_k] \quad \textbf{(5.15)}$$

$$C = \mathrm{Max}[S_0 - X_i, ((p* C_u)+(1-p)* C_d)*e^{-r\delta t}, I_k] \quad \textbf{(5.16)},$$

where I_k is the initial net present value for Alternative-1 (k=1), Alternative-2 (k=2), Alternative-3 (k=3), and Alternative-4 (k=4), respectively, without deploying any capital equipment for manufacturing purposes. Utilizing the net present value for alternatives with material handling equipment only and without exercising the option of deploying any capital equipment for manufacturing purposes can be considered analogous to not exercising an option and thus resulting in an option value of \$0. The aforementioned difference in the binomial lattice logic is the interpretation of "do-nothing" approach for this practical business application in terms of manufacturing equipment deployment.

The resulting binomial lattices for the options of Group-1 and Group-2 and the suggested policy, where the marketing performance is low, are represented in the following Figure 5.17, Figure 5.18, and Figure 5.19, respectively. The italicized numbers at the bottom of each node represent the option values.

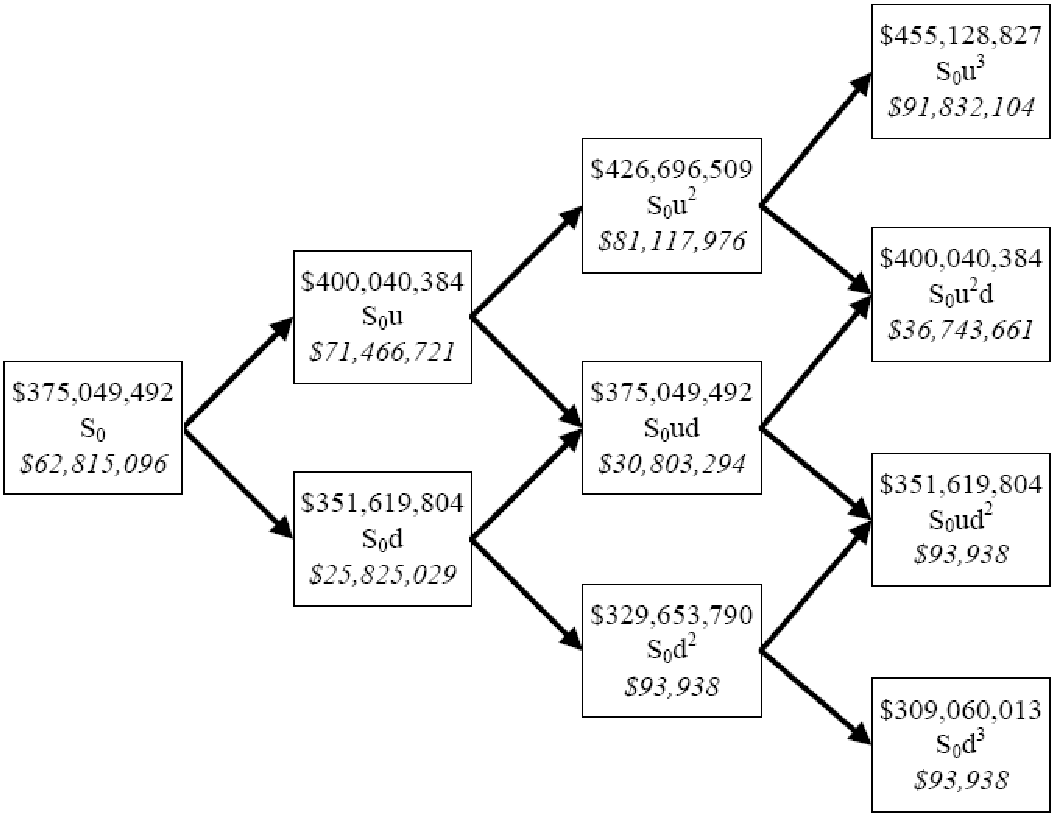

Figure 5.17 Binomial Lattice for Group-2 with Low Marketing Performance

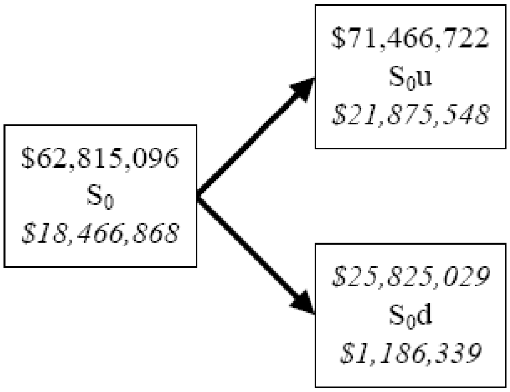

Figure 5.18 Binomial Lattice for Group-1 with Low Marketing Performance

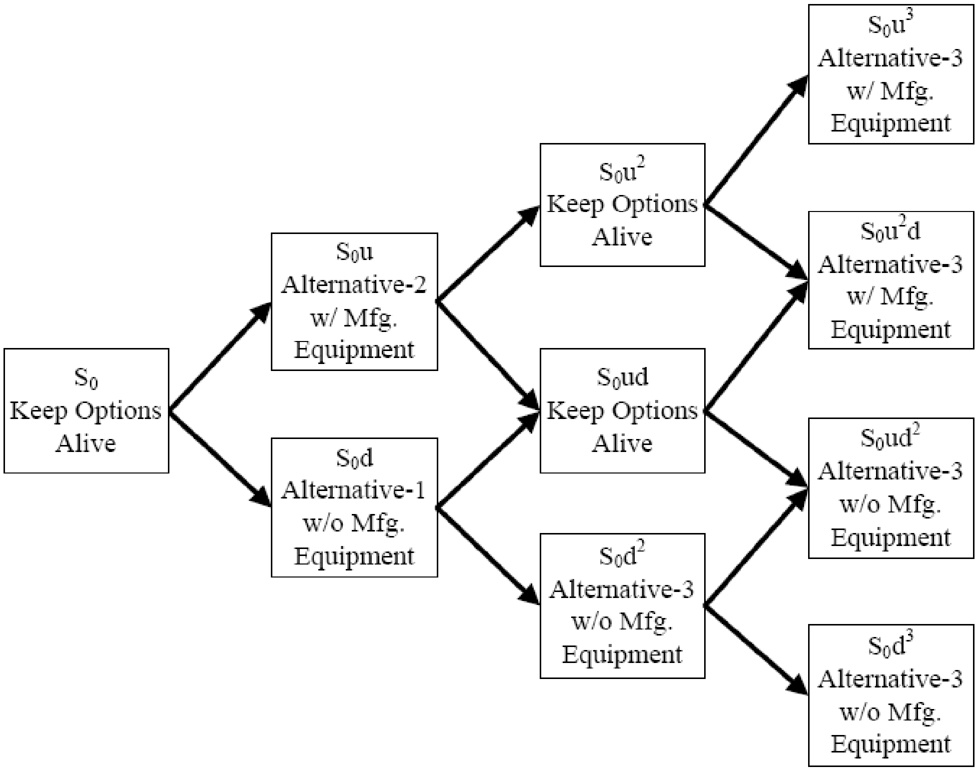

Figure 5.19 Suggested Policy for Low Marketing Performance

The resulting binomial lattices for the options of Group-1 and Group-2 and the suggested policy, where the marketing performance is medium, are represented in the following Figure 5.20, Figure 5.21, and Figure 5.22, respectively. The italicized numbers at the bottom of each node represent the option values.

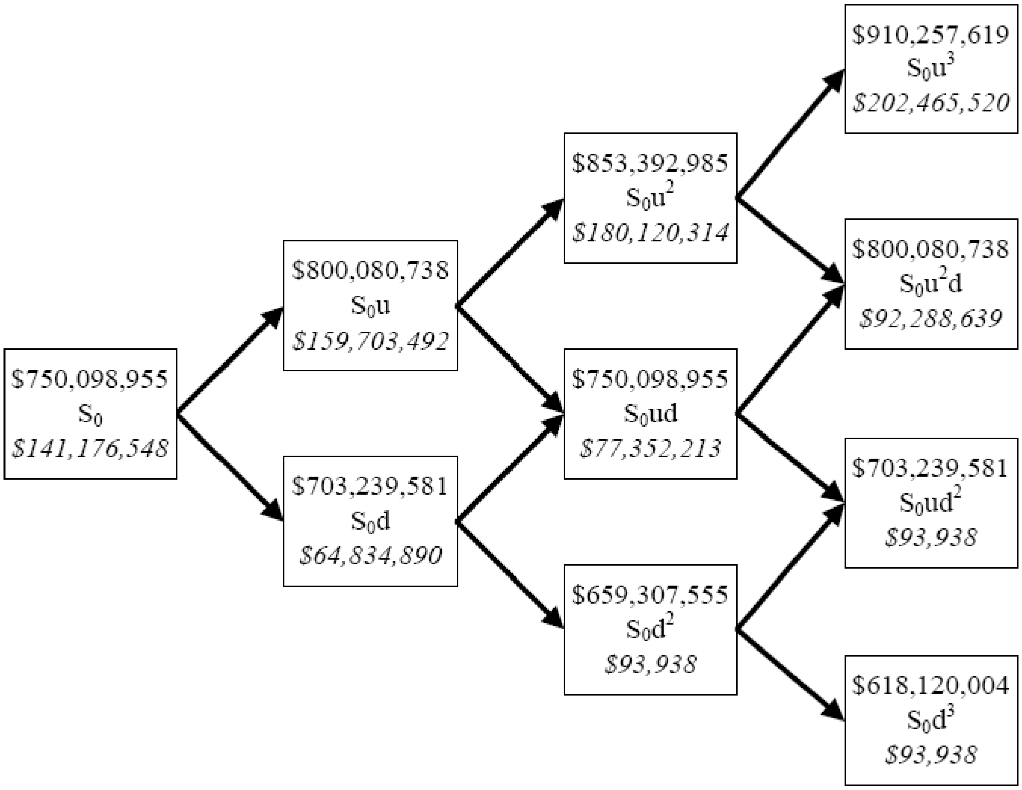

Figure 5.20 Binomial Lattice for Group-2 with Medium Marketing Performance

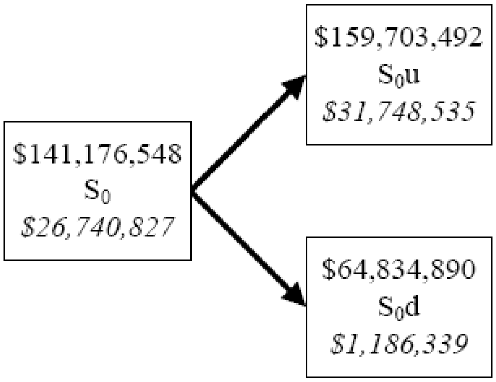

Figure 5.21 Binomial Lattice for Group-1 with Medium Marketing Performance

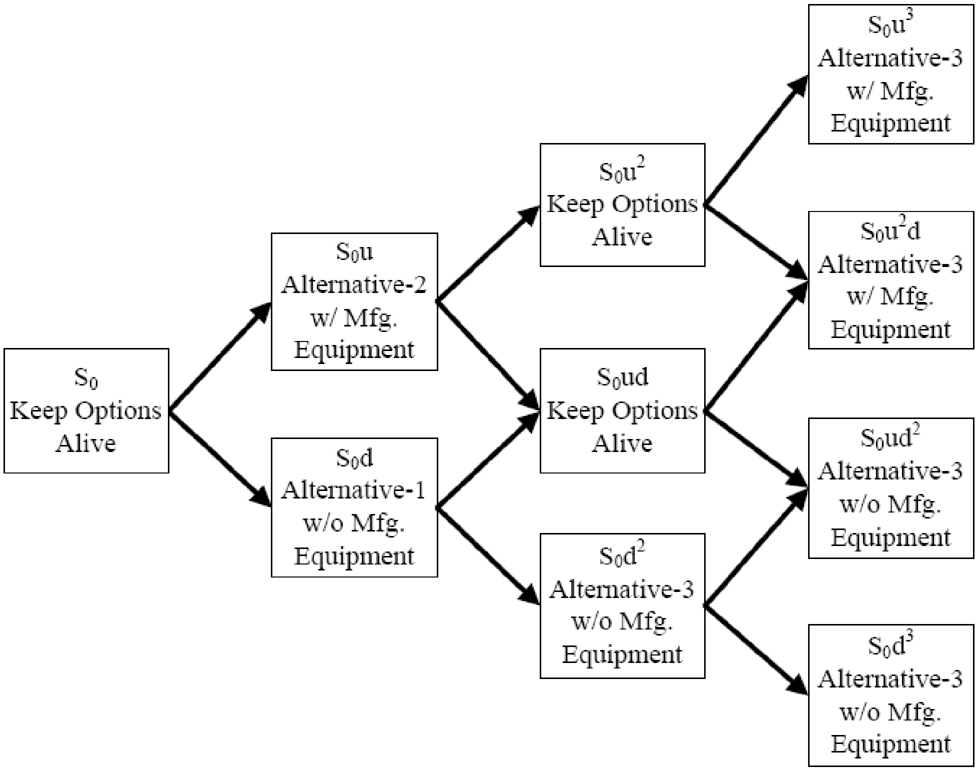

Figure 5.22 Suggested Policy for Medium Marketing Performance

The resulting binomial lattices for the options of Group-1 and Group-2 and the suggested policy, where the marketing performance is high, are represented in the following Figure 5.23, Figure 5.24, and Figure 5.25, respectively. The italicized numbers at the bottom of each node represent the option values.

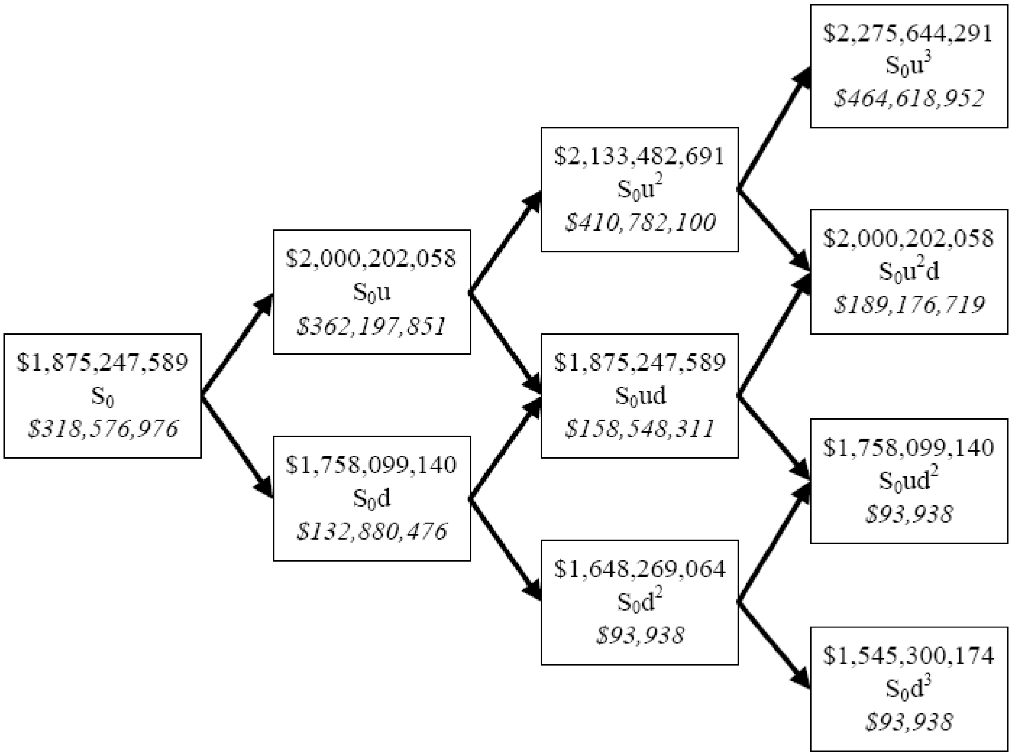

Figure 5.23 Binomial Lattice for Group-2 with High Marketing Performance

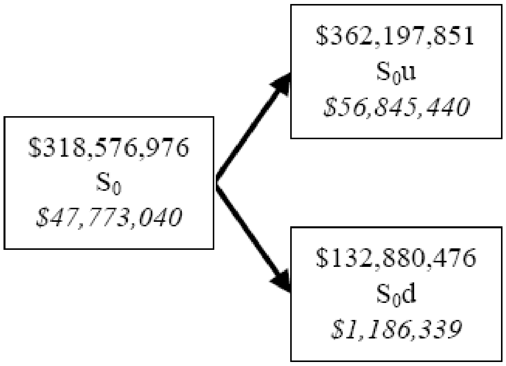

Figure 5.24 Binomial Lattice for Group-1 with High Marketing Performance

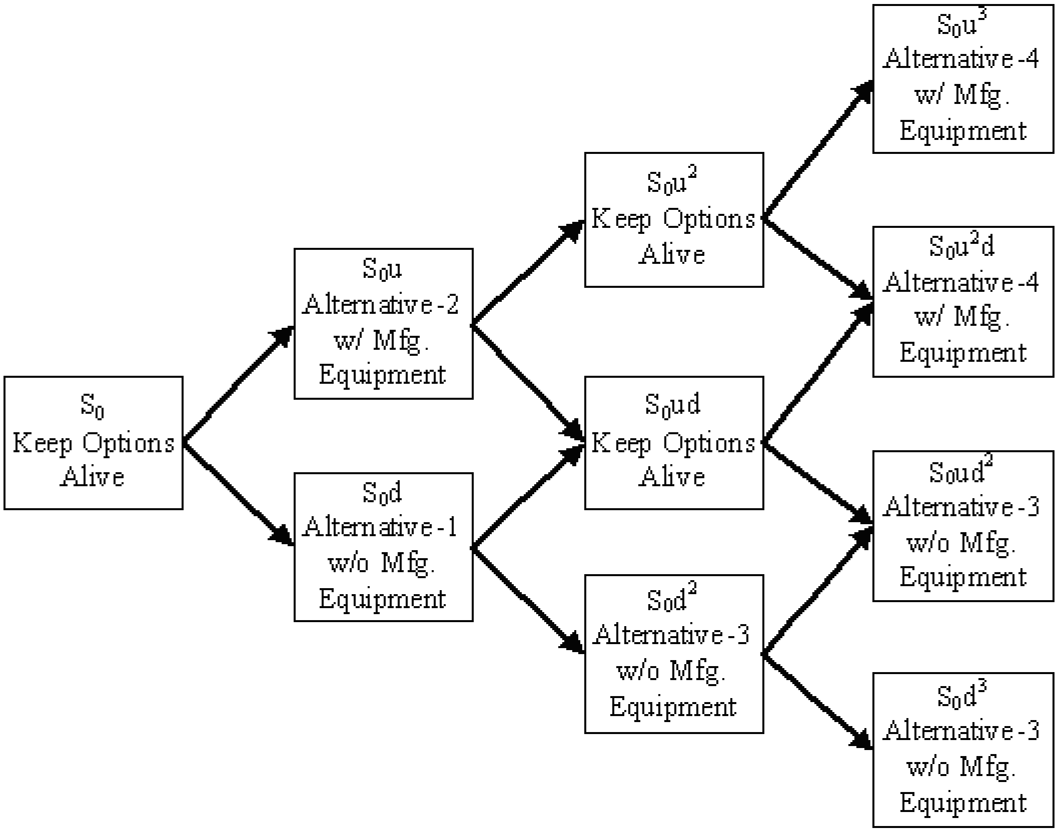

Figure 5.25 Suggested Policy for High Marketing Performance

Pascal's Triangle in the following Figure 5.26 is utilized in order to define the weighted average floor space value per square foot by calculating the probability distribution of each option.

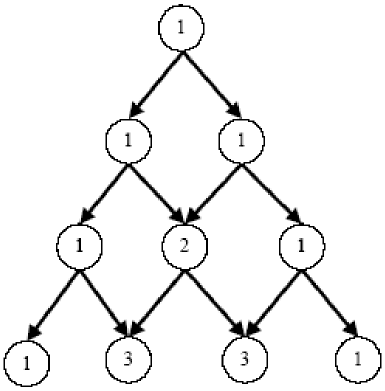

Figure 5.26 Pascal's Triangle

The weighted average floor space for Group-1 with low, medium, and high marketing performance is 7,500 sq. ft. The weighted average floor space for Group-2 with low and medium marketing performance is 45,000 sq. ft., while it is 52,500 sq. ft. with high marketing performance. The corresponding weighted average floor space value utilizing the real option value and the associated weighted average floor space for each marketing performance level is represented in the following Table 5.24.

Table 5.24 Weighted Average Floor Space Value

	Marketing Performance		
	Low	**Medium**	**High**
Option Value	$18,466,868	$26,740,827	$47,773,040
Weighted Average Floor Space	52,500 sq. ft.		60,000 sq. ft.
Probability of Marketing Performance	.55	.40	.05
Weighted Average Real Option Value	$23,241,760.2		
Floor Space Value per Square Foot	$351.75	$509.35	$796.22
Weighted Average Floor Space Value	$437.01		

5.6 Summary of Results

The decision recommendations are summarized in the following Table 5.25. With no additional business volume, the decision recommendation is always to replace the existing mini-load AS/RS, to replace AGV control software, to retrofit mechanical AGV components, and to expand the existing floor space by 50,000 sq. ft. without utilizing any manufacturing equipment. As the additional business volume increases, the decision recommendations proposed by the techniques that include stochastic behavior of the input variables shift toward generating more floor space in order to meet additional demand.

While MCS analysis takes the stochastic behavior of all the input variables into account simultaneously, DTA includes the private risk into the valuation through the management's subjective assessment. ROA supported by DTA, on the other hand, adds the market risk into the valuation more realistically through risk neutral probability approach by estimating the volatility utilizing historical data instead of the probability distribution that is subjectively assessed by the management. It should be noted that the risk-neutral probability approach does not depend on the state of the nature at each node; it is a function of the up and down movements, and the risk-free rate. Moreover, since it remains constant from node to node, it is considered more convenient to include the market risk through ROA than utilizing a subjectively assessed probability distribution through DTA, which may be rarely perfectly correlated with the state of the nature at each node. Similarly to the results of the former techniques, ROA indicates that, as the additional business volume increases, the decision recommendation shifts from using less expensive alternatives without manufacturing equipment, which offer less floor space, toward using expensive alternatives with manufacturing equipment, which offer more floor space. Hence, DCF approach is recommended to be supported by a combination of MCS analysis, DTA, and ROA in order to include the stochastic behavior of the input variables, the private risk, and the market risk, respectively.

The sequence of the utilized techniques is evolutionary in nature. As the techniques evolve from the very basic DCF approach toward more sophisticated techniques, stochastic behavior of the inputs are more included into the valuation. The recommendations generated by this method are in-line with intuition, which is to use more floor space when there is an opportunity to generate more revenue.

Table 5.25 Decision Recommendations Summary

Decision Technique	Implementation Time Combinations of the Alternatives	Additional Business Volume	Total Floor Space in sq. ft.	Floor Space Value	Mfg. Equipment Gr.-1/Gr.-2
DCF	1030	None	50,000	$29.20	No/No
DCF Best Case	1030	None	50,000	$43.78	No/No
DCF Worst Case	1033	None	50,000	$6.98	No/No
MCS Phase-1	1030	None	50,000	$25.57	No/No
MCS Phase-2	2040	Maximum	70,000	$1,106.57	Yes/Yes
MCS Phase-3	2140	Medium	70,000	$629.45	Yes/Yes
DTA (WACC)	1130	Low	50,000	$257.08	Yes/Yes
DTA (WACC)	1130	Medium	50,000	$868.06	No/Yes
DTA (WACC)	2130	High	55,000	$1,103.97	No/Yes
DTA (risk-free rate)	1130	Low	50,000	$257.78	Yes/Yes
DTA (risk-free rate)	1130	Medium	50,000	$868.75	No/Yes
DTA (risk-free rate)	2130	High	55,000	$1,111.02	No/Yes
ROA	Figure 5.19	Low	52,500	$351.75	Figure 5.19
ROA	Figure 5.22	Medium	52,500	$509.35	Figure 5.22
ROA	Figure 5.25	High	60,000	$796.22	Figure 5.25

CHAPTER 6

CONCLUDING REMARKS AND FUTURE RESEARCH

6.1 Concluding Remarks

The fiercest competition today is in the automotive and high technology industries due to globalization, rapid technological improvements, and the need for new energy resources. OEM's in the aforementioned industries exert their power mostly over their first-tier suppliers. Moreover, high market demand volatility, short product life cycles, long design and production lead times, high capital investment requirements, and irreversibility of the investments require extremely intelligent decision making.

Controlling fuel prices, interest rates, investments in other industries and/or competitors, tax system, and insurance costs is impossible. Thus warehousing and obsolescence costs become the most accessible targets for industries in terms of logistics costs. Controlling warehousing costs starts with accurate warehouse sizing, adequate floor space allocation, and, thus accurate inventory allocation, and streamlining the relevant processes which can be translated as waste removal from the warehousing activities.

Companies that can control the aforementioned costs can also control immediate internal extensions. Such in-house logistics operations as inbound delivery scheduling, inventory planning and analysis, process streamlining, and waste elimination can be considered as natural resource acquisition and exploitation activities depending on their revenue generating potentials.

Similarly, any operation that does not require core-competency of the enterprises can either be handled in-house or contracted out to effectively utilize the existing floor space depending on the generated value. The bottom line is to effectively utilize the existing floor space in order to obtain the greatest return for an investment, and thus to compete in today's environment.

Effective floor space utilization provides in the flexibility to manage the capacity needed to generate more revenue or more cost savings, thereby contributing to the competitive advantage. Thus making capital investment decisions without taking floor space valuation into account might be premature.

This research study is unique in its nature. The value of floor space in electronics manufacturing is discussed in detail for the first time in the literature through different techniques, and the decision recommendations are utilized by a real-world business entity for capital investment decisions. The scope of this research study is limited to plant level capital investment decisions of a global publicly held high-volume high-mix automotive electronics manufacturer. A method using traditional DCF techniques supported by Monte Carlo simulation, decision-tree analysis, and ROA is developed in order to capture the floor space value by including the stochastic behavior of the input variables, the private risk, and the market risk, respectively.

The proposed method is applied to a real-world practical business application using real data, where decisions made using the aforementioned techniques are compared to each other. Numerical results obtained through the aforementioned techniques intuitively indicate that, as additional business volume increases, the decision recommendation shifts from alternative combinations offering less floor space toward the ones offering larger floor space.

From the timing perspective, DCF approach suggests making the investments at Year 0 by not considering the stochastic behavior of the input variables, especially the revenues generated through additional business volume. Meanwhile DTA and ROA suggest taking advantage of the arrival of the new information about the private and market risks involved regarding the additional business volume by emboldening the "wait-and-see" approach.

Finally, the value of the floor space exhibits a very wide spectrum depending upon the diversity of the solution methodology applied to the practical business application and the associated features of each technique. It sounds unrealistic to assign such low values as $25.60 to floor space without considering any revenue-generating potential. Thus valuation efforts that do not take into account the opportunities mislead practitioners.

The floor space value calculated through the aforementioned techniques indicates that, when the floor space is not utilized for non-revenue generating activities, the associated value is expressed in hundreds or thousands of US dollars.

Hence, aside from analyzing purely from a capital investment justification perspective through DCF techniques, it is important to take into account the revenue-generating potential of the floor space generated by the investment. As discussed in this practical business application, the most attractive capital investment alternatives may turn out to be the least attractive ones when the revenue-generating potential of the corresponding floor space is taken into account, together with the timing aspects. The floor space valuation utilizing an ROA framework allows decision makers to include market risk into the valuation more realistically since it estimates the market volatility utilizing historical data instead of a subjectively assessed probability distribution and it is easy to understand each course of action under all possible circumstances with strong emphasis on revenue-generating opportunities with the value of additional information. This method can be used as a practical way to evaluate business decisions for high-volume high-mix electronics manufacturing facilities if the associated decision alternatives offer floor space with revenue-generating potential. The aforementioned method is considered as a useful tool for this specific practical business application since corporate planners do not have a thorough method to understand and value the floor space in order to make business decisions regarding future product allocations to manufacturing plants. Such decisions are too complicated to be made by just dividing the overall budget by the total floor space.

6.2 Future Research Areas

Irreversible capital investments generally require a significant amount of implementation time.

The cash flow structure pertaining to implementation time lags might effect the decision. The implementation time lag is assumed to be zero for this research study since the required resolution negatively impacts the mathematical tractability. The magnitude of the model becomes unmanageable if high resolution is required. Further research efforts utilizing combinatorial optimization techniques might help implementation time lags when used with ROA in order to enhance the mathematical tractability, especially for complex real-world models regardless of the size of the model.

The useful project life for this research study is assumed to be fixed as five years. It would be more realistic to assume dynamic project life, which would change the planning horizon by reflecting real-world situations such as early contract terminations. The impact of dynamic project life might lead to the optimum product type and facility pair selection associated with available floor space alternatives. Then the research question becomes which floor space alternative to allocate to which product at which facility. Bayesian learning real options might be a valuable tool to tackle the dynamic project life challenge.

In this research study lost sales are assumed to have zero impact on the cash flow structure of the decision alternatives. The reason for that assumption is that the customer demand is assumed to be satisfied by other facilities of the corporation in case the selected facility is not capable of meeting the aforementioned demand. However, the inclusion of the lost sales might be considered as an add-on to the future research opportunity, since finding the optimum product allocation for different manufacturing plants within to the same corporation by taking the lost sales into consideration might be another valuable tool for corporate decision makers.

Including the effects of volatility in oil price, exchange rates, labor costs, and transportation costs might take the former opportunity one step further in terms of understanding the business decisions regarding the transfer of business towards low cost countries.

Corporate level business decisions such as expansions, contractions, plant closings, and acquisitions might be better understood via game theory in the existence of competition in the automotive electronics industry. Future research utilizing game theory combined with options pricing theory might help decision makers to better understand, analyze, and improve the aforementioned decisions as well as the associated behaviors of the corresponding actors during the decision-making process.

Although WACC is treated as an input variable due to the acquisition that Plant I went through, the risk-free interest rate is assumed to be fixed in order to control the scope of this research study. However, with the ongoing uncertainty in the global economy stemming from increasingly fluctuating oil prices, the effect of the dynamic risk-free interest rate, together with the inflation on business valuation is worth researching, especially for automotive industry decision makers and strategists.

Binomial lattices are easy to understand, manageable, and mathematically tractable. A combination of decision-tree and binomial lattices are utilized in this research study in order to reflect the multinomial nature of the practical business application. The aforementioned scheme might not always fit the decision problem on-hand. Multinomial lattices, on the other hand, become error prone and intractable, especially for large models. Further research might be valuable in order to make multinomial lattices mathematically tractable and attractive for practitioners.

Finally, since an analogy between financial options and real options is made in order to establish a real options analysis framework, a similar analogy can be made between trading strategies of the financial options and trading strategies of floor space options in the existence of extra office space for lease and value-added floor space requirements or in the existence of facilities for sale and facilities that require expansion.

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APPENDIX A

ADVANTAGES OF ROA OVER TRADITIONAL TECHNIQUES

Decision makers, analysts, and other finance professionals use DCF analysis, DTA, and MCS analysis for valuation purposes. Although those may very well serve the purpose for many applications, their limitations still leave some holes from the valuation perspective. Miller and Park (2002) define the main limitations of the traditional methods as follows:

- Selecting an appropriate discount rate poses problems. If the project involves high uncertainty, a high discount rate, which reflects a high risk premium, is used.
- Traditional methods ignore the flexibility to modify decisions along the value chain as new information arrives.
- Investment decisions are typically viewed as now-or-never or go-no-go type decisions rather than decisions that may be delayed.

Traditional methods use deterministic cash flows, adjusting them for risk utilizing a constant and risk-adjusted discount rate all along the decision horizon, and subtract the aforementioned cash flows from the investment outlays for NPV calculation. It should also be noted that the risks are often hedged by high discount rates and the downswings are always taken into account undervaluing opportunities.

ROA, on the other hand, captures the upside potential only by not exercising the option when the circumstances are unfavorable. ROA only needs the risk-free interest rate since the risk can be perfectly hedged, and thus there is no need for discount rate adjustment. In other words, the risk behavior of the decision maker, thus his or her utility function is not required. Hence it is possible to eliminate subjectivity from the valuation process.

Traditional methods are unrealistically deterministic, whereas ROA accounts for managerial flexibility, which is about understanding and managing the risk, as well as capturing the embedded opportunities or switching between multiple options in a financial decision problem as new information arrives and resolves uncertainty. Thus, instead of steering away from uncertainty, decision makers, analysts, and other finance professionals treat uncertainty as a profit opportunity since ROA enables them to make intelligent decisions through uncertain market circumstances. In addition to uncertainty, the length of the decision horizon increases the value of the real options, as well. However, traditional methods often consider that the long decision horizons have negative impact on NPV due to increasing uncertainty over time. Kodukula and Papudesu (2006) argue that ROA accounts for the whole range of uncertainty using stochastic processes and calculates a "composite" options value for a project, considering only those outcomes that are favorable (i.e., options are exercised) and ignoring those that are not by letting the options expire.

Future cash flows that can be generated by uncertain opportunities are often ignored through valuation since traditional methods unrealistically require perfect certainty to evaluate projects. ROA, however, is capable of evaluating projects with uncertain payoffs that may occur at uncertain points in time. ROA is more valuable when embedded options are about delaying, abandoning, and expanding commitments before making a final decision. Hence, riskier projects become more favorable under uncertain circumstances especially when they are market-driven. In other words, as new information arrives and the uncertainty resolves, wait-and-see approach boils down all possible outcomes into a single scenario, where decision maker may switch to a more favorable alternative instead of following an irreversible and predetermined decision path that may end up with a financial loss.

The value of ROA is illustrated with a simple numerical example below. Suppose that you have a choice between investing \$1M in a project today expecting to yield either \$1.6M or \$0.8M with 50 percent probability each and delaying that investment by one year, where the payoff uncertainty clears. The discount rate is given as 10 percent. Using traditional DCF method, the NPV for the first choice is:

$$NPV = \frac{\$1.2M}{(1+0.10)^1} - \$1M = \$0.0909M$$

On the other hand, since the uncertainty is expected to clear in one year, the investment will be made only if the outcome is favorable, which is \$1.6M with 50 percent probability. Thus, the expected NPV for the delayed investment is calculated as follows:

$$NPV = 0.5\left[\frac{-\$1M}{(1+0.10)^1} + \frac{\$1.6M}{(1+0.10)^2}\right] = \$0.207M$$

The value of delaying the decision is the difference between the two NPV's calculated above: \$0.207M-\$0.0909M = \$0.1161M.

Also suppose that the uncertainty is increased. Thus the same project is now expected to yield either \$1.9M or \$0.3M with 50 percent probability each and delaying that investment by one year, where the payoff uncertainty clears. The discount rate is given as 10 percent. Then the expected NPV for the delayed investment is calculated as follows:

$$NPV = 0.5\left[\frac{-\$1M}{(1+0.10)^1} + \frac{\$1.9M}{(1+0.10)^2}\right] = \$0.3306M$$

The value of delaying the decision when the uncertainty is increased is calculated as: \$0.3306M-\$0.0909M = \$0.2397M. The value of the option is increased by \$0.1236M demonstrating that the ROA generates more favorable results under uncertainty.

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APPENDIX B

TRADITIONAL DCF TECHNIQUES FOR VALUATION

In today's business environment strategic decisions are mostly multi-period decisions. Valuation of these decisions is a function of three fundamental factors: cash, timing, and risk (Luehrman, 1997). Capital investments in real assets such as equipment, machinery, plants, and buildings are being valued by the traditional approach known as the NPV method. The NPV of a capital investment project is calculated by discounting expected future incremental cash flows at a risk-adjusted discount rate. The NPV represents a measure of cash flow relative to the time point "now" with provisions that account for earning opportunities (Park, 2002). The NPV formulation with discrete (Park, 2002) and continuous (Hull, 2006) compounding is respectively as follows:

$$PW(i) = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n} \qquad \textbf{(B1)}$$

$$PW(i) = \sum_{n=0}^{N} A_n e^{-i \cdot n} \qquad \textbf{(B2)},$$

where i is the minimum attractive rate of return or cost of capital, n is the service life of the project, PW(i) is the net present value calculated at the interest rate i, and A_n is the net cash flow at the end of period n.

Suppose that company ABC invests \$500,000 in a new machine, where annual labor savings with a 3-year project life are \$300,000; \$350,000; and \$400,000, respectively. If the minimum attractive rate of return is 15 percent, the NPV of this project using equations (B1) and (B2) are:

$$PW(15\%) = \frac{-\$500k}{1.15^0} + \frac{\$300k}{1.15^1} + \frac{\$350k}{1.15^2} + \frac{\$400k}{1.15^3} = \$288.5k$$

$$PW(15\%) = -\$500k \cdot e^{(-0.15\times 0)} + \$300k \cdot e^{(-0.15\times 1)} + \$350k \cdot e^{(-0.15\times 2)} + \$400k \cdot e^{(-0.15\times 3)} = \$272.5k$$

Within the framework of the NPV method, other DCF techniques such as the internal rate of return (hereafter IRR), the payback method, and the economic value added (hereafter EVA) are commonly used by corporate managements to value strategic capital investment projects.

The IRR is the interest rate charged on the unrecovered project balance of the investment such that, when the project terminates, the unrecovered project balance will be zero (Park, 2002). Suppose Company ABC invests \$2.5 million in a new automated material handling system with a 5-year useful life and annual equivalent labor savings of \$500,000. The cash flow transaction is given in the following Table A1.

Table B.1 Sample Cash Transaction

Period	Ending Cash Payment
0	-\$2,500,000
1	\$800,000
2	\$800,000
3	\$800,000
4	\$800,000
5	\$800,000

The internal rate of return of this project is 18 percent. As indicated in Park (2002), if the investing firm and the project are viewed as the lender and borrower, respectively, the amortized loan transaction is as follows:

Table B.2 Sample Amortized Loan Transaction

Period	Beginning Project Balance	Return on Invested Capital	Ending Cash Payment	Project Balance
0	$0	$0	-$2,500,000	-$2,500,000
1	-$2,500,000	-$450,767	$800,000	-$2,150,767
2	-$2,150,767	-$387,798	$800,000	-$1,738,564
3	-$1,738,564	-$313,475	$800,000	-$1,252,039
4	-$1,252,039	-$225,751	$800,000	-$677,790
5	-$677,790	-$122,210	$800,000	$0

The IRR is a relative measure and depending on the project cash flow structure, it may exhibit inconsistencies with other profitability measures since it does not provide absolute monetary values. Hence it fails to measure the scale of the investment (Park, 2002).

The payback method screens projects on the basis of how long it takes for net receipts to equal investment outlays. Conventional payback method ignores time value of money whereas discounted payback method includes time value of money (Park, 2002). Suppose Company ABC invests $1 million in a state-of-the-art automated data capture system with 3-year useful life and generates annual equivalent net benefits of $500,000. The conventional payback period (hereafter CPP) is calculated as follows:

$$\text{CPP} = \frac{\text{Investment Amount}}{\text{Annual Equivalent Benefit}} = \frac{\$1{,}000{,}000}{\$500{,}000} = 2 \text{ Years}$$

If Company ABC requires an internal rate of return of 10 percent, the following Table B3 is constructed to determine the discounted payback period to recover the capital investment and the cost of funds required to support the project.

Table B.3 Sample Cash Flow Transaction for Discounted Payback Period Calculation

Period	Cash Flow	Cost of Funds	Cumulative Cash Flow
0	-$1,000,000	$0	-$1,000,000
1	$500,000	-$100,000	-$600,000
2	$500,000	-$60,000	-$160,000
3	$500,000	-$16,000	$324,000

If the cash flows are assumed to be continuous the discounted payback period is approximately 2 years and 3 months, or, if the end-of-year approach is adopted, then the discounted payback period is 3 years. The payback method determines how fast the investor can restore the initial position so that additional investment opportunities that may come along can be evaluated. Hence it is a supplementary component of the decision making process. However, it is not a profitability measure and, since it ignores the timing of the cash flows, it is not possible to determine the contribution of the investment.

EVA is a financial performance measure developed and defined by Stern Stewart & Co. as the amount by which earnings exceed or fall short of the required minimum rate of return, which shareholders and lenders could get by investing in other securities of comparable risk (Zimmerman, 2000). It is calculated by taking adjusted accounting earnings and subtracting the WACC multiplied by total capital employed. It is focused on shareholder value and measures the economic value of an investment.

Suppose Company ABC invests \$100,000 in a new assembly line and they can generate \$250,000 in sales revenue. The annual operating cost is \$200,000, the tax rate is 30 percent, and the cost of capital is 7 percent. EVA is calculated as follows:

$$\begin{aligned}
&EBIT = Sales - Operating\ Costs = \$250{,}000 - \$200{,}000 = \$50{,}000\\
&NOPAT = EBIT \times \left(1 - Tax\ Rate\right) = \$50{,}000 \times 0.70 = \$35{,}000\\
&Capital\ Costs = Investment \times Cost\ of\ Capital = \$100{,}000 \times 0.07 = \$7{,}000\\
&EVA = NOPAT - Capital\ Costs = \$35{,}000 - \$7{,}000 = \$28{,}000,
\end{aligned}$$

where EBIT represents earnings before interest expenses and income taxes. EVA has limited use for valuation because defining the cost of capital of an investment is complicated in terms of determining the comparable risk of other securities. In other words, the riskiness of the "other securities" may not always be truly comparable.

Park (2002) indicates that the equivalent present worth (hereafter PW), together with its variations; the equivalent future worth (hereafter FW); and the equivalent annual worth are the three common measures based on cash flow equivalence that establish a foundation for accepting or rejecting a capital investment.

The future worth (hereafter FW) measures the NPV of an investment at a time period other than 0. In other words it computes the value of an investment at the end of any period rather than at the beginning (Park, 2002). The FW formulation is given as follows:

$$FW\left(i\right) = \sum_{n=0}^{N} A_n \left(1 + i\right)^{N-n} \qquad \textbf{(B3)}$$

The annual equivalent worth (hereafter AEW) criterion provides a basis for measuring investment worth by determining equal payments on an annual basis.

The AEW is calculated by multiplying the NPV by the capital recovery factor. The capital recovery and AEW formulations are given respectively as follows (Park, 2002):

$$\left(A/P,i,N\right)=\frac{i(1+i)^N}{(1+i)^N-1} \qquad \textbf{(B4)}$$

$$AEW=NPV\left(A/P,i,N\right) \qquad \textbf{(B5)},$$

where P represents the NPV, and N is the service life of the investment. Suppose the NPV of an investment is \$500,000 and the service life is 5 years. If the minimum attractive rate of return is 15 percent, the FW and the AEW of this project are calculated as follows:

$$\left(A/P,15\%,5\right)=\frac{0.15(1.15)^5}{(1.15)^5-1}=0.298$$
$$AEW=\$500{,}000\times 0.298=\$149{,}157.8$$
$$FW(15\%)=\$500{,}000\times(1.15)^5=\$1{,}005{,}678.6$$

The AEW is considered as a useful method especially for comparing mutually exclusive projects with unequal service lives and for annual financial reporting including unit profit/cost analysis. However McLaughlin and Taggart (1992) discuss that AEW relies on stringent assumptions about the timing of future investment expenditures. By assuming that all future investment will take place with certainty at particular dates, it ignores the option component of the investment decision. According to their research even if the AEW is implemented with a risk-adjusted discount rate, it cannot capture the option component embedded in the investments, since risk-adjusted discounting at a constant rate is ill-equipped to handle situations in which decisions will be postponed until more uncertainty is resolved.

APPENDIX C

OPTIONS PRICING THEORY AND TRADING STRATEGIES

C1 Introduction

Black and Scholes developed a model based on risk-free arbitrage by providing a closed form solution for the equilibrium price of a European call option. An investor can create a hedged position, consisting of a long position in the stock and a short position in the option, whose value does not depend on the price of the stock, but depends only on time and the values of known constants under the following assumptions (Black and Scholes 1973):

- The short term interest rate is known and is constant through time.
- The stock price follows a random walk in continuous time with a variance rate proportional to the square of the stock price. Thus the distribution of possible stock prices at the end of the finite interval is lognormal. The variance rate of the return on the stock is constant.
- The stock pays no dividend or other distributions.
- The option is "European", that is, it can only be exercised at maturity.
- There are no transaction costs in buying or selling the stock or the option.
- It is possible to borrow any fraction of the price of a security to buy it or to hold it, at the short term interest rate.

- There are no penalties to short selling. A seller who does not own a security will simply accept the price of the security from a buyer and will agree to settle with the buyer on some future date by paying him an amount equal to the price of the security on that date.

The above ideal conditions do not hold for real world investment decisions, therefore relaxing one or maybe more of these assumptions is required to make realistic analysis. Their valuation formulation for a European call option is as follows:

$$w(x,t) = xN(d_1) - ce^{-r(t-t^*)}N(d_2) \qquad \textbf{(C1)}\text{, where}$$

$$d_1 = \frac{\ln(x/c) + \left(r + \frac{1}{2}v^2\right)(t^* - t)}{v\sqrt{t^* - t}} \qquad \textbf{(C2)}$$

$$d_2 = \frac{\ln(x/c) + \left(r - \frac{1}{2}v^2\right)(t^* - t)}{v\sqrt{t^* - t}} = d_1 - v\sqrt{t^* - t} \qquad \textbf{(C3)}$$

In the above expressions, x is the stock price or the price of the underlying asset, c is the exercise price of the option, t is the current date, $w(x,t)$ is the value of the option as a function of the stock price x and time t, t^* is the maturity date, r is the continuously compounded risk free rate, v^2 is the variance rate of the return on the stock, v is the stock price volatility, and $N(d)$ is the cumulative probability distribution function for a standardized normal distribution. $xN(d_1)$ is the expected value of the stock price, and $ce^{-r(t^*-t)}N(d_2)$ represents the expected risk-free value of the exercise price.

The value of a put option by the same token is calculated as follows (Hull, 2006):

$$w(x,t) = ce^{-r(t-t^*)}N(-d_2) - xN(-d_1) \quad \textbf{(C4)}$$

The graphical representation of Black and Scholes formulation in terms of the relation between the option value and the stock price for a European call option is illustrated in the following diagram (Black and Scholes, 1973):

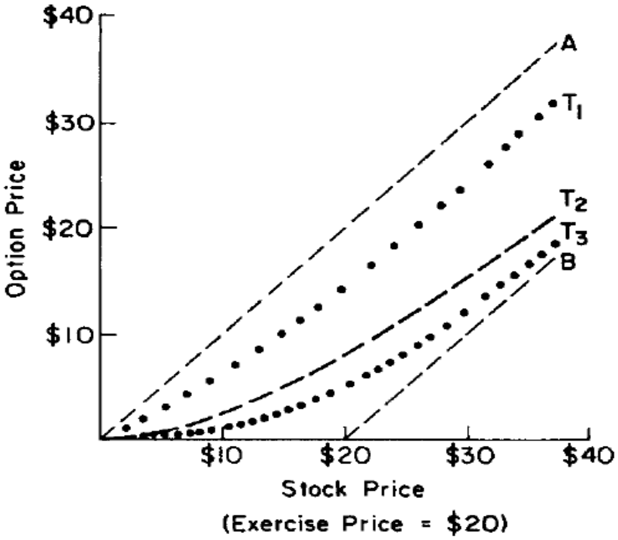

Figure C.1 The Relation Between Option Value And Stock Price

In the above figure, Line A represents the maximum value of the option, where Line B represents the minimum value of the option. The rationale is that the value option can neither exceed the value of stock nor be less than the stock price minus the exercise price, hence it can not be negative for a call option. The respective curves T_1, T_2, and T_3 represent the value of the option for successively shorter maturity dates.

It is obvious that

- As the stock price increases the value of the option increases.
- If the time to maturity is very long, then the value of the option is approximately equal to the stock price (See Line A in Figure C1).

- If the time to maturity is very short, then the value of the option will be very low or zero.
- As the time to maturity decreases the resulting decline in the option value means an increase in the equity in the hedged position, hence possible losses are offset by a large change in the stock price.

Hull (2006) discusses that the only problem in implementing equations (C5) and (C13) is in calculating the cumulative normal distribution function. Although the NORMDIST function of Microsoft Excel software calculates, he proposes a polynomial approximation that gives six-decimal-place accuracy:

$$N(x) = \begin{cases} 1 - N'(x)\left(a_1 k + a_2 k^2 + a_3 k^3 + a_4 k^4 + a_5 k^5\right) & \text{when } x \geq 0 \\ 1 - N(-x) & \text{when } x < 0 \end{cases} \qquad \textbf{(C5).}$$

where

$$k = \frac{1}{1 + \gamma x} \qquad \textbf{(C6)}$$

$$\gamma = 0.2316419 \qquad \textbf{(C7)}$$

$$a_1 = 0.31938153 \qquad \textbf{(C8)}$$

$$a_2 = -0.356563782 \qquad \textbf{(C9)}$$

$$a_3 = 1.781477937 \qquad \textbf{(C10)}$$

$$a_4 = -1.821255978 \qquad \textbf{(C11)}$$

$$a_5 = 1.330274429 \qquad \textbf{(C12)}$$

$$N'(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \qquad \textbf{(C13)}$$

The Black and Scholes valuation formulation implies that the stock price fits to a lognormal distribution since it can not be negative and the return on stock, which is continuously compounded, is normally distributed. It should also be noted that creating a risk-free position is always possible since the source of uncertainty for both the stock price and the option value is the same. The Black and Scholes equations can be derived by either solving their differential equations or by using the risk neutral valuation, assuming that the world is risk neutral.

C2 Wiener Processes

The closed form solution referred to as Black-Scholes-Merton in the previous chapter generates a hedging portfolio depending on the stock price. Thus both the movement of the stock price and the change in the value of the stock price require further investigation.

Any variable whose value changes over time in an uncertain way is said to follow a stochastic process, which can be classified as discrete time or continuous time (Hull, 2006). The value of the variable changes only at certain fixed points in time through a discrete time stochastic process, whereas the value of the variable can change at any time through a continuous time stochastic process.

Stock prices are assumed to follow a specific type of stochastic process, where the memory-less property of the underlying distribution plays a significant role. The future price of a stock should not be influenced by its price one month ago, but by the present price.

Suppose we know that the current value and the change in the value for a stock price follows a standard normal distribution $\phi(\mu,\sigma)$ with $\mu = 0$ and $\sigma = 1$ for one period. Estimating the change in the value for two periods is the sum of two normal distributions since two periods follow independent processes because of the Markov process. The change in the value for two periods will follow a normal distribution $\phi\left(0,\sqrt{2}\right)$ because the variance of the changes in Markov processes is additive. As the multiplier of the time period or the length of the consecutive time intervals decreases and the size of the change in value is proportional to the length of the time period, the standard deviation becomes much larger than the variance. This stochastic calculus property translates itself into increased resolution in the pattern of the change in the variable value as the length of time interval approaches zero.

Hull (2006) defines two intriguing properties of Wiener processes related to the aforementioned property as follows:

- The expected length of the path followed by the variable z in any time interval is infinite.
- The expected number of times z equals any particular value in any time interval is infinite.

The variable z is the formal expression of a variable following a Wiener process, which is also referred to as Brownian motion. The variable z has the following properties (Hull, 2006):

- The change Δz during a small period of time Δt is $\Delta z = \varepsilon\sqrt{\Delta t}$, where ε has a standard normal distribution $\phi(0,1)$.

- The values of Δz for any two different short intervals of time, Δt , are independent.

Due to the aforementioned properties, the change in the value of z during a relatively long period of time, T, consisting of N small time intervals of Δt , can be expressed as follows (Hull, 2006):

$$z(T) - z(0) = \sum_{i=1}^{N} \varepsilon_i \sqrt{\Delta t} \qquad \textbf{(C14)}$$

Since Δz follows a Wiener process, $z(T) - z(0)$ also follows a Wiener process and is normally distributed with

- Mean of $[z(T) - z(0)] = 0$
- Variance of $[z(T) - z(0)] = N\Delta t = T$
- Standard deviation of $[z(T) - z(0)] = \sqrt{T}$

The mean change per unit of time for a stochastic process is known as the drift rate and the variance per unit of time is known as the variance rate (Hull, 2006). So far the drift rate of the variable z has been given as zero and the variance rate as 1.0. The drift rate being zero means that the expected future value of z is equal to its current value. However a zero drift rate is not realistic. Hence a more generalized Wiener process for a variable x is defined by Hull (2006) as follows:

$$dx = adt + bdz \qquad \textbf{(C15)},$$

where a and b are constants. If *bdz* equals zero then the change in the value of x with respect to the change in time is equal to a. Integrating that equation gives

$$x = x_0 + at \qquad \textbf{(C16)}$$

Hence the generalized Wiener process can be expressed as follows(Hull, 2006):

$$\Delta x = a\Delta t + b\varepsilon\sqrt{\Delta t} \qquad \textbf{(C17)}$$

The generalized Wiener process is graphically represented by Hull (2006) as follows:

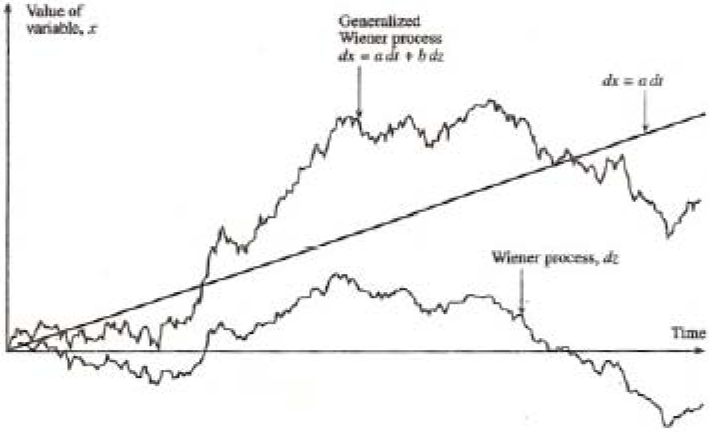

Figure C.2 Generalized Wiener Process

The only drawback of the above model is that the shareholders are reluctant to expect the assumption of constant drift rate. Whatever the stock price is, the target increase expected by the shareholders does not change. Hence Hull (2006) proposes to replace the former assumption with the assumption that the expected return (i.e., expected drift divided by the stock price) is constant. Thus Hull (2006) suggests the following continuous time and discrete time models, respectively:

$$dS = \mu S dt + \sigma S dz \qquad \textbf{(C18)}$$

$$\Delta S = \mu S \Delta t + \sigma S \varepsilon \sqrt{\Delta t} \qquad \textbf{(C19)},$$

where S is the stock price, μS is the expected drift rate for some constant parameter μ. With Hull's (2006) suggested assumption the equation (C18) and (C19) can be expressed respectively as follows:

$$\frac{dS}{S} = \mu dt + \sigma dz \qquad \textbf{(C20)}$$

$$\frac{\Delta S}{S} = \mu \Delta t + \sigma \varepsilon \sqrt{\Delta t} \qquad \textbf{(C21)}$$

C3 Trading Strategies

The profit pattern of the portfolios heavily depends on the relationship established between the options and the underlying assets. Hull (2006) discusses trading strategies involving both a single option with a stock and combinations of different options with the underlying assets.

C3.1 Trading Strategies Involving a Single Option and a Stock

The profit patterns generalized by Hull (2006) consist of

- Long position in a stock combined with short position in a call
- Short position in a stock combined with long position in a call
- Long position in a put combined with long position in a stock
- Short position in a put combined with short position in a stock

Suppose there are two portfolios A and B, where portfolio A consists of one European call option and an amount of cash equal to Ke^{-rT} and portfolio B consists of one European put option and a share. Since both have a value of max(S_T, K) the portfolios have the same value, where the relationship can be expresses by the put-call parity defined by Hull (2006):

$$p + S_0 = c + Ke^{-rT} + D \qquad \textbf{(C22)}$$

Where p is the price of a European put, S_0 is the present value of the stock price, c is the price of a European call, K is the strike price of both call and put, r is the risk free interest rate, T is the time to maturity of both call and put, and D is the present value of the dividends anticipated during the life of the options. The shapes of the general profit patterns described above are respectively as follows:

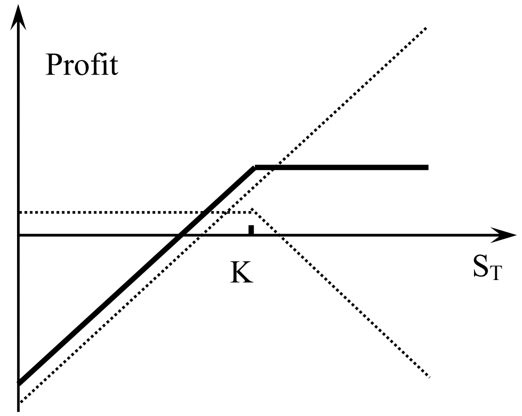

Figure C.3 The Profit Pattern of a Long Position in a Stock Combined with Short Position in a Call (Hull 2006)

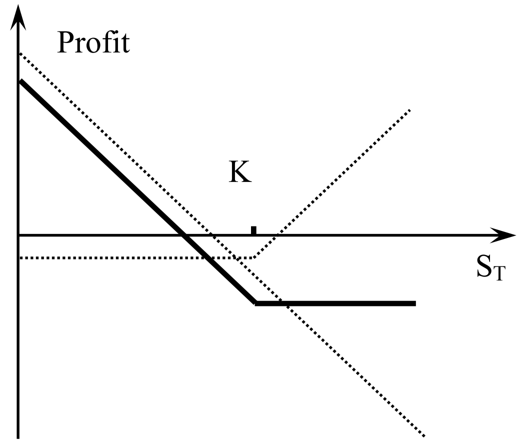

Figure C.4 The Profit Pattern of a Short Position in a Stock Combined with Long Position in a Call (Hull 2006)

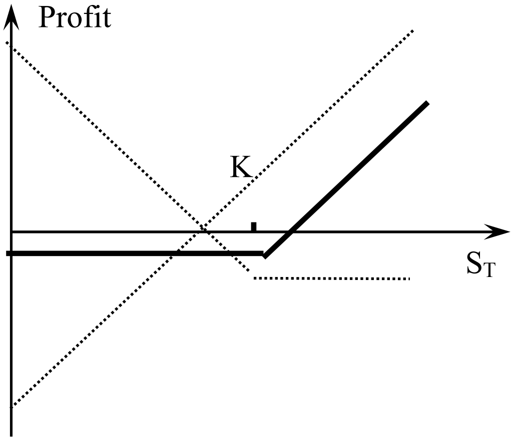

Figure C.5 The Profit Pattern of a Long Position in a Put Combined with Long Position in a Stock (Hull 2006)

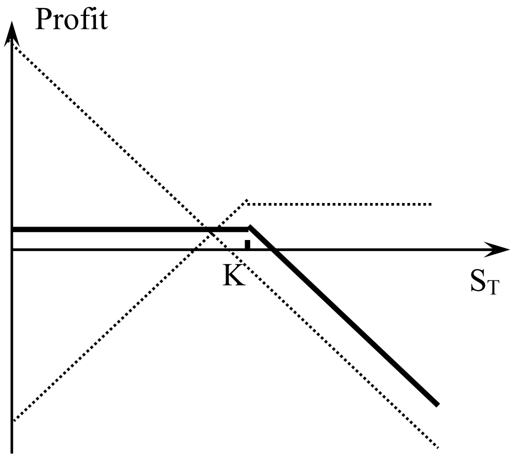

Figure C.6 The Profit Pattern of a Short Position in a Put Combined with Short Position in a Stock (Hull 2006)

The profit pattern of a long position in a put combined with long position in a stock (Figure C.5 by Hull (2006)) is very similar to the profit pattern of a long call option, which is also explained by equation (C22). The similarity between the profit pattern of long position in a stock combined with short position in a call and the profit pattern of a short put can be expressed by the following equation using equation (C23) (Hull 2006):

$$S_0 - c = Ke^{-rT} + D - p \qquad \textbf{(C23)}$$

C3.2 Spreads

Hull (2006) explains the spread trading strategy as the combination of two or more options of the same type.

A bull spread consists of buying an option with a certain strike price and selling another option with a higher strike price on the same stock, where the expiration date is the same for both options. Since a call price always decreases as the stock price increases, the value of the option sold is always less than the value of the option bought. A bull spread created from calls requires an initial investment, while the one created from put options involves a positive up-front cash flow to the investor. Three types of bull spreads are

- Both options are initially out of the money.
- One option is initially in the money, the other is initially out of the money.
- Both options are initially in the money.

An investor who enters a bull spread expects that the stock price will increase, hence the bull logic is "buy cheap sell expensive." Thus the bull spread limits the investor's upside profit as well as the downside risk (Hull 2006).

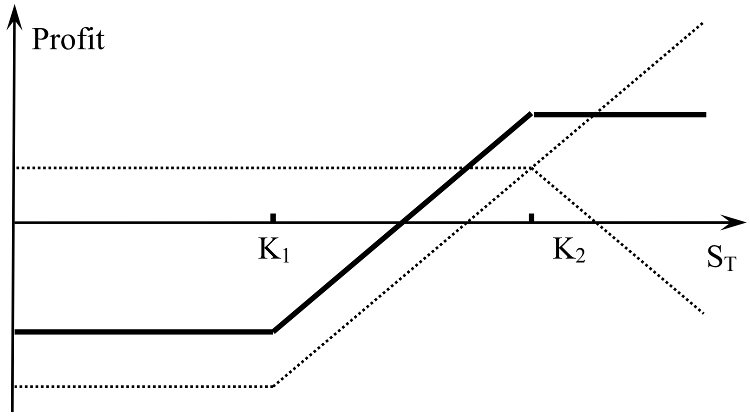

Figure C.7 The Profit Pattern of a Bull Spread Using Call Options (Hull 2006)

Table C.1 Payoff from a Bull Spread Using Call Options (Hull 2006)

Stock Price Range	Payoff from Long Call Option	Payoff from Short Call Option	Total Payoff
$S_T \geq K_2$	$S_T - K_1$	$-(S_T - K_2)$	$K_2 - K_1$
$K_1 < S_T < K_2$	$S_T - K_1$	0	$S_T - K_1$
$S_T \leq K_1$	0	0	0

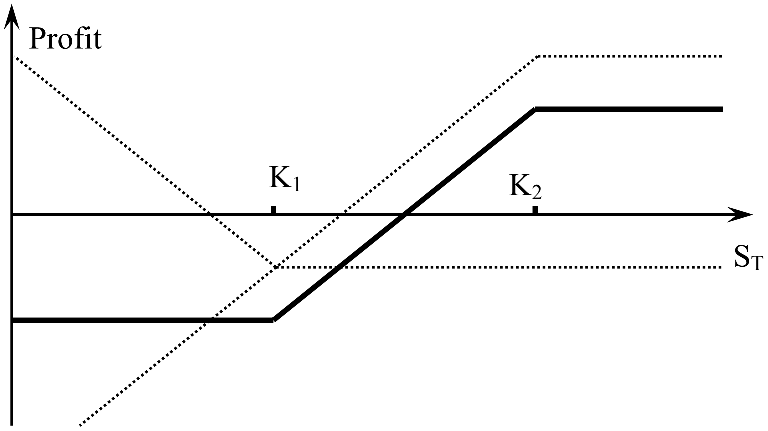

Figure C.8 The Profit Pattern of a Bull Spread Using Put Options (Hull 2006)

Table C.2 Payoff from a Bull Spread Using Put Options (Hull 2006)

Stock Price Range	Payoff from Long Put Option	Payoff from Short Put Option	Total Payoff
$S_T \geq K_2$	0	0	0
$K_1 < S_T < K_2$	0	$-(K_2 - S_T)$	$-(K_2 - S_T)$
$S_T \leq K_1$	$K_1 - S_T$	$-(K_2 - S_T)$	$K_1 - K_2$

A bear spread can be created by buying an option with a certain strike price and selling another option with a lower strike price. An investor who enters a bear spread expects that the stock price will decline. Bear spreads also limit both the upside profit and the downside risk. The bear logic is "buy expensive sell cheap." A bear spread created from calls involves an initial cash inflow, while the one created from puts involves an initial cash outflow (Hull 2006).

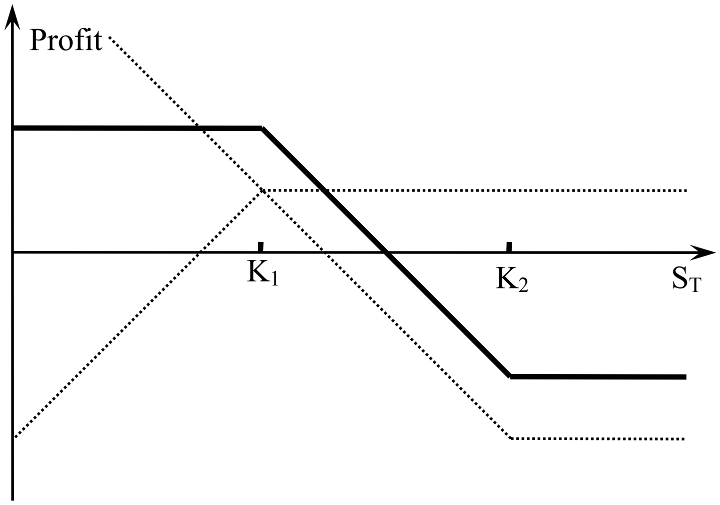

Figure C.9 The Profit Pattern of a Bear Spread Using Put Options (Hull 2006)

Table C.3 Payoff from a Bear Spread Using Put Options (Hull 2006)

Stock Price Range	**Payoff from Long Put Option**	**Payoff from Short Put Option**	**Total Payoff**
$S_T \geq K_2$	0	0	0
$K_1 < S_T < K_2$	$K_2 - S_T$	0	$K_2 - S_T$
$S_T \leq K_1$	$K_2 - S_T$	$-(K_1 - S_T)$	$K_2 - K_1$

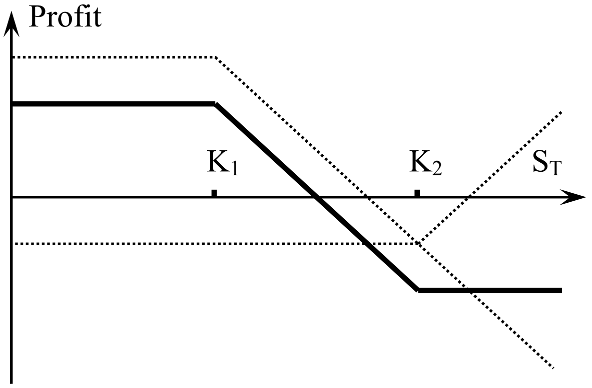

Figure C.10 The Profit Pattern of a Bear Spread Using Call Options (Hull 2006)

Table C.4 Payoff from a bear Spread Using Call Options (Hull 2006)

Stock Price Range	Payoff from Long Call Option	Payoff from Short Call Option	Total Payoff
$S_T \geq K_2$	$S_T - K_2$	$-(S_T - K_1)$	$K_1 - K_2$
$K_1 < S_T < K_2$	0	$-(S_T - K_1)$	$-(S_T - K_1)$
$S_T \leq K_1$	0	0	0

A box spread is a combination of a bull call spread with strike prices K_1 and K_2 and a bear put spread with the same two strike prices (Hull 2006). This means buying a call with strike price K_1, buying a put with strike price K_2, selling a call with strike price K_2, and selling a put with strike price K_1. The payoff of a box spread is always K_2-K_1.

A butterfly spread involves positions in options with three different strike prices. It can be created by buying a call option with a relatively low strike price, K_1, buying a call option with a relatively high strike price, K_3, and selling two call options with a strike price, K_2, halfway between K_1 and K_3. Generally K_2 is close to the current stock price. A butterfly spread is profitable if the stock price stays close to K_2, but it gives rise to small loss if there is a significant stock price move in either direction. It is a good strategy if the investor does not expect large stock price moves (Hull 2006).

A butterfly spread can also be created with put options. A butterfly spread can be shorted by the reverse strategy, which means buying two options with the middle strike price, K_2, and selling one with a relatively low strike price, K_1, and selling the other with a relatively high strike price, K_3 (Hull 2006).

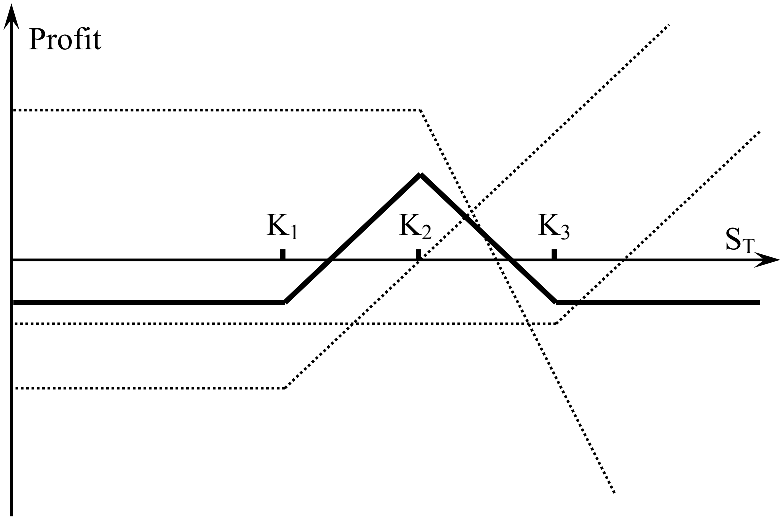

Figure C.11 The Profit Pattern of a Butterfly Spread Using Call Options (Hull 2006)

Table C.5 Payoff from a Butterfly Spread Using Call Options (Hull 2006)

Stock Price Range	**Payoff from First Long Call Option**	**Payoff from Second Long Call Option**	**Payoff from Short Calls**	**Total Payoff**
$S_T<K_1$	0	0	0	0
$K_1< S_T<K_2$	$S_T – K_1$	0	0	$S_T – K_1$
$K_2< S_T<K_3$	$S_T – K_1$	0	$-2(S_T– K_2)$	$K_3 – S_T$
$S_T>K_3$	$S_T – K_1$	$S_T – K_3$	$-2(S_T– K_2)$	0

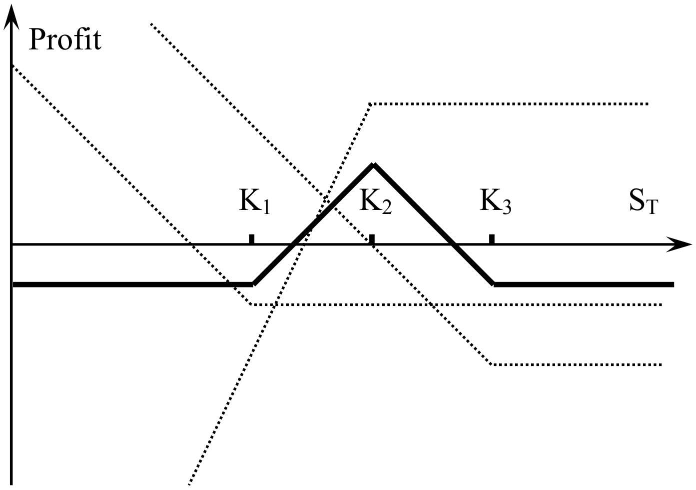

Figure C.12 The Profit Pattern of a Butterfly Spread Using Put Options (Hull 2006)

Table C.6 Payoff from a Butterfly Spread Using Call Options (Hull 2006)

Stock Price Range	Payoff from First Long Put Option	Payoff from Second Long Put Option	Payoff from Short Puts	Total Payoff
$S_T<K_1$	0	0	$-2(K_2 - S_T)$	$2S_T - K_1 - K_3$
$K_1< S_T<K_2$	$K_1 - S_T$	0	$-2(K_2 - S_T)$	$S_T - K_3$
$K_2< S_T<K_3$	$K_1 - S_T$	0	0	$K_1 - S_T$
$S_T>K_3$	$K_1 - S_T$	$K_3 - S_T$	0	$K_1 + K_3 - 2S_T$

A calendar spread is created by selling an option with a certain strike price and buying a longer maturity option of the same type with the same strike price. The important feature is that options have the same strike price but different maturity dates. A calendar spread requires an initial investment since the option becomes more expensive as the maturity date gets longer. A calendar spread is profitable if the strike price of the option with the shorter maturity date is close to the strike price of the option with the longer maturity date. A neutral calendar spread involves a strike price close to the current strike price, a bullish calendar spread involves a higher strike price, and a bearish calendar spread involves a lower strike price (Hull 2006).

A reverse calendar spread involves buying a short maturity option and selling a long maturity option. It is profitable only if the stock price of the short maturity option is well above or well below its strike price (Hull 2006).

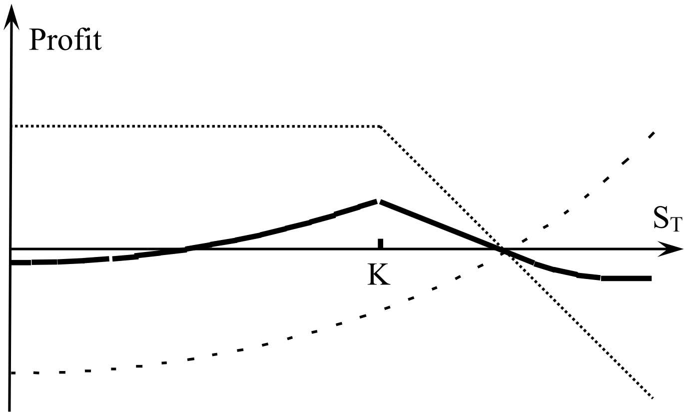

Figure C.13 The Profit Pattern of a Calendar Spread Using Call Options (Hull 2006)

Table C.7 Payoff from a Calendar Spread Using Call Options (Hull 2006)

Stock Price Range	Payoff from Long Call	Payoff from Short Call	Total Payoff
$S_T<K$	0	$-(S_T - K)$	$-(S_T - K)$
$S_T>K$	$S_T - K$	0	$S_T - K$

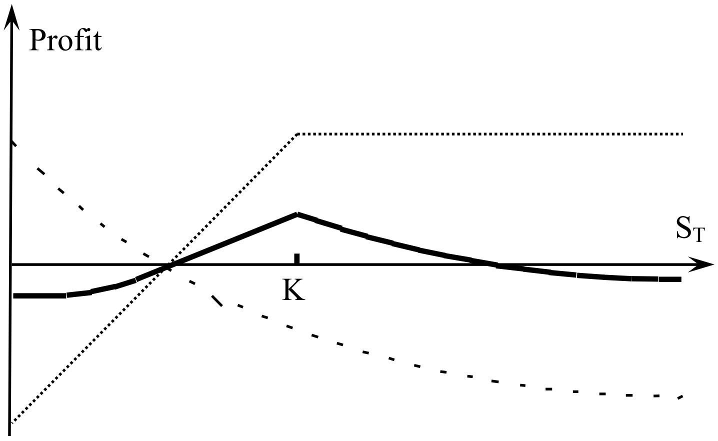

Figure C.14 The Profit Pattern of a Calendar Spread Using Put Options (Hull 2006)

Table C.8 Payoff from a Calendar Spread Using Put Options (Hull 2006)

Stock Price Range	Payoff from Long Put	Payoff from Short Put	Total Payoff
$S_T<K$	0	$-(K - S_T)$	$-(K - S_T)$
$S_T>K$	$K - S_T$	0	$K - S_T$

The final spread is called a diagonal spread, which involves buying and selling options with different strike prices and maturity dates (Hull 2006). Thus the profit ranges can be extended.

C3.3 Combinations

A popular combination is a straddle, which involves buying a call and a put with the same strike price and maturity date. A straddle is profitable if the stock price is well above or well below the strike price. An investor enters a straddle if bi-directional large moves in the stock price are expected. A spread can also be created by selling a call and a put, which is called a top straddle or straddle write, whereas the former is called a bottom straddle or straddle purchase. A top straddle is very risky since the loss is unlimited (Hull 2006).

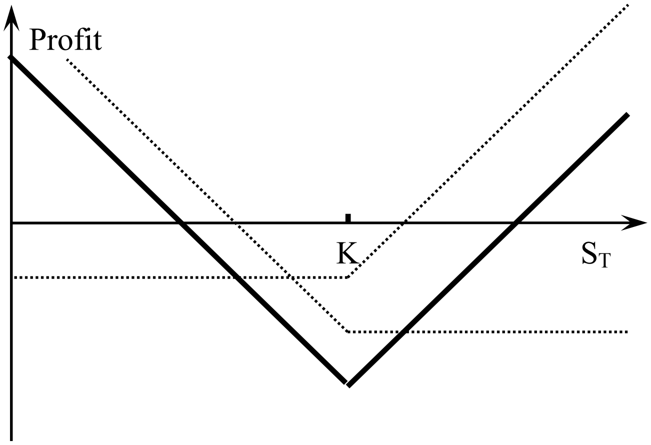

Figure C.15 The Profit Pattern of a Bottom Straddle (Hull 2006)

Table C.9 Payoff from a Straddle (Hull 2006)

Stock Price Range	Payoff from Call	Payoff from Put	Total Payoff
$S_T<K$	0	$K-S_T$	$K-S_T$
$S_T>K$	S_T-K	0	S_T-K

A strip consists of a long position in one call and two puts with the same strike price and maturity date. The investor expects that a big stock price decrease is more likely than a big stock price increase (Hull 2006).

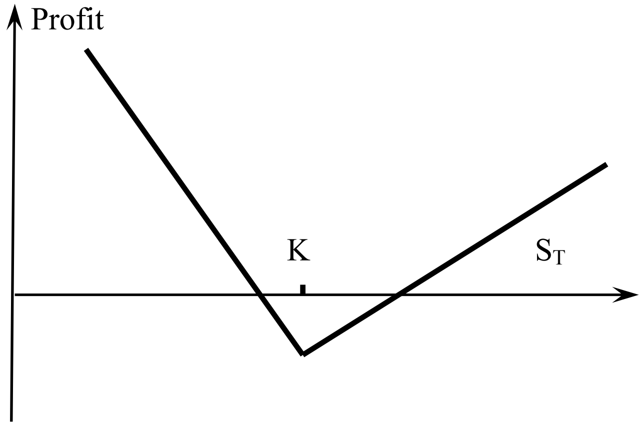

Figure C.16 The Profit Pattern of a Strip (Hull 2006)

A strap consists of a long position in two calls and one put with the same strike price and maturity date. The investor expects that a big stock price increase in more likely than a big stock price decrease (Hull 2006).

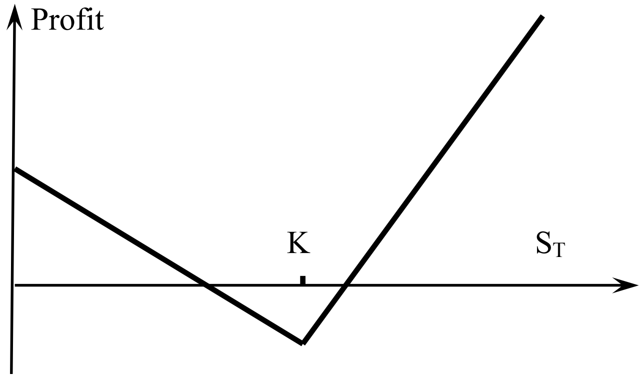

Figure C.17 The Profit Pattern of a Strap (Hull 2006)

A strangle or a bottom vertical combination involves buying a put option and a call option with the same maturity date and different strike prices. An investor who enters a strangle expects a large bi-directional price move. A strangle is similar to a straddle, where the downside risk is less than the straddle (Hull 2006). It should be noted that as the strike prices get further apart the downside risk decreases, and as the stock price increases the profit increases. If the combination involves selling a put option and a call option with the same maturity date and different strike prices, it is called a top vertical combination. It is profitable when the investor does not expect large stock price moves. However it is a risky trading strategy involving unlimited potential losses (Hull 2006).

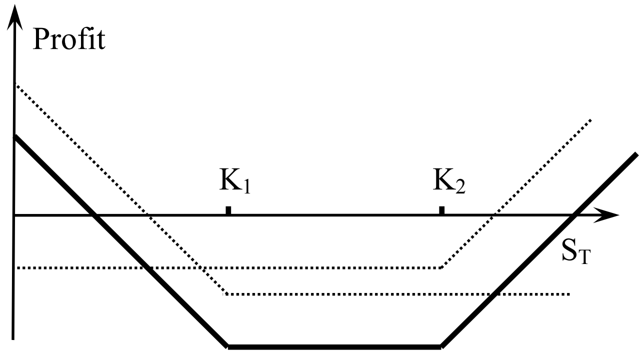

Figure C.18 The Profit Pattern of a Bottom Vertical Combination (Hull 2006)

Table C.10 Payoff from a Bear Spread Using Call Options (Hull 2006)

Stock Price Range	**Payoff from Call**	**Payoff from Put**	**Total Payoff**
$S_T \leq K_1$	0	$K_1 – S_T$	$K_1 – S_T$
$K_1 < S_T < K_2$	0	0	0
$S_T \geq K_2$	$S_T – K_2$	0	$S_T – K_2$

APPENDIX D

NORTH DOCK LAYOUT

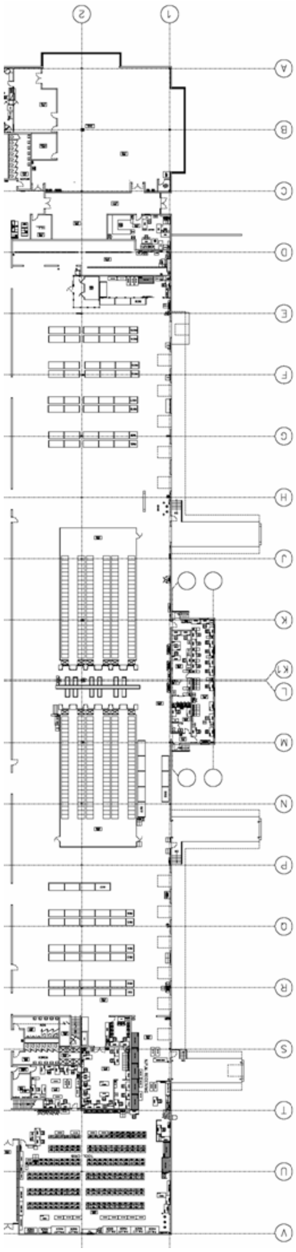

Figure D.1 North Dock Layout