Application of Real Options to Reverse Logistics Process

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Abstract

In this thesis, real options are used to identify the optimal model for the reverse logistics process of a technology company in the circuit board business. Currently, customers return defective boards and the company repairs the boards and sends them back. Now that the new product cost is falling below the level of the repair cost, the company is considering an alternative operational model, which is to scrap the returned boards and swap them with new products. As the product cost declines, it is also widely fluctuating, and it is this fluctuation that makes the switching option between the repair and swap model valuable.

The repair and swap models (with and without switching options) will each produce different cost saving amounts with different degrees of risk. As a result of real options analysis, the swap model with the switching option to repair is determined to be optimal and has only modest risk. Specifically, the costs would be reduced by $1.3 million (of which $0.9 million is the option value) and by 18% compared to the costs under the current model, and the volatility will only moderately increase from 8% to 11%. However, it should be noted that the model is sensitive to both volatility and switching cost.

Unlike the traditional methodologies, such as optimization or discounted cash flow analysis, real options quantifies the option value as well as the risk and hence shows the maximum investment necessary to obtain the option. That being said, in this thesis, optimization (the news vendor approach), simulation (Monte Carlo simulation), and discounted cash flow analysis take complementary roles to real options analysis. The option value is significant when the key uncertainties (e.g., the product cost, repair cost, and volume) are volatile because the option allows businesses to capture upside opportunities while protecting them from downside risks.

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Finally, I would like to thank my father and brother for their continuous support in our difficult time. This thesis is dedicated to my mother in heaven. I thank my parents for allowing me to take the opportunity to work and study in the U.S. As God has given me so much, I hope to give back in some way by sharing my knowledge through this thesis project at MIT.

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1. INTRODUCTION

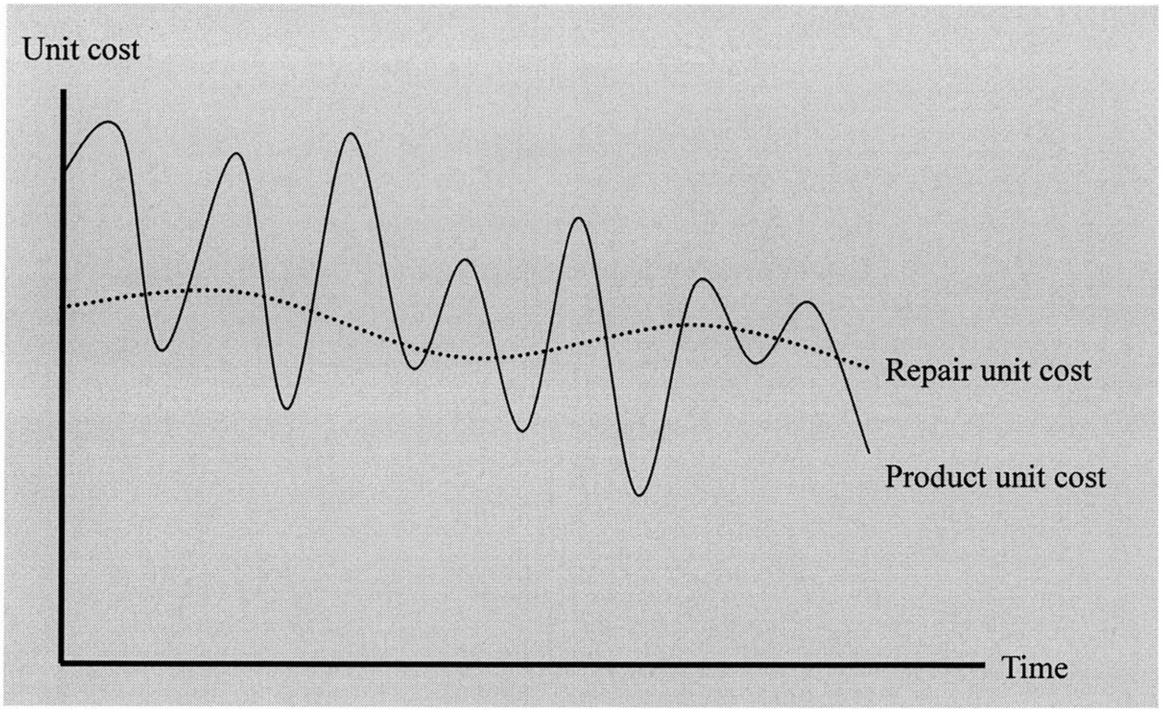
In this chapter, the key research questions and methodology are described. Additionally, the importance of real options in logistics is discussed and a general roadmap of the thesis is provided.

1.1. Background

This thesis addresses the problem of a reverse logistics process for the circuit board business. The objective is to minimize the cost of reverse logistics operations over the next few years. The specific question we ask is, "Which method is the cheapest when you process return products — repairing, swapping, or switching between the two operational models?"

We examine the reverse logistics process of a technology company (called company X hereafter due to confidentiality). The current operational model is to repair return products as much as possible (some return products cannot be repaired and need to be replaced with new products). In recent years, the circuit board market has been growing rapidly, so the new product cost is approaching the level of the repair cost. This is why company X is considering an alternative operational model called the swap model. Under the swap model, all return products are scrapped and new products are shipped to the customer. The issues here are uncertainty in product cost, repair cost, and return volume. Because of the high fluctuation of the product cost as shown in Figure 1, the product cost can become more or less expensive than the repair cost. This makes it difficult to plan an optimal model for the next few years.

Figure 1. Trend of product unit cost and repair unit cost



What makes the planning more complicated is that the repair unit cost is affected by the return volume, which also shows a long term growth trend with volatility. As Figure 2 shows, there are economies of scale in the repair unit cost when the volume increases. This is because the fixed cost of repair operations can be smaller at a per unit level as the volume increases. On the other hand, the new product unit cost is not sensitive to the volume changes, for the new product unit cost does not incur any fixed cost. As Figure 3 shows, due to these economies of scale, the total cost of the repair model can be cheaper than the total cost of the new product swap model. So even though the product unit cost is declining, the increasing trend of the return volume may keep the current repair operation cheaper than the alternative new product swap operation.

Figure 2. Relationship between unit cost and volume

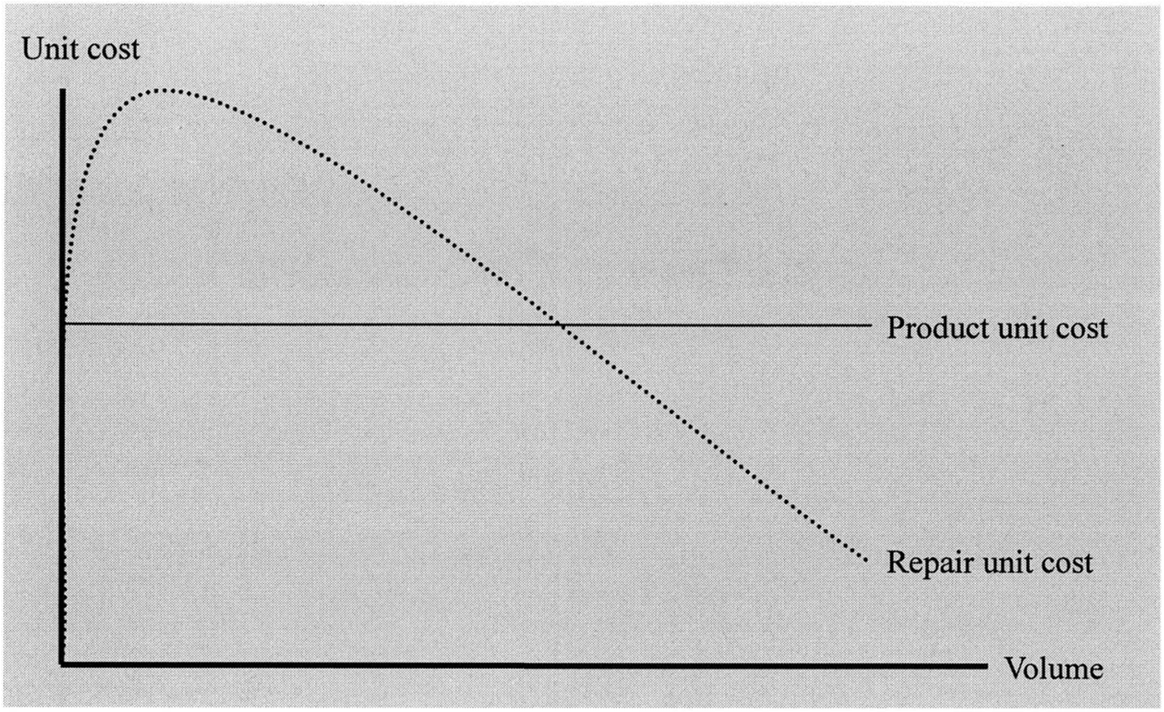
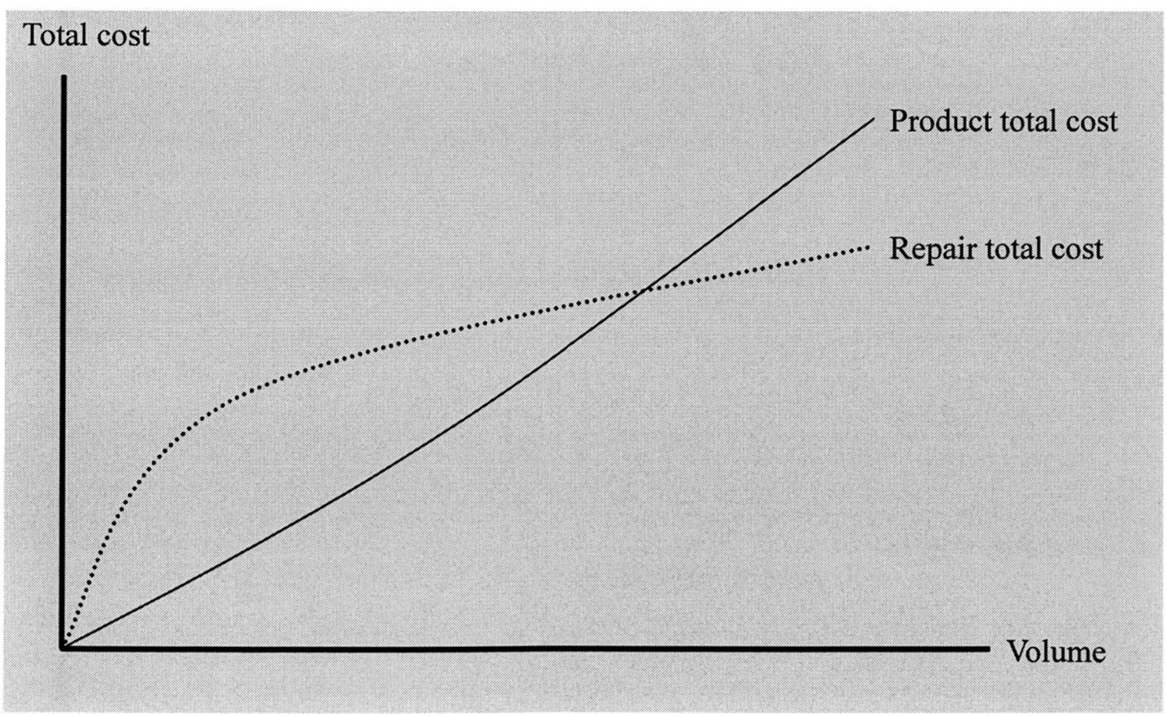


Figure 3. Relationship between total cost and volume



In such an uncertain situation, the switching option between the repair and swap models can become valuable. For example, the new product swap operation can be used as the basic operational model as the product cost is declining in the long run. Meanwhile, the repair operation can be kept as an option to exercise when the product cost becomes higher than the repair cost in the short term fluctuation. In a sense, the repair option for a high value product (some circuit boards have relatively high value) is like auto insurance for an expensive car. When you cannot replace the car with a new one at a reasonable price, you need to use your insurance money to repair it.

However, if the price of the car drops and the price of insurance remains relatively high, you may want to get rid of the insurance. Why spend $200 insurance per month for a $2000 car? If the new product cost drops below the repair cost, why keep expensive repair operations as insurance? Conversely, if the product cost picks up well above the repair cost, it is better to keep the repair option. Keeping the repair option fosters flexibility as a hedging mechanism for the uncertainty in the product cost. It should be noted, however, that keeping the option not only provides value but also costs.

1.2. Research Questions and Motivation

The main research questions to be addressed in this thesis are:

- What is the optimal model for the reverse logistics process, taking into consideration the trend and volatility of the repair cost, the new product cost, and the volume?
- What are the cost savings and risks associated with different models over the next few years?
- What is the value of the switching option between repair and new product swap?

How much should be paid to obtain the option?

- How robust is the optimal model when the variables deviate from the forecasts and assumptions?

Because of the simultaneously changing variables over multi-periods, the optimization approach, which simply chooses the lowest cost model using fixed values for variables, is not appropriate to answer the questions above. Sensitivity analysis may help, but it does not measure the impact of the variables that change simultaneously over the time horizon. Discounted cash flow analysis takes into account the changing variables over time but does not provide the degree of risks or the value of the option. Discounted cash flow analysis with Monte Carlo simulation can show the degree of risks by simulating the variables that follow their probability distributions. However, it cannot provide the value of option. Therefore, real options analysis is used to identify an optimal model with a value of option. The fundamental difference between the simulation concept and the option concept is contingent strategy. Simulation says, "If variables A, B, and C change, X happens." But it does not incorporate chess-like thinking, "If X happens, do Y." On the other hand, the options concept is the contingent strategy, and this is why it makes a significant difference in uncertain situations.

There have been many instances of real options application to capital intensive projects, such as an electric power plant, a gold mine, an oil field, real estate development, and pharmaceutical R&D. On the other hand, real options have rarely been applied to logistics systems or processes (real options have been used to analyze supply chain management, especially supply contract). In the future, real options will become increasingly important in analyzing logistics systems because they are becoming more global, more capital intensive, and more uncertain.

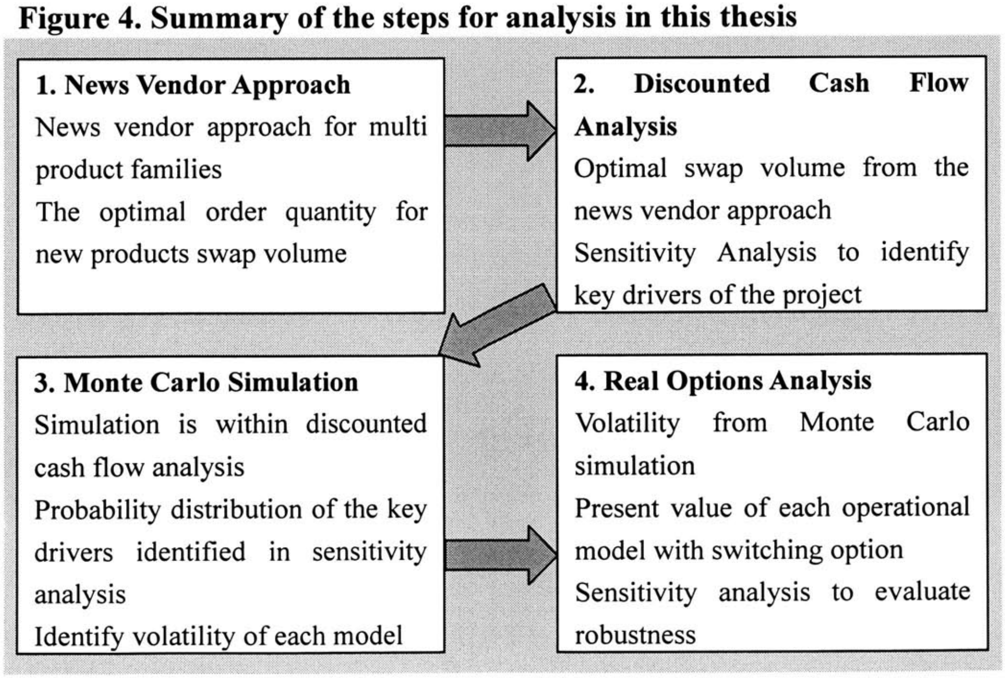
Because of this uncertainty, it is often the case that everyone has subjective prospects and the mentality "there is no right answer" prevails. This is why a warehouse manager mentioned that all logistics consultants gave different solutions for the optimal warehousing location. According to Amram and Kulatilaka [1998], "In volatile markets, where prices and demand are always in flux, it is hard to predict how a particular investment will ultimately influence a company's value. Senior executives spend a lot of time structuring their decisions, tracing possible implications, assigning probabilities, and assessing risk. Rarely, though, does everyone agree about how an investment will play out." Real options would help resolve the difference in personal views by bringing in financial options theory.

There are many potential logistics problems that real options is good at solving. For example, a shipper that normally uses air freight may want to consider obtaining the option of using sea freight in case air freight cost goes up dramatically. This was a problem faced by shippers a few years ago when the air freight cost increased dramatically because of the security surcharge introduced after September 11^{th} and the fuel surcharge increased due to the Iraqi war. In fact, many shippers shifted to sea freight. Another example is that Asia is becoming a world factory, and there is a high concentration of export freights at a few hubs such as Hong Kong, Shanghai, and Singapore. The costs of freight from these hubs are becoming higher, and the capacity is getting tight, so it may be wise to obtain an option to use different logistics hubs to manage freight cost and capacity. Real options helps quantify the value of such options and clarify how much should be paid to keep the option. As real options are becoming important to solve logistics problems, the motivation of this thesis is to show practical steps to apply real options to a logistics problem and demonstrate its effectiveness in the area.

1.3. Roadmap of Thesis

The reminder of this thesis is organized as follows. In chapter 2, the current reverse logistics practice of company X is described and alternative models including switching options are introduced. In chapter 3, the real options literature is reviewed, the concept is introduced, and the steps for conducting real options analysis are described. In chapter 4, to determine the inventory policy applicable to different reverse logistics models, the news vendor approach is used and modified to consider the multi-product lines that company X currently handles. In chapter 5, discounted cash flow analysis, Monte Carlo simulation, and real options analysis are performed to evaluate the cost saving of different models and the value of the switching option. (See Figure 4 for the connections of different analyses.) The sensitivity analysis for the optimal model is also conducted at the end of chapter 5. In chapter 6, the result is evaluated in light of the implementation costs as well as key sensitivities. Finally, areas of further research are discussed.

Figure 4. Summary of the steps for analysis in this thesis



2. COMPANY BACKGROUND

This chapter clarifies the company objective to minimize the cost of the reverse logistics process. Additionally, the current model for the reverse logistics process and the alternative models including the switching option are discussed. Most of the content of this chapter is based on the internal documentation of and the interview with company X.

2.1. Company Objective

In this section, the size and cost of the reverse logistics of company X, as well as the reverse logistics organization and processes are mentioned. At the end of the section, the cost issue is emphasized as a company objective.

2.1.1. Introduction

Company X holds 10% of the circuit board market worldwide. Over the past year, approximately 3% of the circuit boards sold by company X have been returned. This 3% includes products returned as defective (2%) as well as customer stock rotations (1%). Most of the returned circuit boards come from two major customer segments: large electronics manufactures and wholesale distributors who resell circuit boards to small individual customers. Half of the volume is from large electronics manufacturers and half comes from wholesalers. Recently the volume from wholesalers has been growing dramatically.

Operational costs for the reverse logistics process can be divided into repair costs and swap exchange costs. Over the past year, more than $20 million was spent for repairing circuit boards. The cost associated with the swap has grown significantly over the past few years and has now reached $10 million. These figures exclude transportation costs, swap product costs, and inventory holding costs. These costs are not easy to capture because some of them are tracked at the business unit level, while other costs are tracked at the corporate level. There has been pressure to reduce the reverse logistics costs because the circuit board business has become less and less profitable.

2.1.2. Organization and Network

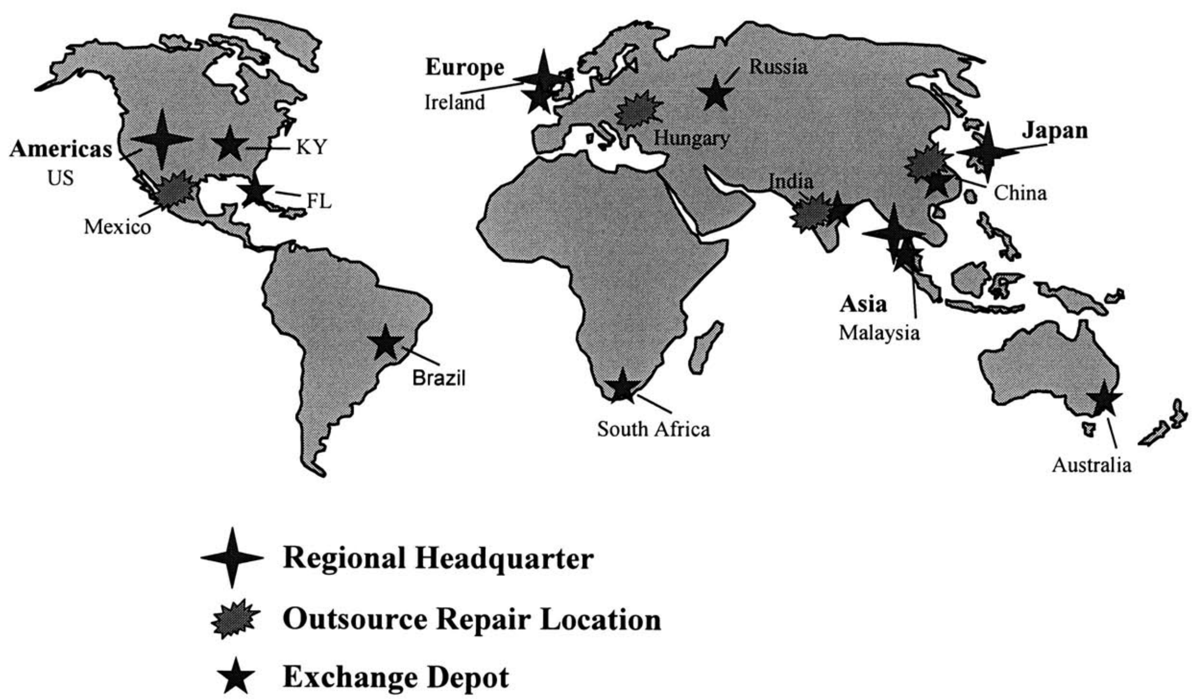
Company X's reverse logistics group serves electronics manufactures and wholesalers by providing warranty repair, product replacement, failure analysis, and credit compensation. The mission of this group is to protect customer loyalty and assist product improvement.

The primary regional headquarters of the reverse logistic group are in the U.S. for North America, in Ireland for Europe, and in Malaysia for Asia. Repair capability is mostly outsourced, with 80% of American operations handled by a contract manufacturer in Mexico and 100% of European operations handled by a contract manufacturer in Hungary. Repair operations in Japan, China, and India are also outsourced.

In-house repair capability is in the U.S., where most sophisticated operation lies, and in Malaysia, where most of the repair volume in Asia is handled. In-house capability has taken an important role in transferring knowledge and skills to the repair outsourcing company. Repair operations at company X have followed the outsourcing trend in its circuit board manufacturing. Most of the effort in recent years has been spent for knowledge transfer to and start up of repair outsourcing, so the forecast for outsourcing repair costs remains uncertain. This is one of the risky factors involved in planning an optimal operational model in the next few years.

Exchange depots for wholesale customers are spread over the U.S., China, Russia, Asia, India, Europe, and Latin America (see Figure 5). All depots are run by third party logistics providers. Unlike the repair operations, the logistics costs paid to the third party logistics providers are relatively stable.

Figure 5. Reverse Logistics Worldwide Network



2.1.3. Return Profile

Returns due to either stock rotations or product failure during the assembly process are termed RMA (return material authorization) returns. Defective RMAs are issued only if items are likely to be repaired. They are restocked to inventory and eventually swapped with return products. Stock rotation RMAs can be put back into inventory.

Circuit boards that failed when used by the end users are called DRA returns (direct return authorization). All returned DRAs are considered broken and are repaired and sent back directly to the customer. DRAs are expected to be repaired within 10 days and RMAs within 30 days. The optimal backlog has tended to be around 4 to 5 days of work to provide good batching. Because RMA repairs are less time sensitive, they are often used to smooth out the repair volume. Volume fluctuations can vary widely from week to week. For example, during an average one week period, the standard deviation of total receipts is 24%. There are also quarter to quarter fluctuations due to seasonality. These standard deviations are less pronounced at 6%, and the annualized standard deviation is 15%.

2.1.4. Repair, Swap, and Scrap Processes

All defective products are first swapped with the products (new or repaired) in inventory. Then the returned products get screened to see whether they are repairable. If they are, they are sent to a repair outsource location, and if not, they are sent to a scrap site. If scrapped, they need to be replaced with new products sent from the manufacturing site of company X at the beginning of each product lifecycle, which is three years. Therefore, this is a single period inventory replenishment, which will be discussed in Chapter 4:

Inventory Policy. While RMA and DRA are handled similarly across customer segments, processes around swap, repair, and scrap are handled differently, depending on whether the customer is a large manufacturer or a wholesaler.

Large manufacturers are served at a depot next to the manufacturing site. The depot provides special service and handles large volumes. Meanwhile, all wholesalers are handled by a regional depot. The volume split between electronics manufacturers and depot is about half and half, as the volume handled by wholesalers has increased dramatically in recent years. This thesis focuses on depot operations in the U.S. as a pilot project. If this project proves to be successful, the model should be rolled out for both wholesalers and electronics manufacturers worldwide. The volume handled by the U.S. depot operation is only 10% of worldwide volume, so the impact can be much more than that of the U.S. depot operation. In any case, it should be noted that only the U.S. depot operation is discussed in the following.

When a defective product is returned to a depot from a wholesaler, it is screened to verify the claimed defection. Currently minor screening at the depot is not implemented for every product, but it is going to start by the end of 2004 to reduce the volume shipped to the repair outsourcing company. Therefore, in this thesis, it is assumed that there is already a minor screening for all products at a depot site, and the screening reduces the current volume by 40%. If there is no defection found through minor screening, the board is sent back to the customer. If defection is confirmed, it is sent from the depot in the U.S. to the repair outsourcing company in Mexico.

When the circuit board is sent through the floor at the repair center in Mexico, it is tested with a mock set-up and then quality inspected. If repair is possible, it is considered a "repair board" and if it cannot be fixed, it is a "scrap board." To determine the cause of a failure, a board may need to pass through debug and repair loops multiple times and undergo subsequent testing. Therefore, the average board goes through some activities more than once, and hence the process can become quite complicated.

While the return product is sent to Mexico, a swap board in the inventory at the depot in the U.S. is sent to customers. This shortens the wait time but is costly to operate from an inventory holding cost perspective. If boards are repaired and placed into inventory, they are subject to having to be re-upgraded if a new mandatory revision is released. Also, inventory must be tracked not only by part number, but also by revision level to ensure no improper down-revision boards are sent to customers. Meanwhile, old leftover boards can hardly be upgraded and replenished to the inventory when stock out occurs.

New swap boards sent from the manufacturing site of company X are used to help replace boards that could not be fixed (scrap) and therefore mitigate credit costs. Credit would otherwise have to be paid to customers when a board under warranty cannot be replaced. Currently, approximately 10% of the return volume is swapped with new products and scrapped. Company X is considering increasing the percentage as the cost of new product is declining compared to repair costs. However, one of the problems with the new product swap process is that it usually ends up leaving excess inventory or stock outs.

2.1.5. Cost Issue

The circuit board business can no longer afford what they have been spending on warranty returns. Competition in recent years has become fierce among the major circuit board manufacturers, and every penny is scrutinized as circuit board manufacturers struggle to break even. Since most of the product cost is materials-related and viewed to be fairly fixed, the remaining costs, such as warranty-related costs are increasingly being examined for any possible savings opportunities.

Additionally, recent industry benchmarking research suggests that company X has spent more money on its reverse logistics, while it provides a lesser degree of customer satisfaction than its competitors. Furthermore, scalability to meet the growing needs of the business is poor, and the gap is going to increase with expected growth in volume, if the reverse logistics process remains the same.

A reverse logistics manager at Company X says, "The only boundary conditions are that the solution cannot negatively impact our current customer terms and conditions (such as service level, etc.), and the savings must be real savings to the company, not saving money for one business unit at the expense of another or 'funny money' type allocation games, which move spending from our books to another's." Clearly, the objective function is to minimize cost subject to the given service level and demand volume.

2.2. Problem Definition

This discusses different approaches to streamline the reverse logistics system. The reverse logistics process is identified as the focus of cost improvement. For the process, both the current and alternative models, including a switching option are discussed.

2.2.1. Approaches

In order to reduce reverse logistics costs, basic questions need to be answered as follows. The answers to the question should vary for each customer segment.

- Who handles reverse logistics operations? Should the operation be kept in-house or outsourced?
- What kind of operational model should be taken? Which is cost optimal with moderate risks, the repair model or the swap model? Is the switching option valuable?
- How long should the lead time be?
- How many repair centers and depots should be deployed?
- Should operations be located in each region, i.e. the U.S., Europe, and Asia? Or should it be centralized at one region?

Below is the example of decision sets for the reveres logistics case.

Table 1. Decisions around reverse logistics system review

Questions	For Whom	Who	What	When	Where	Which region
Description	Customer Segment	In-house or Outsource	Process	Lead Time	Number and Type of Sites	Global or Regional
Examples	Small but highly profitable	In-house	New product swap everything	10 days	3 depots	Global
	Mid customers	Outsource Firm X	Hybrid	15 days	2 depots and 1 repair center	U.S., Europe, Asia
	Large but less profitable	Outsource Firm Y	Repair everything	20 days	1 repair center + 1 depot	Combination

Table 2. Example of decisions around reverse logistics system review

Customer Segment	In-house or Outsource	Process	Lead Time	# and Type of Sites	Global or Region
Wholesalers	Outsource 3PL	New product swap everything	10 days	3 depots	Regional
Large PC Manufacturer	Outsource Contract Manufacturing	Repair everything	15 days	1 repair center, 1 depot	Global

In this example, wholesalers are supported through depot swap operations by third party logistics providers. To maintain relatively short lead times, company X uses a new product swap process in which the depots are scattered to each region. On the other hand, large electronics manufacturers can allow a longer lead time, so company X chooses repair operation, which is handled by outsourcing repair companies that have flexibility and economies of scale. To further leverage economies of scale, company X has globally centralized repair and depot operations at more cost efficient locations, such as China.

In the past five years, company X has made decisions about most of these questions. They have differentiated the service offerings based on the customer segment. They have expanded externalized repair operations significantly by outsourcing 100% of the operation in Europe and 80% of the operation in the U.S. The number of depot locations has been trimmed and streamlined. Company X has determined that regional operations across the U.S., Europe, and Asia make better sense to balance operating costs, labor costs, logistics costs, lead time requirements, and operational and political risks.

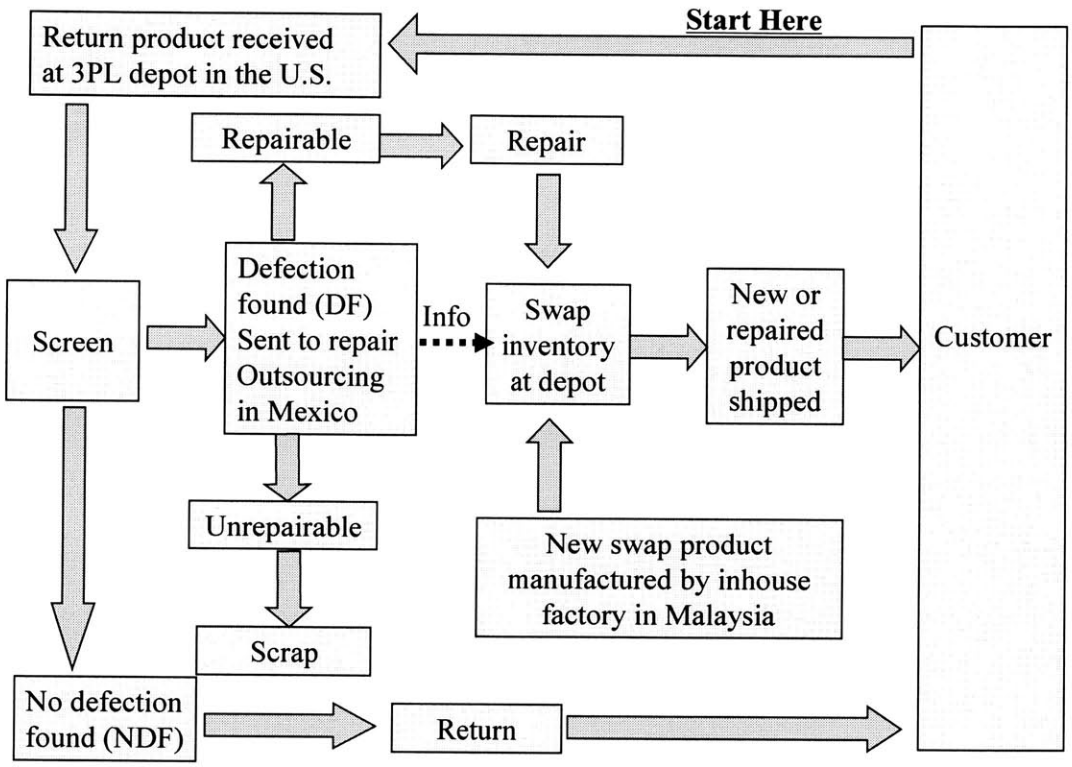
Thus, company X is now turning its attention to the operations process. Cost drivers of operations such as repair costs, product costs, and volumes fluctuate over time, making it difficult to optimize the process. For example, the circuit board market has dramatic month-to-month volume fluctuation, but it shows a long-term growth trend. Repair cost per circuit board can fluctuate, depending on the volume fluctuation and must be reviewed every quarter. The product price, which affects new product swap cost, changes at every product release, but shows a declining trend in the long run. Company X needs to review the operations process models taking these uncertainties into consideration.

2.2.2. Current Model: Repair Everything Model

As it has been implied above, the reverse logistics process review is about how much split should be made between new product swap and repair. The current U.S. depot operation is the so-called repair everything model. Under the repair everything model, 90% of return volume is repaired, and 10% of return volume is scrapped and swapped with new products. The reason why 100% of return volume is not repaired is that 10% of total return volume is too defective to repair: they need to be scrapped and swapped with new circuit boards. The repair everything process is mentioned also in 2.1.4: Repair, Swap, and Scrap Processes. But because this is one of the key concepts in this thesis, the process is explained here. As the following process map shows, the return process of the repair everything model starts when a customer returns a circuit board to company X's depot, a division run by 3PL in the U.S. Once the board is received at the depot, it is screened to confirm whether it is actually defective or not. If no defect is found, the board is returned to the customer. If a defect is found, it is communicated to the shipping operation and a new or repaired board is sent to the customer. Meanwhile, the defective board is sent to an outsourcing company in Mexico to be repaired. If the board is deemed unrepairable through the repair process, it is scrapped. If the board is repaired, it is sent back to inventory in the depot to replace another defective product and be shipped to customers.

Because about 10% of total return volume is deemed unrepairable, new products, which account for 10% of forecasted total volume, are ordered from company X's manufacturing site in Malaysia at the beginning of the release of each product line.

Figure 6. Process map for repair everything model



Total costs for the current repair everything model can be calculated as in the following table and the cost components are explained below. Note that all data is actual data in the year of 2003.

Table 3. Total cost for repair everything model

Current Model: Repair Everything Model	Unit Cost	Volume	Total Cost
Repair Variable	$43	27,899	$1,204,100
Repair Unit	$37		
Repair Logistics	$6		
Repair Overhead			$941,030
New Product Swap Variable	$68	2,968	$202,444
Product Unit	$55		
Product Logistics	$8		
Scrap	$6		
Inventory Carrying	$8	2,905	$23,969
Total Cost			$2,371,543

A. Unit cost

The repair variable cost is the sum of the following cost items.

- The repair unit cost: this is charged by repair outsourcing company.
- The repair logistics cost includes freight and handling between depot and repair outsourcing company.

The repair overhead cost includes the cost of information systems infrastructure for the reverse logistics process and the cost of staff to manage the repair outsourcing company. The overhead cost was approximated in the following manner: the overhead cost at the U.S. depot was considered equal to the worldwide overhead cost times 10%. The 10% came from the volume at the U.S. depot divided by worldwide volume.

New product swap variable cost is the sum of the following costs items.

- The product unit cost is the amount charged at company X's factory in Malaysia.
- The product logistics cost includes freight and handling cost from the manufacturing

site to the depot charged by the third party logistics provider.

- The scrap unit cost includes the logistics cost to the scrap site and the actual scrap process cost.

Inventory carrying cost is defined as the product unit cost times the weighted average cost of capital. Weighted average cost of capital of company X is 15%, which is relatively higher than other industries because of the risky nature of the technology industry.

B. Volume

Repair volume is calculated as follows:

Repair volume = (total returned volume - new product swap volume) x 10/9

Because new product swap volume is first determined at the beginning of the release of each product, new product volume should be consumed first to replace return volume. After all new product volume is swapped, the repaired volume needs to replace the rest of the return volume which is the total return volume minus the new product swap volume. The reason why the difference is multiplied by 10/9 is that 10% of the repair volume does not get fixed as mentioned before, so the volume that goes through the repair process (including repairable and unrepairable items) must be inflated by this percentage.

New product swap volume and inventory carrying volume is determined by the news vendor approach, which is discussed in Chapter 4: Inventory Policy. It should be noted that all inventory for new product swap volume is purchased at the beginning of the year for the next three years of product life cycle. Therefore, this is a single period inventory problem or so-called news vendor problem.

2.2.3. Alternative Model: Swap Everything Model

While the repair everything model strives to repair as much as possible, which is usually 90% of total volume, the swap everything model replaces all return products with new products and all return products are scrapped. Because there is no repair operation, stock out can occur.

As the process map below shows, the return process of the swap everything model starts when a customer returns a circuit board to company X's depot. Once the board is received at the depot, it is screened to confirm whether it is actually defective or not. If no defects are found, the board is sent back to the customer. If a defect is found, it is communicated to the shipping operation and the new board is sent to the customer. Meanwhile, the defective board is sent to a scrap site and gets scrapped. The inventory is replenished by only new products (not repaired products) sent from company X's manufacturing site in Malaysia at the beginning of the release of each product line.

Total costs for the swap everything model can be calculated as in the Table 4. (It is assumed that the alternative model had been taken in 2003.) The cost components are the same as in the repair everything model and they are already explained above.

Figure 7. Process map for the swap everything model

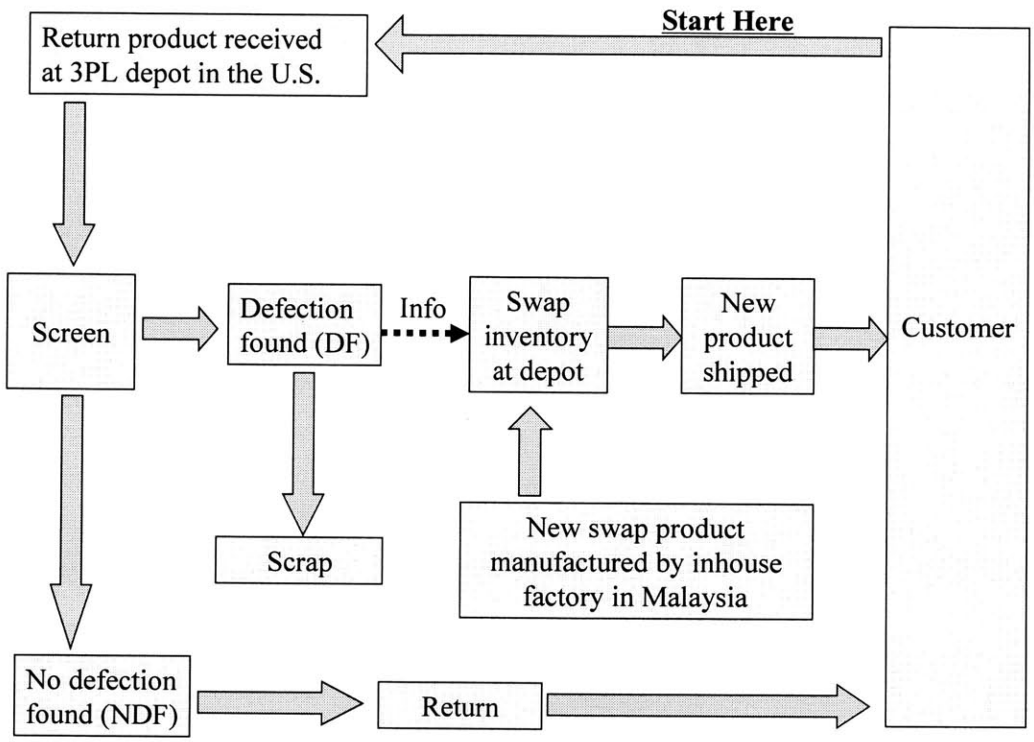


Table 4: Total cost for the swap everything model

Swap Everything Model	Unit Cost	Volume	Total Cost
Repair Variable	$43	0	$0
Repair Unit	$37		
Repair Logistics	$6		
Repair Overhead			$0
New Product Swap Variable	$68	29,684	$2,024,440
Product Unit	$55		
Product Logistics	$8		
Scrap	$6		
Inventory Carrying	$8	29,053	$239,685
Total Cost			$2,264,125

As the total cost tables of the two models show, the swap everything model is slightly more cost effective, that is, about $0.1 million less than the current repair everything model. However, in the reverse logistics process review that examines the optimal model in the next three to four years, this information is not sufficient because the costs and volume change over the time horizon. Therefore, discounted cash flow analysis is more appropriate to evaluate the cost efficiency of the two models. The discounted cash flow analysis for the two models is discussed in Section 5.1: Discounted Cash Flow Analysis.

2.2.4. Switching Option

Another alternative is to keep the swap option with the basis of the repair model. Company X can maintain the repair model as a normal operation, and when the swap model becomes more cost effective than the repair model, company X should exercise the switching option to new product swap. This situation is highly likely because product cost has shown a long term decline with short term fluctuations in response to volatile circuit board volume.

The opposite model, which is the repair model with a switching option to repair, is also possible. Intuitively, this fits the trend of product cost above. In the long run, the product cost is declining, so the new product swap model should be used as the basis, while in the short term the increase in product cost makes the switching option to repair more valuable. Additionally, when there is no more new product to swap, the switching option to repair would prevent a stock out situation.

The switching option is a good alternative to consider rather than just examining the repair everything model or the swap everything model. Switching options in real options analysis can help choose which model is optimal. Real options analysis can not only value the switching option quantitatively but also shows total present value of each model with risk measures if used with the discounted cash flow model. In the next chapter, the recent literature on real options is introduced, examples of switching options are explained, and steps for real options analysis is discussed.

3. METHODOLOGY

In this chapter, the steps to conduct real options analysis are discussed. Specifically, the binomial model and Monte Carlo simulations are explained. Additionally, the literature review on real options and the classifications and approaches within real options analysis are introduced.

3.1. Literature Review

After the literature on real options is reviewed, the literature specifically on logistics problems is introduced. Then, the frameworks and examples of switching options are discussed.

3.1.1. Real Options

Myers [1977] first used the term "real options" when he applied financial options theory to value real assets projects with flexibility. While interest in this subject was limited to academia in the 1980's, interest has increased significantly in the 1990's. In the past decade, not only has the theoretical framework been strengthened but also the application range has been expanded. As a result, practitioners such as management consultants and business analysts have begun to apply the tool for business valuation, project investment, and corporate strategy. Real options have been developed and applied to many areas.

Different types of real options (e.g., timing option, growth option, abandon option, contract option, switching option, and compound options) have been discussed as follows. The value of the timing option to wait for better information was identified quantitatively as most investment decisions are irreversible (Dixit and Pyndick, 1994). Additionally, the growth option of investors for a venture business was explained by real options (Sahlman, 1997). The switching option for closing and reopening a gold mine was also evaluated by real options (Moel and Tufano, 1998 and Luenberger 1998). Compound options were discussed in many cases such as the oil field lease, Ford's investment in fuel cell technology, and R&D in the pharmaceutical industry (Paddock, Siegel, and Smith 1998, Oueslati, 1999, and Schwartz and Moon, 1999). Furthermore, the impact of competition on compound options was examined (Triegrogis, 1996).

Aside from the discussion of these types within real options, various decision-making frameworks related to real options have been developed. In a strict sense, real options is derived from financial options theory, so only the Black-Scholes model or the binomial model should be used. However, a more qualitative approach has been developed (Boer, 2002). For example, decision analysis instead of financial options models was applied to approximate the value of option (Faulkner, 1996). They hybrid method was also used to analyze project risks with real options analysis and market risks with decision tree analysis (Neely and de Neufville, 2001). Moreover, simulation was applied to calculate multiple interacting options on a harbor project (Juan et al., 2002). Finally, the advantages and disadvantages of these different approaches were discussed (Borison, 2003).

Besides the academic discussions above, the practical application process of real options as a consultant and a business analyst have been introduced (Rogers, 2002 and Brach, 2003). Specifically, an underlying asset was defined as the present value of a project and a Monte Carlo simulation was conducted to estimate the volatility of the underlying asset (Copeland

and Antikarov, 2001). Furthermore, a real options software program called Crystal Ball was introduced (Mun, 2003).

3.1.2. Real Options Application to Logistics Problems

The real options application has also expanded to the area of logistics and supply chain management. For example, Hewlett Packard has tried to apply real options to their business operations since the 1990's. As a result, HP has developed a postponement strategy to customize inkjet printers at assembly sites closer to the demand locations as demand uncertainty unfolded (Billington, C., Johnson, B., and Triantis, A., 2002). From an academic perspective, Van Hoek [2001] mentions postponement strategy to retailer order to cope with the seasonal cycle.

In addition to postponement, real options applications are concentrated around supply chain management, specifically supplier relationships. Tan [2001] valued a contingent capacity agreement to meet unexpectedly high demand. Another example is that Pochard [2003] applied real options analysis to value dual sourcing strategies. With real options, sourcing decisions can be adapted to changes in risk parameters. Related to dual sourcing, Sheffi [2001] discussed that redundancy can respond better to supply chain disruptions. Martha and Subbakrishna [2001] also recommended that firms add redundancies in supply resources, transportation modes, inventory stocks, and process. They also discussed that flexibility such as switching option and postponement can replace redundancies.

3.1.3. Switching Option

According to Brach [2003], "switching option captures the managerial flexibility to alter the modus operandi of any given business. This includes exchanging input or output parameters, volume, processes, and global locations. The value drivers of the switching option include the costs saved and additional cash flows generated by having the ability to respond to future uncertainties and change a cost-driving operational parameter."

There are many examples of switching options. GM's plants have the flexibility to switch output from one car model to a different one to respond to demand change in car models. Enron utilized the switching option between different fuel sources to take advantage of cost fluctuations of the fuel sources.

Tufano and Moel [2000] use an example of gold mine operations to illustrate how real options analysis can value the switching options. Let us assume that the average exploitation cost is $300 per ounce and that the international price of gold is currently $350 per ounce. Intuitively, it seems that if the international price falls below $300, the mine field should be closed. However, the following factors make this problem more complicated.

- Fixed costs for closing and restart, such as paying retirement benefits, retraining, and redeploying equipment are high and overall costs may actually increase if the mine is shut down and restarted frequently without keeping fixed assets alive.
- The price of gold fluctuates and is uncertain. Soon after closing the mine, the price may rise above $300 per ounce. Then, the cost to restart would incur the aforementioned fixed costs immediately.

Therefore, maintaining the flexibility to stop and restart would increase the value of mine operations. The value of the flexibility, the switching option, primarily depends on the volatility of fixed costs, price, and exploitation cost.

Another example would be a lay-off policy with partial compensation. By spending partial wages during the lay-off period, an employer can avoid incurring hiring and training costs when business picks up again. But this option should be used only when the value of retaining employees outweighs the cost of the partial wage.

In the technology industry, alternative processes and capacities can provide important flexibility. According to Billington, Johnson, and Triantis [2002], "these processes may differ in terms of fixed cost, variable cost, throughput, or lead time. For instance, a high-volume process with high fixed costs but low variable costs can be used as base capacity to satisfy a large component of expected demand. If demand exceeds this base level, additional capacity with lower fixed but higher variable costs can then be brought on to manage such short-term fluctuations."

In this thesis, real option analysis will show the value of the option to switch between repair and swap models. The option value will be the maximum amount that company X should spend to keep the switching option. While it is reasonable to keep options open just in case, keeping options open comes at a cost. What makes the theory of real options useful is that it quantifies the value of options so that you know how much you should spend to obtain the option. The framework of real options is explained in the following section.

3.2. Real Options Analysis

This section explains the mechanics of real options analysis. Specifically, the binomial model and Monte Carlo simulations are explained. Then the four steps to conduct the analysis are developed. Different classifications and approaches within real options are also introduced.

3.2.1. Introduction

Real options is like call and put in financial options. The call option is the right to buy stock if the stock price becomes higher than the predetermined price under the call option. Basically this is "riding gains" when outcome becomes favorable. The put option purchases the right to sell a stock when the stock price becomes lower than the predetermined selling price under the put option. This is an example of "cutting losses" when outcome becomes unfavorable.

In the case of the swap model with a switching option to repair, the call option is like exercising the repair option when the product cost rises above the repair cost. Similarly, the put option is like switching back to the swap model when the product cost falls back below the repair cost. The term "real options" means options on real assets, such as logistics processes, facilities, locations, etc., instead of financial options on stocks and bonds.

Because options minimize downside risks while taking advantage of most upside opportunities, they become valuable under uncertainty, where risks can swing in both a positive and a negative direction. The following is an example of how options make it possible to capture most of the upside swing while protecting against most of the downside swing and hence produce better expected profit without options.

Let us assume that a $200 stock can increase to $300 or decrease to $100 with a probability of 50% in one month. If you purchase the $200 stock now to sell it in one month, there is a 50% risk that you could lose $100, while you could also make $100 with the same probability. Therefore, the expected profit of the investment is calculated as follows.

$\$0 = 50\ \% \times \$100 + 50\% \times (-\ \$100)$

Meanwhile, if you pay the option price of $20 and obtain a call option with the predetermined exercise price of $200 in one month, you will be able to buy the stock with the $200 when the actual stock price goes up to $300 in one month. By taking advantage of the upside opportunity, you can make a profit of $80 ($100 (capital gain) - $20 (option price)). Even if the stock price drops to $100, you are not obliged to purchase and just lose the small option price. Consequently, the expected profit becomes as follows.

$\$30 = 50\ \% \times \$80 + 50\% \times (-\$20)$

Table 5 shows that the value of the option is $30, the difference between the expected profit with and without option.

Table 5: Value of call option

	Loss of 50% Probability	Profit of 50% Probability	Expected Profit
Without Option	\$100	\$100	\$0
With Option	\$20	\$80	\$30

3.2.2. Classifications and Approaches of Real Options

Before discussing the classification and approaches of real options, other decision-making frameworks closely related to real options should be discussed to emphasize the usefulness of real options under uncertainty. According to Amram and Kulatilaka [2001], other frameworks have the shortcomings that real options can overcome in the following ways.

- Scenario-based discounted cash flow method

  The traditional discounted cash flow (DCF) model does not consider uncertainty, as it assumes single values for each variable. Meanwhile, managers can use DCF even under uncertain situations if DCF is performed in different scenarios. However, the problem of scenario-based DCF is that the probability of each scenario is set subjectively. Additionally, there is no chess-like thinking, i.e. "if A happens, do B." Scenario-based DCF simply says, "If A happens, the result would be C." So it does not consider contingent strategies under uncertainty.

- Decision analysis (or decision tree analysis)

  This portrays the decision framework with a decision tree, which incorporates chess-like thinking i.e. "if A happens, do B." This is easy to understand, but in decision analysis, managers still have to set probabilities subjectively. If they avoid quantification because of subjectivity, the analysis becomes qualitative and can be useful for creating strategy. However, it fails to become an investment decision framework.

- Simulation

  Simulation provides thousands of values for each variable, following given mean value and probability distributions of the variable. As a result, mean value and probability distributions of the outcome can be captured, and hence, risk can be assessed. However, simulation does not provide contingent strategies.

Real options analysis incorporates contingent strategies and uses objective probability under no-arbitrage assumption, the first principle of financial theory. Let us assume that IBM is trading at $100 in New York, GBP 60 in London, and JPY 11,000 in Tokyo. As a result of arbitrage behavior of investors taking advantage of the different prices in the three markets, all the prices in these markets converge into one and there is a no-arbitrage opportunity in the financial markets. This assumption of the financial theory is applied to real options and this is why returns of all projects converge into the risk free rate (this is typically the short term interest rate of the U.S. government bond). Based on the risk free rate and the volatility of projects, the risk neutral probability of the up and down of an underlying asset is determined. This is the ground that probabilities used in real options are objective. This will be explained in Section 3.2.3: Binomial Approach.

While the above is about decision frameworks related to real options, there are different classifications within real options. Amram and Kulatilaka [2001] divide real options into three categories: operational, investment, and contractual.

- Operational option

  This option provides the flexibility to change inputs and outputs in response to changes in operational factors such as price, cost, and volume. The switching option is one of the operational options.

- Investment option

  This is about whether to modify investment decisions during the project. A typical case is adjusting investment scale or timing, e.g. expand, contract, delay, or abandon a project. This classification has been the major area of real options application.

- Contractual option

  An example of a contractual option would be that venture capitalists maintain special contractual clause to give the right to sell the asset of the venture business.

In addition to these classifications, there are different approaches within real options. Some of the most popular approaches are the Black Scholes model and the binomial model. According to Mun [2003], Black-Scholes is easy and quick to implement because all you need to do is to find the value of inputs to the Black-Scholes equation and calculate the equation. But it is difficult to explain because it requires knowledge of high level calculus. Additionally, there are many conditions required by the Black-Scholes model as follows:

- Options can be exercised only during the maturity period. This is called European options as opposed to American options that can be exercised anytime until the maturity period.
- There is only one uncertain factor and are no multiple uncertainties.
- There is only one option. Therefore, compound options cannot be applied.

- There is no dividend paid by the underlying asset.
- Price and volatility of the underlying asset is market traded and observable.
- Volatility of the underlying asset is fixed over time.

Because many real option cases do not meet the conditions required by the Black-Scholes model, the binomial model is normally used.

3.2.3. Binomial Model

Unlike Black-Scholes, the binomial model developed by Cox, Ross, and Rubenstein [1979] is easy to explain to business practitioners and is flexible enough to be applied to various cases in real options. The basic inputs of the binomial lattice and the description are as follows:

S: value of underlying assets, i.e. the present value of a real assets project ("S" has come from the capital letter of Stock price in financial options theory)
According to Copeland and Antikerov [2001], in many cases of real options, the underlying asset, a value of a project, is not publicly traded, unlike stocks and bonds defined as underlying assets in financial options. For example, revenue or operational costs that can be an underlying asset of a real asset project are not publicly traded and their volatility is not observed in the market. Therefore, it is assumed that the present value of the project itself is the underlying assets. This assumption is called market asset disclaimer (MAD).

X: price of exercising option
This is the cost to exercise the option. Examples would be the cost to buy additional

capacity for the expansion option or the cost to switch one mode of operation to another for switching option.

σ: volatility of the present value of the underlying asset

Volatility measures how hard it will be to predict the underlying asset's value into the future. According to Mun [2003], volatility is "the standard deviation of the lognormal growth of the present value of the cash flow at the current moment to the present value of cash flow at the next period. This can be expressed as follows.

$$Volatility = \sigma\left[Ln\left(\frac{PVt=1}{PVt=0}\right)\right]$$

It is important to note that only the numerator is simulated and the denominator is unchanged." The reason why volatility is the standard deviation, not of the present value itself but of the growth rate of the present value, is to measure the fluctuation around the growth trend and eliminate the trend factor and extract the risk factor.

He also adds that volatility can be "annualized value: multiplying it by the square root of stepping time breaks it down into the time-step's equivalent volatility. Stepping time is simply the timescale between steps. That is, if an option has ten steps in one year maturity, each stepping time becomes 0.1 years."

$$Volatility = \sigma\left[Ln\left(\frac{PVt=1}{PVt=0}\right)\right]\times\sqrt{\frac{T}{n}}$$

Where σ: standard deviation

T: maturity period or project period

n: time-step: the number of times that option can be exercised per the basic time unit

Monte Carlo simulation provides the probability distribution and standard deviation of the lognormal growth rate. What it does in short is to show how the growth of present value of a project from time 0 to time 1 can change when inputs such as the repair cost, the product cost, and the volume change, following the given mean and standard deviation. The reason why the volatility is the standard deviation of the growth rate and not of the mean value of the present value of the project is to eliminate the trend factor and to measure the up and down factors around the trend. In other words, the volatility shows how unpredictable the present value of the project can be. Therefore, high volatility means high risk (both downside and upside).

rf: risk free rate or the rate of return on a riskless asset
This can be the interest rate of the U.S. short term government bond. Under no-arbitrage opportunity assumption, returns (growth rates) of all real asset projects converge into the risk free rate.

u: up factor
While returns of all real assets projects converge into the risk free rate, volatility remains specific to each project as risks remains different from project to project. The up factor is defined as the exponential function of the volatility multiplied by the square root of stepping time. The equation is as follows.

$$u = e^{\sigma\sqrt{\frac{T}{n}}}$$

In the Excel spreadsheet, this equation can be expressed as below:

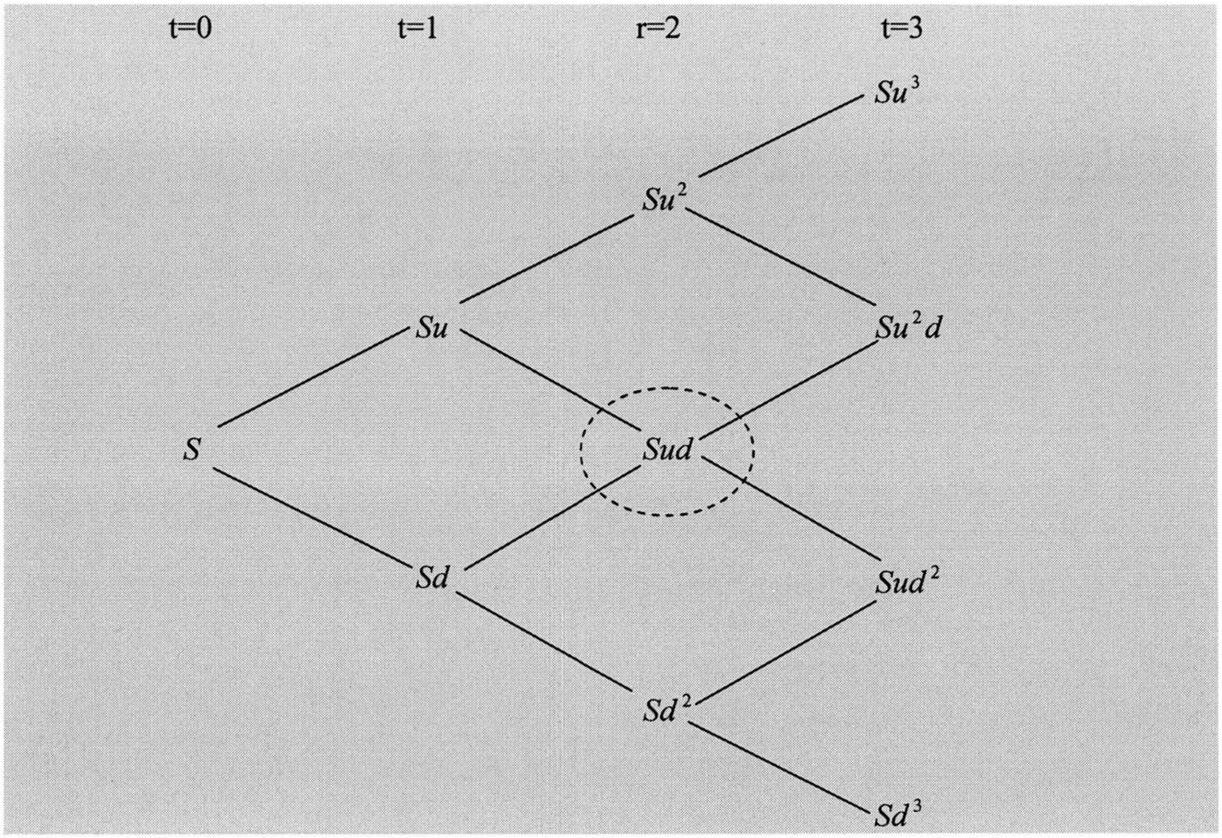
$$u = EXP(\sigma*(SQRT(T/n)))$$

The stepping time is already explained in the section of volatility. As the value of the time step increases, the level of granularity, i.e. accuracy, increases and the result of the binomial model becomes similar to that of Black-Scholes (Copeland and Antikarov, 2001).

d: down factor

Down factor is simply the reciprocal of the up factor because of the assumption that the value of the underlying asset follows a multiplicative probability process (or geometric process). The multiplicative process is widely used, as opposed to the additive probability process (or arithmetic process), because the multiplicative process follows lognormal probability distribution that does not take negative values. Because of the multiplicative process, the binomial tree becomes recombining. "Recombining" means that the up and down trees meet at the node circled in Figure 8 below, and the multiplication of the two factors become 1 by the definition of the multiplicative process.

Figure 8. Binomial lattice



p: risk neutral probability for the up factor

Let S an expected present value of a project: let u up factor in one year and let d down factor in one year. The expected value of the project in one year is:

$$Su \times p + Sd \times (1 - p)$$

Meanwhile the project grows with risk free rate because of the no-arbitrage assumption, so the expected value in one year is:

$$S(1 + r) \text{ or } Se^{r}$$

Therefore, the risk neutral probability is obtained as follows.

$$Su \times p + Sd \times (1 - p) = S(1 + r)$$

$$\therefore \; p = \frac{(1 + r - d)}{(u - d)}$$

q: this equals to (1-p) and is the risk neutral probability for the down factor

p and q are mathematical intermediates to ensure risk neutrality of the binominal lattice.

With the inputs above, binomial lattice can be built and the lattice shows how the present value changes over time following the up and down factors. In Figure 8 in the previous page, in period 1, S (present value of project i.e. price of the project) becomes Su with risk neutral probability of p or Sd with risk neutral probability of u. In period 2, S becomes Su^2 or Sud or Sd^2. Because of the reciprocal magnitude (ud=1), lattices recombines at the circled area. In period 3, the range of the present value is between Sd^3 and Su^3.

High volatility makes the value of the up and down factors large as shown in the equation in the up factor above. So the large value of the up and down factors makes the range of values between the upper and lower branches wider. On the other hand, the low volatility will make the range smaller. At the extreme where volatility equals zero, the lattice collapses into a straight line. This means that no volatility and no uncertainty, and hence, discounted cash flow analysis can be applied. If there is uncertainty and volatility is high, the options can better help protect the downside risk while taking advantage of the upside opportunity. The actual calculation of the options through the binomial tree is explained in Section 5.3.1. Repair Model with Switching Option to Swap.

3.2.4. Monte Carlo Simulation

The purpose of Monte Carlo simulation is to obtain the volatility of the present value of project. As discussed above, volatility is the key input for the binomial lattice and only without volatility, real options analysis cannot be performed. Through the simulation, it can be observed how the lognormal growth of present value of project fluctuates and forms a probability distribution as well as standard deviation (volatility) when value drivers such as volume and costs change randomly, following given mean and standard deviation.

The name of Monte Carlo simulation came from a gamble city called Monte Carlo in Monaco. The randomness of gamble is similar to how Monte Carlo simulation randomly generates values for uncertain variables over and over, following a given probability distribution. The purpose of simulation is to analyze the effect of varying inputs on the output. This is useful especially when optimization is too complex to solve. Normally software such as Crystal Ball® is used for performing large scale simulations.

3.2.5. Steps for Real Options Analysis

The steps to conduct binomial model with Monte Carlo simulation are described by Copeland and Antikerov [2001]. The following is the modified version that clarifies practical procedure rather than conceptual steps that Copeland and Antikerov mention.

- Phase 1: Create a discounted cash flow model to obtain the present value of the project. The values for the inputs for the discounted cash flow model need to be forecasted through the project period based on historical data, market projection, and management insights.

- Phase 2: Obtain volatility (standard deviation of lognormal growth) of the present value of the project through Monte Carlo simulation. Value drivers of the project i.e. key inputs of the discounted cash flow model are identified through the sensitivity analysis. Mean and standard deviation for the value drivers are necessary inputs to run Monte Carlo simulation.

- Phase 3: Build a binominal tree of the present value of the project. The volatility, risk free rate, project period, and steps per year are the key inputs to the build binomial tree.

- Phase 4: Build a binominal tree of the present value of the project with option and compare the result with the present values of the project without option. Naturally, the difference is the value of option. In order to examine the robustness of optimal model and option, sensitivity analysis should be conducted when value drivers for DCF model and/or inputs for real options analysis change. Finally, sanity check on results should identify mistakes in calculation or discover insights that qualitative analysis would not have gained.

4. INVENTORY POLICY

In this chapter, inventory policy, specifically the single period inventory policy is introduced. In order to meet the specific situation currently faced by company X, the news vendor approach for multi product lines is developed.

4.1. News Vendor Approach

When new product is released, the forecast of return demand is conducted. Usually the return volume is between 2.5% to 3% of the total expected sales volume. Under the current repair everything model, 10% of the return volume need to be swapped with new products, for this 10% cannot be usually repairable. Therefore, new circuit boards of 10% of return volume are sent from the factory in Malaysia into the depot in the U.S. at the beginning of the product release. The period is the only time that the inventory can be replenished through the three-year product lifecycle. In the literature, this situation is referred to as news vendor approach or single period inventory problem.

When company X decides the order quantity of new product swap, it shall consider trade-off between the costs resulting from leftover and the costs resulting from stock out and lost sales on the other. This trade-off is evident when considering a single-period inventory decision process, where company X orders all the swap volume at the beginning of the product life cycle for the next three years guarantee period.

According to Sheffi [2003], the solution to the single period inventory problem is based on maximizing the expected profit as the objective of an optimal solution. This maximization balances the risk of "underage" (running out) with the risk of "overage" (having too many). The cost of "overage" is product cost, etc. and the cost of "underage" is the loss of customer loyalty, etc. Consequently, the critical ratio, that is to say, the optimal cumulative distribution can be interpreted as:

$$Critical\ Ratio = \frac{(Underage\ Cost)}{(Underage\ Cost + Overage\ Cost)}$$

In the case of company X, the underage cost and the overage cost is calculated as follows.

Table 6. Overage and underage costs

	2004 Cost	Discounted Cost
Overage Cost	**$65**	**$64**
Product Unit Cost	$52	$52
Product Logistics Cost	$8	$8
Scrap Cost	$6	$4
Underage Cost	**$92**	**$70**
Credit	$60	$45
Relationship with Customer	$32	$25
Relationship with Customer %	50%	50%

Overage cost is the cost when there is no return demand even though the product unit cost, the logistics cost, and the scrap cost were already paid for the return demand. Therefore, the overage cost is defined as the sum of these costs.

On the other hand, a component of the underage cost is the credit value that is paid to customer when company X cannot replace defective product under warranty. Another component of the underage cost is the customer loyalty cost, which is difficult to measure. Because it is hard to measure, the customer relationship ratio is used to give some range in the company's perception on the customer loyalty cost. In this case, it is assumed that the customer loyalty cost is the overage cost multiplied by the customer relationship ratio. Underage will cause future overage because customer who faced underage may not buy the product again. So the overage cost can approximate the impact of the loss of customer loyalty. The calculated overage cost is $62 and the credit value is $60 so the amount of loyalty cost seems to be reasonable. The customer relationship ratio depends on how much company X values customer loyalty. The ratio should be determined by the company strategy that prioritizes the cost over the service level or vice versa. If the cost is the objective function and the service level is the constraint, the ratio may be defined low and if the service level is the objective function and the cost is constraint, the ratio should be set high. In this case, it is assumed that company X is taking neither of the extremes and the ratio is assumed to be 50%. The sensitivity analysis is performed in 5.4.2. Other Sensitivities.

The data in 2004 in the table above should be discounted as some of the costs will be incurred at the end of the three-year warranty period. While company X currently faces the product cost and the product logistics cost, it will face the scrap cost, the credit, and the customer loyalty cost at the end of the three-year product life cycle. Therefore, these costs need to be discounted by the weighted average cost of capital for company X so these costs in 2004 are divided by 1.15^2.

Now that the overage cost and the underage cost are calculated, the critical ratio i.e. the optimal cumulative distribution can be obtained as follows.

$$Critical\ Ratio = \frac{70}{(70+64)} = 52\%$$

This means that the optimal distribution is a little bit more than the expected demand. This is because the underage cost is higher than the overage cost. As we change the customer relationship ratio, this critical ratio will change accordingly. For example, if customer relationship ratio is 0%, the critical ratio becomes 42% and if the customer relationship ratio is 100%, the critical ratio is 60%. 52% is reasonable because it is closer to the company X's current practice of 50% than are the two extremes.

4.2. News Vendor Approach for Multi Product Lines

The reverse logistics processes for multiple product lines (or multiple product families) are operated simultaneously by company X. Therefore, the news vendor approach should be applied to the multiple items.

The assumptions here are as follows.

- Each product family is released once a year every year.
- The annual growth rate for the return volume is 12%. For example, the swap demand of product family B is 1.12 times the swap demand of product family A.
- The life cycle (warranty period) of each product is three years. This applies to all product families.
- Demand distribution of the three-year period is 60% for the first year, 30% for the second year, and 10% for the last year. This applies to all product families.
- Demand distribution is normal distribution and coefficient variance is 15%. This also applies to all product families.

Under the repair everything model, the new product swap volume is approximately 10% of total return demand because the 10% is usually unrepairable. Total demand in 2003 was 27,899 so the new product swap volume was 2,790. It should be noted that the swap volume is the sum of the swap demands for all product families during the year 2003.

Meanwhile, swap volume for product A for the entire life cycle is 2,345. This number is calculated so that the total swap demand in 2003 becomes 2,790. Now that the mean demand for product family A, its standard deviation, and the critical ratio are obtained, the optimal order quantity for product family A can be drawn. The optimal order quantity is the value of the inverse function of the cumulative distribution function of normal distribution with the given mean and standard deviation. So the following equation should be used in an Excel spreadsheet.

Swap Order Quantity = NORMINV(critical ratio, swap demand mean, swap demand mean * coefficient variance of swap demand)

Below is the table of the news vendor approach for multi product families.

Table 7. News Vendor Approach for Repair Everything Model

	Life Cycle	2003 (t=-1)	2004 (t=0)	2005 (t=1)	2006 (t=2)	2007 (t=3)
Product Family Total						
Swap Demand		2,790	3,122	3,497	3,917	4,387
Swap Order Quantity		2,968	3,325	3,724	4,170	4,671
Average Inventory		2,905	3,253	3,643	4,080	4,570
Leftover		21	23	26	29	33
Stock Out		0	0	0	0	0
Product Family A	Released in 01					
Swap Demand	2,345	237				
Swap Order Quantity	2,366					

Average Inventory		139				
Leftover		21				
Product Family B	Released in 02					
Swap Demand	2,627	788	263			
Swap Order Quantity	2,650					
Average Inventory		680	155			
Leftover			23			
Product Family C	Released in 03					
Swap Demand	2,942	1,765	883	294		
Swap Order Quantity	2,968	2,968				
Average Inventory		2,086	762	173		
Leftover				26		
Product Family D	Released in 04					
Swap Demand	3,295		1,977	989	330	
Swap Order Quantity	3,325		3,325			
Average Inventory			2,336	853	194	
Leftover					29	
Product Family E	Released in 05					
Swap Demand	3,691			2,214	1,107	369
Swap Order Quantity	3,724			3,724		
Average Inventory				2,616	956	218
Leftover						33
Product Family F	Released in 06					
Swap Demand	4,133				2,480	1,240
Swap Order Quantity	4,170				4,170	
Average Inventory					2,930	1,070
Leftover						
Product Family G	Released in 07					
Swap Demand	4,629					2,778
Swap Order Quantity	4,671					4,671
Average Inventory						3,282
Leftover						

Because the critical ratio is 52%, the order quantity is always slightly larger than the demand mean. Therefore, the leftover volume is the order quantity minus the demand mean. In case of product family A, the leftover volume is 21=2366-2345 in 2003. The swap demand for product family A in 2003 is 10% of the swap demand during the life cycle, for this is the last year of its life cycle and it is assumed that only the last 10% is the demand for the year. The average inventory for product family A in 2003 is the leftover volume plus the demand in 2003 divided by two.

Explanation if the data for product family B is as follows. Swap demand is 12% more than that of product family A due to the assumption of the annual growth rate of 12%. Swap demand in 2003 is 30% of the life cycle demand and that in 2004 is 10% of the life cycle demand. The swap order quantity can be drawn from the demand mean and the equation above. The leftover is the order quantity minus the swap demand during the life cycle. The average inventory in 2004 is the leftover plus the swap demand in 2004 divided by two. The average inventory in 2003 is the leftover plus the swap demand in 2004 plus the swap demand in 2003 divided by two.

Explanation for the data for product family C is as follows. The swap demand is 12% more than that of product family B. The swap demand in 2003 is 60% of the life cycle demand as this is the first year. In 2004 and 2005, the swap demand is 30% and 10% respectively. The swap order quantity is again drawn from the news vendor approach. Because the swap volume order is made in 2003, the value should be shown in 2003 as well as in the life cycle cell. The leftover is again the swap demand during the life cycle minus the swap order quantity. The average inventory in 2005 is the leftover plus the swap demand in 2005 divided by two. Average inventory in 2004 is the leftover plus the swap demand in 2005 plus the swap demand in 2004 divided by two. The average inventory in 2003 is the swap order quantity minus the swap demand in 2003 divided by two. This process is applied to the rest of the product families.

The figures in the product family total are the sum of the product families from A to G. It should be noted that the leftover is not the swap demand minus the swap order quantity at the aggregate level because leftover is calculated at each product family level. A similar table can be drawn for swap everything model, which is shown in Section 5.1.3. Swap Everything Model. The swap demand for product family A is the total return volume for product family A times the swap percentage, so the swap percentage determines the swap volume (in the case of the swap everything model, it is 100%). The swap volume for product family A determines the swap volumes for the rest of the product families because of the annual growth rate of 12%.

5. ANALYSIS AND RESULT

This chapter is the core of this thesis: discounted cash flow analysis and real options analysis are applied to evaluate the different models (the repair everything model, the swap everything model, the hybrid model, the repair model with a switching option to swap, and the swap model with a switching option to repair). As a result of this analysis, an optimal model is identified. The sensitivity analysis for the optimal model is conducted: key sensitivities as well as other sensitivities are identified.

5.1. Discounted Cash Flow Analysis

Discounted cash flow analysis is the first step in conducting real options analysis. The strength of discounted cash flow analysis is that it can evaluate the value of a project over the time period. The weakness is that values of inputs are fixed, so the result can be changed easily when the inputs actually end up different from the assumptions.

5.1.1. Scope of Project

Though the scope is mentioned in Section 2.1.4: Repair, Swap, and Scrap Processes, it should be repeated again and the following analysis should be clarified. The geographical scope of the reverse logistics review project is the depot operations in the U.S. and the repair outsourcing location in Mexico. The role of the depot is to swap returned circuit boards with those in inventory and send them to customers. Some of the swapped circuit boards are new products and most are repaired products sent from the repair outsourcing location. Meanwhile, all returned products are screened at the depot and defective products are sent to the repair center in Mexico. Once repaired, the boards are sent back to inventory in the depot in the U.S. The depot inventory is also replenished with new products from the factory in Malaysia.

The depot serves only the wholesalers, and the wholesalers, in turn, distribute circuit boards to individual customers. Large electronics manufacturers are served by depots located at customers' sites. To simplify the calculation of cost, especially the logistics costs, this thesis does not include the analysis of these depots at large manufacturers. However, once the decision framework has been identified for the pilot depot operation, it can be applied to other operations and geographies. Then, all operations at all locations will implement the optimal model generated through the decision framework discussed in this chapter.

5.1.2. Repair Everything Model

Discounted cash flow analysis for the repair everything model is as follows.

Table 8. DCF analysis for repair everything model

	2003 (t=-1)	2004 (t=0)	2005 (t=1)	2006 (t=2)	2007 (t=3)
A. Unit Cost					
Repair Variable	$43	$43	$43	$43	$43
Repair Unit	$37	$37	$37	$37	$37
Repair Logistics	$6	$6	$6	$6	$6
New Product Swap	$68	$65	$62	$59	$56
Product Unit	$55	$52	$49	$46	$43
Product Logistics	$8	$8	$8	$8	$8
Scrap	$6	$6	$6	$6	$6
Inventory Carrying	$8	$8	$7	$7	$6
Stock Out	$70	$70	$70	$70	$70
B. Volume					
Return Demand	27,899	31,247	34,996	39,196	43,899
Repair Volume	27,899	31,246	34,996	39,195	43,899
Swap Order Quantity	2,968	3,325	3,724	4,170	4,671
Average Inventory	2,905	3,253	3,643	4,080	4,570
Stock Out	0	0	0	0	0
C. Total Costs					
Repair Subtotal	$2,145,130	$2,289,622	$2,451,453	$2,632,704	$2,835,705
Repair Variable	$1,204,100	$1,348,592	$1,510,423	$1,691,674	$1,894,675
Repair Overhead	$941,030	$941,030	$941,030	$941,030	$941,030
Swap Subtotal	$202,444	$215,766	$230,108	$245,560	$262,225
Inventory Carrying	$23,969	$25,225	$26,557	$27,959	$29,435
Stock Out Cost	$0	$0	$0	$0	$0
Total Cost	$2,371,543	$2,530,613	$2,708,117	$2,906,223	$3,127,365
WACC		15%	15%	15%	15%
Discount Multiplier		100%	87%	76%	66%
Present Value of Total Cost		$2,530,613	$2,354,885	$2,197,522	$2,056,293
Present Value of Project Cost		$7,083,020	$6,608,700		

The base year is 2004 and the project period is through 2007. The data in 2003 is actual data and the rest of the data are forecasts based on the 2003 data. The cost structure of the repair everything model in 2003 is already mentioned in Section 2.2.2: Current Model: Repair Everything Model. The product cost is forecasted to drop by 6% per annum and return demand is expected to increase by 12% annually.

The swap order quantity, average inventory, and stock out volume are derived from the result of the news vendor approach shown in Section 4.2: News Vendor Approach for Multi Product Lines. The repair volume is calculated as follows:

$$\text{Repair Volume} = (\textit{Total Return Volume} - \textit{New Product Swap Volume}) \times \frac{10}{9}$$

Because the new product swap volume is first determined by the news vendor approach at the beginning of the product release, the new product swap volume should be consumed first. After all new product volume is swapped, the repaired volume needs to replace the rest of the return volume, which is the total return volume minus the new product swap volume. The reason why the difference, which is the repairable volume, is multiplied by 10/9 is that 10% of the repair volume does not get fixed, as mentioned before. So the repair volume that goes through the repair process, including both repairable and unrepairable, is the repairable volume times this percentage.

The weighted average cost of capital for company X is 15%. So the discount multiplier is (1/1.15)^t and the present value of the total cost is equal to the total cost multiplied by the discount multiplier. The present value of the project cost equals to the sum of the present values of the total cost across the three periods. So the present value of the project cost from 2004 to 2006 is about $7.1 million and the present value of project cost from 2005 to 2007 is about $6.6 million. The investment cost is zero, as this is the current model, so the net present value of the project cost equals the present value of the project cost.

DCF analysis is usually run for projects that bring in profits, but in this case, cost is the measure of the value of the project. So it should be noted that the smaller present value means smaller costs and greater value of the project, unlike under normal DCF analysis.

5.1.3. Swap Everything Model

In Section 2.2.3. Alternative Model: Swap Everything Model, the model was discussed as an alternative. DCF analysis should be conducted for the model to evaluate the project value compared to that of the repair everything model.

Before DCF analysis for the swap everything model, the swap order quantity, average inventory, and stock out volume needs to be derived from the news vendor approach. The result of the news vendor approach is as presented in Table 9. Note that the values in the swap model where 100% is the swap ratio are simply ten times as much as that in the repair everything model where 10% is the swap ratio.

Table 9. News vendor approach for swap everything model

Life Cycle	2003 (t=-1)	2004 (t=0)	2005 (t=1)	2006 (t=2)	2007 (t=3)
Product Family					
Total					
Swap Demand	27,899	31,224	34,971	39,167	43,867
Swap Order Quantity	29,684	33,246	37,235	41,704	46,708
Average Inventory	29,053	32,527	36,431	40,802	45,699
Leftover	210	235	263	295	330

Stock Out		0	0	0	0	0
Product Family A	Released in 01					
Swap Demand	23,454	2,366				
Swap Order Quantity	23,664					
Average Inventory		1,393				
Leftover		210				
Product Family B	Released in 02					
Swap Demand	26,268	7,881	2,627			
Swap Order Quantity	26,503					
Average Inventory		6,802	1,548			
Leftover			235			
Product Family C	Released in 03					
Swap Demand	29,421	17,652	8,826	2,942		
Swap Order Quantity	29,684	29,684				
Average Inventory		20,858	7,618	1,734		
Leftover				263		
Product Family D	Released in 04					
Swap Demand	32,951		19,771	9,885	3,295	
Swap Order Quantity	33,246		33,246			
Average Inventory			23,361	8,533	1,942	
Leftover					295	
Product Family E	Released in 05					
Swap Demand	36,905			22,143	11,072	3,691
Swap Order Quantity	37,235			37,235		
Average Inventory				26,164	9,556	2,175
Leftover						330
Product Family F	Released in 06					
Swap Demand	41,334				24,800	12,400
Swap Order Quantity	41,704				41,704	
Average Inventory					29,304	10,703
Leftover						
Product Family G	Released in 07					
Swap Demand	46,294					27,776
Swap Order Quantity	46,708					46,708
Average Inventory						32,820
Leftover						

The values of swap order quantity, average inventory, and stock out volume obtained through the news vendor approach are plugged into the DCF analysis below.

Table 10. DCF analysis for swap everything model

	2003 (t=-1)	2004 (t=0)	2005 (t=1)	2006 (t=2)	2007 (t=3)
A. Unit Cost					
Repair Variable	$50	$50	$50	$50	$50
Repair Unit	$37	$37	$37	$37	$37
Repair Logistics	$6	$6	$6	$6	$6
New Product Swap	$68	$65	$62	$59	$56
Product Unit	$55	$52	$49	$46	$43
Product Logistics	$8	$8	$8	$8	$8
Scrap	$6	$6	$6	$6	$6
Inventory Carrying	$8	$8	$7	$7	$6
Stock Out	$70	$70	$70	$70	$70
B. Volume					
Return Demand	27,899	31,247	34,996	39,196	43,899
Repair Volume	0	0	0	0	0
Swap Order Quantity	29,684	33,246	37,235	41,703	46,708
Average Inventory	29,053	32,527	36,430	40,802	45,698
Stock Out	0	0	0	0	0
C. Total Costs					
Repair Subtotal	$-	$-	$-	$-	$-
Repair Variable	$-	$-	$-	$-	$-
Repair Overhead	$-	$-	$-	$-	$-
Swap Subtotal	$2,024,426	$2,157,646	$2,301,060	$2,455,585	$2,622,232
Inventory Carrying	$239,683	$252,248	$265,566	$279,588	$294,350
Stock Out Cost	$-	$-	$-	$-	$-
Total Cost	$2,264,109	$2,409,893	$2,566,626	$2,735,173	$2,916,583
WACC		0.15	0.15	0.15	0.15
Discount Multiplier		1.00	0.87	0.76	0.66
Present Value of Total Cost		$2,409,893	$2,231,849	$2,068,184	$1,917,700
Present Value of Project Cost		$6,709,926	$6,217,733		

The same procedure as that used in the repair everything model is applied here. Because of the nature of the swap everything model, the repair overhead cost is eliminated.

However, this has created a potential cost of stock out. Through the Monte Carlo simulation, which simulates the return demand following the given probability distribution, stock out cost will be included in the present value calculation.

Because the product cost falls below the repair cost over the three year period and repair overhead can be eliminated thorough the swap everything model, the swap everything model achieves a cost advantage compared to the repair everything model. The present value of the swap everything model is $6.7 million, while that of the repair everything model is $7.1 million.

This shows more of a gap than the gap observed in a single year, 2003, which was noted as $0.1 million in Section 2.2.3: Alternative Model: Swap Everything Model. The difference is due to the multi-periods where the cost and the volume fluctuate. Additionally, it should be noted that the present value of the project cost from 2005 to 2007 is smaller than that from 2004 to 2006. One reason is the declining trend of the product cost and another is the high weighted average cost of capital, which is 15%.

5.1.4. Hybrid Model

Now that two extreme models are evaluated over the project period, the hybrid model, somewhere between the repair everything model and the swap everything model, should be considered. In many cases in the logistics industry, the optimal solution is somewhere between because there are often trade-off dynamics in logistics systems.

However, contrary to intuition, Figure 8 shows that extreme models are more cost efficient than hybrid models. This is because the swap everything model eliminates the repair overhead and the repair everything model leverages economies of scale with the repair overhead cost. Therefore, there is no trade-off dynamics observed in this case.

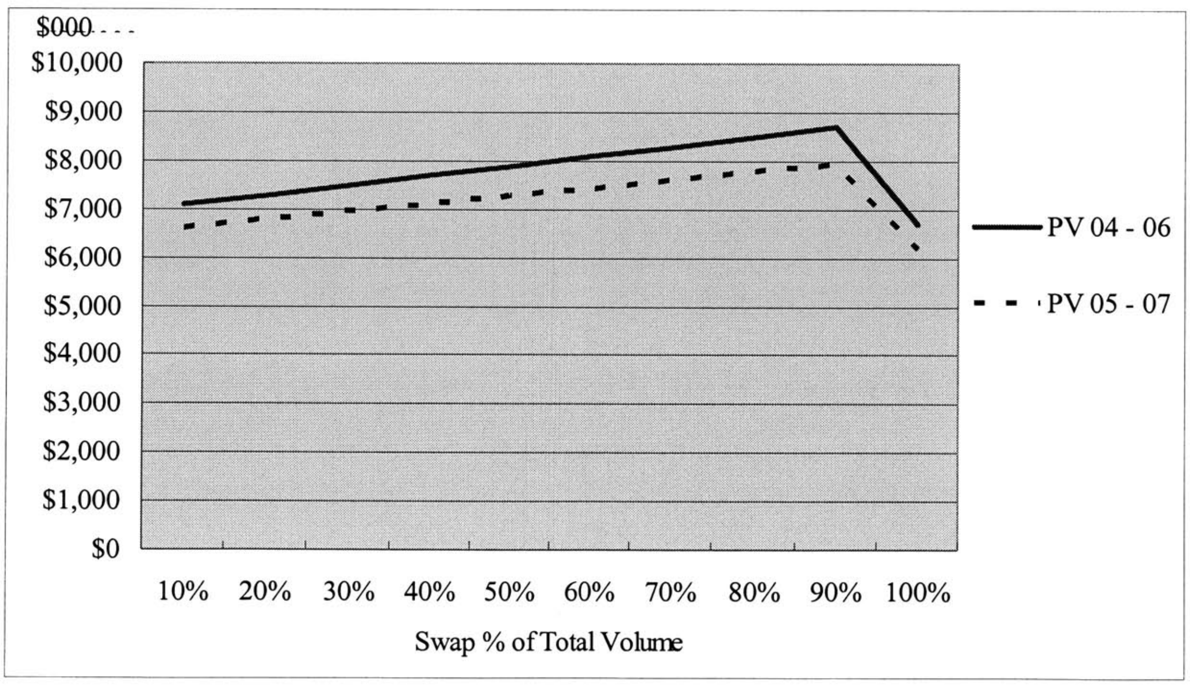
Table 11. Swap ratio and present value

$'000

Swap %	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
PV 04 - 06	$7,083	$7,285	$7,486	$7,688	$7,890	$8,092	$8,293	$8,495	$8,697	$6,710
PV 05 - 07	$6,609	$6,773	$6,938	$7,103	$7,268	$7,432	$7,597	$7,762	$7,927	$6,218

Note that 10% is the minimum swap ratio because 10% of repair volume cannot be repaired even if all volume goes through the repair everything model.

Figure 9. Total present cost and swap ratio of total volume



After all, it should be noted that the flaw of the DCF model is that it does not provide the degree of risks. For example, the present value under the swap everything model decreases if stock out costs increase or product costs decline at a slower rate. This kind of risk and return analysis is exactly what the Monte Carlo simulation and real options analysis attempt to do.

5.2. Monte Carlo Simulation

The purpose of conducting a Monte Carlo simulation is to obtain volatility of the present value of the project so that the volatility can be used to perform real options analysis. In order to conduct Monte Carlo simulations, the key drivers of the present value of the project need to be identified and their probability distributions need to be assigned.

5.2.1. Sensitivity Analysis

In order to conduct the Monte Carlo simulation, sensitivity analysis should be conducted to identify key variables that significantly affect the present value of the project. When the variables increase or decrease by 10% in the repair everything model, the sensitivity of the present value becomes as follows.

Table 12. Sensitivity analysis for repair everything model

Repair Everything Model PV Base Case $7,083,020

Key Variables	Downside +10%	Base Case	Upside -10%	PV downside	PV upside	Range
Return Demand	$30,689	$27,899	$25,109	$7,524,061	$6,641,979	$882,083
Repair Unit	$40.96	$37.24	$33.52	$7,423,077	$6,742,963	$680,113
Demand AGR	13.2%	12.0%	10.8%	$7,177,360	$6,990,004	$187,356
Product Unit	$60.50	$55.00	$49.50	$7,135,457	$7,030,096	$105,362
Customer Loyalty	55%	50%	45%	$7,084,058	$7,081,944	$2,114

According to Table 12, the key variables that have the most significant impact on the present value of the repair everything model are the return demand and the repair unit cost. Other variables have relatively small impact on the present value of the repair everything model. Because the model has only 10% of the new product swap, the product cost gives insignificant impact on the present value.

Similar sensitivity analysis can be conducted for the swap everything model as follows.

Table 13. Sensitivity analysis for swap everything model

Swap Everything Model PV base case $6,709,974

Key Variables	Downside +10%	Base Case	Upside -10%	PV downside	PV upside	Range
Return Demand	30,689	27,899	25,109	$7,380,918	$6,038,933	$1,341,985
Product Unit	$60.50	$55.00	$49.50	$7,212,221	$6,205,402	$1,006,819
Demand AGR	13%	12%	11%	$6,996,138	$6,433,146	$562,992
Customer Loyalty	55%	50%	45%	$6,735,428	$6,683,601	$51,827
Repair Unit	$40.96	$37.24	$33.52	$6,709,926	$6,709,926	$0

In the case of the swap everything model, the key variables are the return demand and the product unit cost. Again, this is obviously because the swap everything model does not incur the repair unit cost.

Thus, it is confirmed that the key drivers of the present value of the repair everything model and the swap everything model are the return volume, the repair unit cost, and the product unit cost.

5.2.2. Scenario Analysis

If the probability of fluctuating up and down 10% is assigned to the sensitivity analysis and the discounted cash flow analysis is conducted for each scenario, the scenario based discounted cash flow analysis is complete. However, the problem of the scenario based discounted cash flow analysis is that the range of possibilities is too large or too small to make inferences. It is uncertain whether 10% fluctuation is appropriate. Additionally, this does not account for changes in the multiple key drivers at the same time. For example, "if the volume changes by 10% with the probability of Y, the present values change this much" does not mean the present value changes the same amount when the volume and the product cost change at the same time. Different combinations of scenarios can be run, but again, the appropriateness of the 10% range and the number of scenarios is difficult to estimate.

Monte Carlo simulation, on the other hand, provides the present value results of 1,000 scenarios when all key variables change at the same time. Thus, the Monte Carlo simulations give a more granular picture. As a result, the probability that the present value falls within a certain range can be obtained.

5.2.3. Simulation

In order to conduct a simulation, key value drivers and their probability distribution need to be given. The important assumptions for the value drivers identified through sensitivity analysis are as follows.

Table 14. Value drivers of reverse logistics process

	AGR	Coefficient Variance of Mean Value not AGR	Dist Form
Repair Unit	0%	5%	Lognormal
Product Unit	-6%	20%	Lognormal
Return Demand	12%	15%	Normal

As the circuit board market is expanding approximately 12% per annum, circuit board unit cost is falling 6% per year, while repair unit cost remains stable. The cost and volume are negatively correlated, following an elastic demand curve. Coefficient variance of mean value is also shown. Note that this is not the coefficient value of annual growth rate (AGR) but of the mean value of the repair unit, the product unit, and the return demand in each year. The mean value increases every year following the annual growth rate. So if product unit cost is $50, its standard deviation is $5, or 10% of $50, it becomes $47 next year because of its AGR, and its standard deviation becomes $4.7. In other words, every year the parameter does not always follow the expected annual growth rates. This is volatility. The stochastic nature of cost and volume fluctuation is the basis for the Monte Carlo simulation.

The standard deviation for the volume and the product unit cost is set high as observed in the high growth but volatile circuit board market. The standard deviation for the repair unit cost is set small because there has already been a large increase in 2003 and it is unlikely to see another large change in the following years. Because the repair unit cost and the product unit cost cannot be negative, lognormal distribution is assigned. Because the value of the volume is high enough to not become negative in almost all cases, normal distribution is assigned.

Once the mean value, standard deviation, and distribution forms are obtained, the Monte Carlo simulation can be performed. Through the simulation, the aforementioned volatility of the present value of the project, which is the standard deviation of lognormal growth of present value times the square root of t (time period of the present value analysis), can be obtained. The reason why volatility is the standard deviation of lognormal growth multiplied by the square root of t and not the mean of the present value is to eliminate the trend factor and extract net volatility around the trend.

As a result of the Monte Carlo simulation, the repair everything model shows 8% volatility; because of the high coefficient variance in the product unit cost, the swap everything model shows 16%. This shows that there is higher risk in the cost efficient swap everything model that in the repair everything model. The high risk can give some probability that it can actually become costly as initially suggested in the product unit cost fluctuation in Figure 1 of Section 1.1: Background. In order to see if using the switching option gives better cost savings and less risk, real options analysis using the volatilities obtained through the simulation will be conducted in the following section.

5.3. Real Options Analysis: Binomial Approach

In this section, binomial approach is taken for the different models (the repair everything model, the swap everything model, the repair model with switching option to swap, and the swap model with switching option to repair). Thus, the present value (present cost) and the volatility (risk) of each model is obtained and an optimal model in terms of the cost and risk is identified.

5.3.1. Repair Model with Switching Option to Swap

A binomial approach is taken for real options analysis of the repair model with a switching option to swap. The result of the analysis is as follows.

Table 15. Real options analysis for repair model with switching option to swap

Inputs *all in $'000*

1. PV of repair everything model	$7,083
2. Switching cost to swap	$100
3. Volatility	8%
4. Risk free rate	5%
5. Option maturity (years)	4
6. Steps per annum	1

Variables

1. Increase per step	1.17
2. Decrease per step	0.85
3. Risk neutral probability for up	62%
4. Risk neutral probability for down	38%
5. Stepping-time	4

Binomial tree: PV of repair everything model

	0	1	2	3
a	$7,083	$8,312	$9,754	$11,447
b		$6,036	$7,083	$8,312
c			$5,143	$6,036
d				$4,383

PV with switching option to swap

	0	1	2	3
a	$6,094	$7,673	$9,501	$11,447
b		$4,928	$6,418	$8,312
c			$3,733	$4,972
d				$2,669

Decision tree on switching to swap

	0	1	2	3
a	Switch	Switch	Switch	Continue
b		Switch	Switch	Continue
c			Switch	Switch
d				Switch

PV after taking switching option to swap

	0	1	2	3
0	$6,094	$7,673	$9,501	$17,624
1		$4,928	$6,418	$9,340
2			$3,733	$4,972
3				$2,669

Inputs are

1. PV of the repair everything model: this is obtained from the DCF analysis above.
2. Switching cost to swap: this is the cost to switch from the repair to the swap model.
3. Volatility: this is the volatility obtained through the Monte Carlo simulation above.
4. Risk free rate per annum: this is the short term interest rate of the U.S. government bond

5. Option maturity (years): this is the project period. This can also be interpreted as the effective period of an option. For example, the effective period of the swap option can be agreed between the reverse logistics group of company X and the manufacturing group of company X in Asia. Similarly, the effective period of the repair option can be agreed between company X and the repair outsourcing company.

6. Steps per annum: the frequency to exercise the switching option is assumed to be once a year because the release of each new product line is once a year.

Variables are defined as follows under the risk neutral assumption of financial options theory. The format of calculation is that used in an Excel spreadsheet.

1. Increase per step = EXP(Volatility*(SQRT(Stepping-time)))
2. Decrease per step = 1/ Increase per step
3. Risk neutral probability for up = ((1+risk free rate) – decrease per step)/(increase per step – decrease per step)
4. Risk neutral probability for down = 1-risk neutral probability for up
5. Stepping-time = maturity / steps per period

These variables are explained in Section 3.2.3: Binomial Approach.

Each cell of the binominal lattice for the PV of the repair everything model is calculated as follows in an Exel spreadsheet. Remember that S would increase by u each period and decrease by d each period.

The first row: nth column: $S = S$ at initial period * u^n

The rest: $S = S$ at previous period of one up case * d

The equations can be better understood with Figure 8. Binomial Lattice in Section 3.2.3 Binomial Model.

Each cell of the binominal lattice for PV with switching option to swap is calculated as follows (review the table of the binomial lattice at the beginning of this section). At the end of the binominal tree, the calculation is drawn that a model that minimizes the cost should be chosen. For example, at the top right cell, the PV of the repair model and the PV of the swap model plus the switching cost are compared, and the model that produces the smaller amount is chosen. Therefore, the following equation is embedded in an Excel spreadsheet.

MIN (PV in the same time period under the repair model, PV in the same time period under the swap model + the switching cost to swap)

From the second to the last period backwards, you need to take smaller amounts of the PV calculated either with the repair model or with the swap model. In other words, in the cell next to the top right cell of the binominal lattice for the PV of the switching option to swap, smaller amounts between the expected PV using the repair model and the expected PV using the swap model plus the switching cost should be chosen. Use the following equation to obtain the expected PV.

Expected PV = (PV in up scenario x probability of up under a model + PV in down scenario x probability of down under a model) / (1 + risk free rate)

In the Excel spreadsheet, the function below is embedded in the next to last nodes of the binomial trees backwards.

MIN (((PV in up scenario * probability for up under repair model + PV in down scenario * probability for down under repair model) / (1 + risk free rate)), (((PV in up scenario * probability for up under swap model + PV in down scenario * probability for down under swap model) / (1 + risk free rate)) + switching cost to swap))

If the present value of using the swap model plus the switching cost is smaller than the present value of continuing the repair model, the decision lattice should show "switch." Otherwise, the decision lattice should show "continue."

As a result of the backward recursion process that minimizes present value, i.e. present cost, "continue" is shown only twice in the decision lattice. This is because the swap model is cost effective in most cases. However, it should be noted that the repair model is used at the last two nodes, where the upside swing is the largest in the highly volatile swap model. The high volatility produces a wider range of outcome, especially in the long run as shown at the last node, where the values become highly diverged. Consequently, the upside becomes extremely costly. Thus, the repair model takes a critical role with its low volatility that mitigates the large risk of cost increase incurred by the high risk high return swap model.

The value of the switching option is the difference between the PV of the repair everything model and the PV of the repair model with switching option to swap. Therefore, the option value here is $1 million = $7.1 million minus $6.1 million. It is assumed that there is no investment cost because the repair operation with switching option to swap should be readily available without further investment. Obviously, the value of the option outweighs the cost of the option, so this option has a net positive value.

5.3.2. Swap Model with Switching Option to Repair

The same procedure can be conducted for the swap model as a base model with switching option to repair. The result is below.

Table 16. Real options analysis for swap model with switching option to repair

Inputs *All in $ '000*

1. PV of swap everything model	$6,710
2. Switching cost to repair	$100
3. Volatility	16%
4. Risk free rate	5%
5. Option maturity (years)	4
6. Steps per annum	1

Variables

1. Increase per step	1.38
2. Decrease per step	0.73
3. Risk neutral probability for up	50%
4. Risk neutral probability for down	50%
5. Stepping-time	4

Binomial tree: PV of swap everything

	0	1	2	3
a	$6,710	$9,240	$12,725	$17,524
b		$4,872	$6,710	$9,240
c			$3,538	$4,872
d				$2,569

PV with switching option to repair

	0	1	2	3
a	$5,807	$7,523	$9,497	$11,547
b		$4,686	$6,317	$8,412
c			$3,538	$4,872
d				$2,569

Decision tree on switching to repair

	0	1	2	3
a	Continue	Continue	Continue	Switch
b		Continue	Continue	Switch
c			Continue	Continue
d				Continue

PV after taking switching option to repair

	0	1	2	3
0	$6,226	$7,981	$9,949	$11,547
1		$5,099	$6,816	$8,412
2			$3,897	$5,072
3				$2,769

The result shows the opposite of the repair model with swap option: there are only two cases to switch to the repair option. The option value is $0.9 million = $6.7 million (PV without option) minus $5.8 million (PV with option). If the cost to keep the repair option is higher than $0.9 million, it is not worthwhile to keep the option.

Table 17. Summary of the result of real options analysis

all in $'000

Result Summary	PV	Volatility	Best case	Worst case	Option value
Repair everything model	$7,083	8%	$4,383	$11,447	NA
Repair model with option to swap	$6,094	10%	$2,669	$11,447	$989
Swap everything model	$6,710	16%	$2,569	$17,524	NA
Swap model with option to repair	$5,807	11%	$2,569	$11,547	$903

Based on this result shown in Table 17, the swap model with option to repair is optimal and will reduce the cost by $1.3 million or 18% compared to the current repair everything model. This is the optimal model, but robustness of the optimality needs to be examined to see whether this solution can easily be changed or not.

5.4. Sensitivity Analysis

In the analysis above, there are many assumptions that can be altered over time. The mean value, volatility, and growth rate of key variables are just forecasts that can always be wrong. Therefore, it is important to examine which sensitivities can affect the conclusion that the swap model with repair option is optimal. It is also important to see the sensitivities for the value of repair option to identify how much company X should pay to obtain the option.

When the sensitivity graphs are reviewed, it should be noted that the higher the present value, the higher the cost, while the higher the option value, the lower the cost. In other words, low present value and high option value are good, while high present value and low option value are bad.

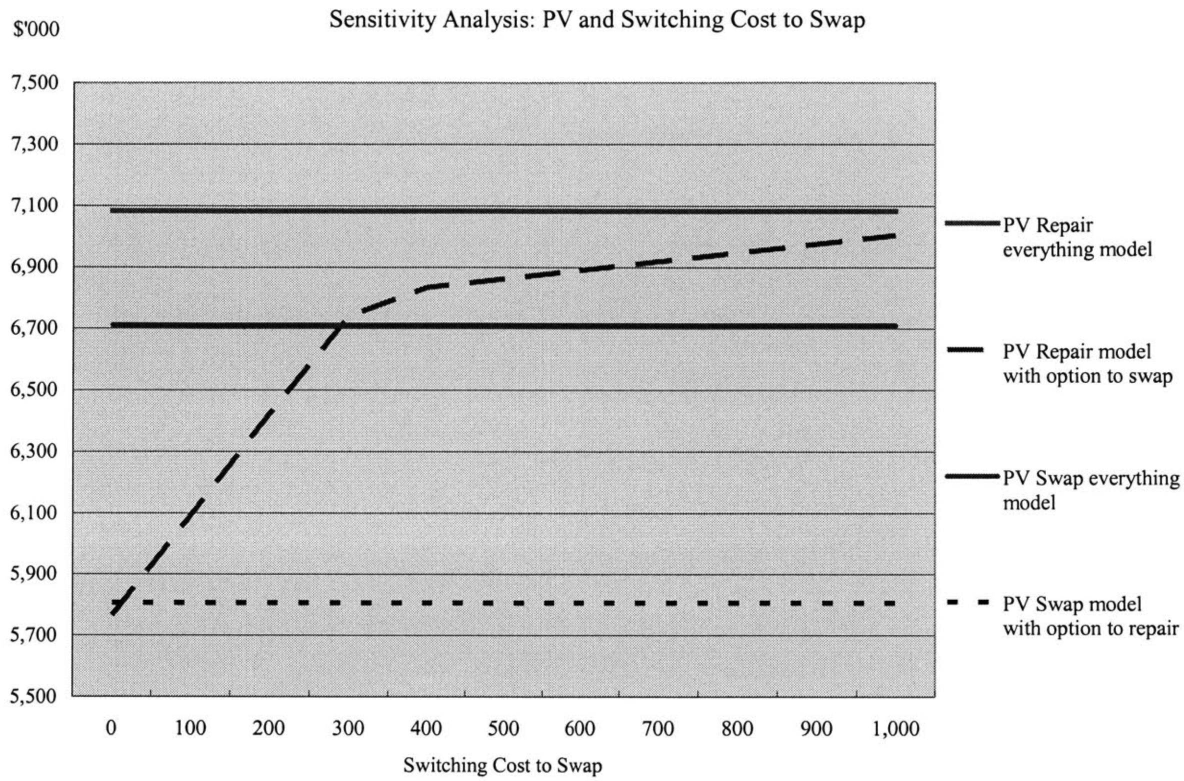
5.4.1. Key Sensitivities

First, key sensitivities are reviewed and in the next section, other sensitivity is discussed. Key sensitivities are about the variables that change the optimal model from the swap model with repair option to the repair model with swap option. On the other hand, other sensitivities only change the present value and/or the option value of different models but do not change the optimality of the swap model with repair option. When the option value is reduced below the cost of obtaining the option due to other sensitivities, the option should be discarded.

A. Switching cost

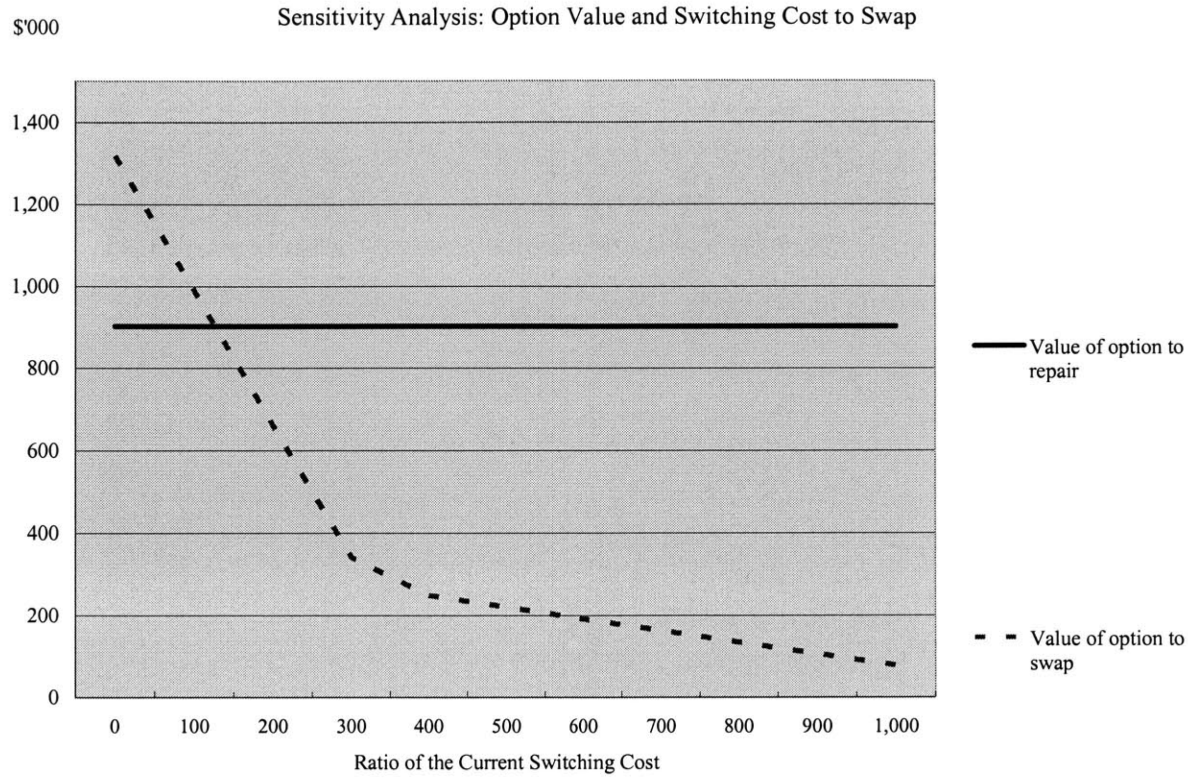
If the switching cost to swap changes from zero to $1 million, the present value of different models change as shown in Figure 10. When the switching cost is zero, optimality changes from the swap model with repair option to the repair model with swap option. The situation is highly likely because it probably does not incur the switching cost to order new products. The switching cost to swap only affects the value of the option to swap. This is why all the models except for the PV repair model with option to swap do not respond to the change in the switching cost to swap in Figure 10.

Figure 10. Sensitivity analysis: present value and switching cost to swap



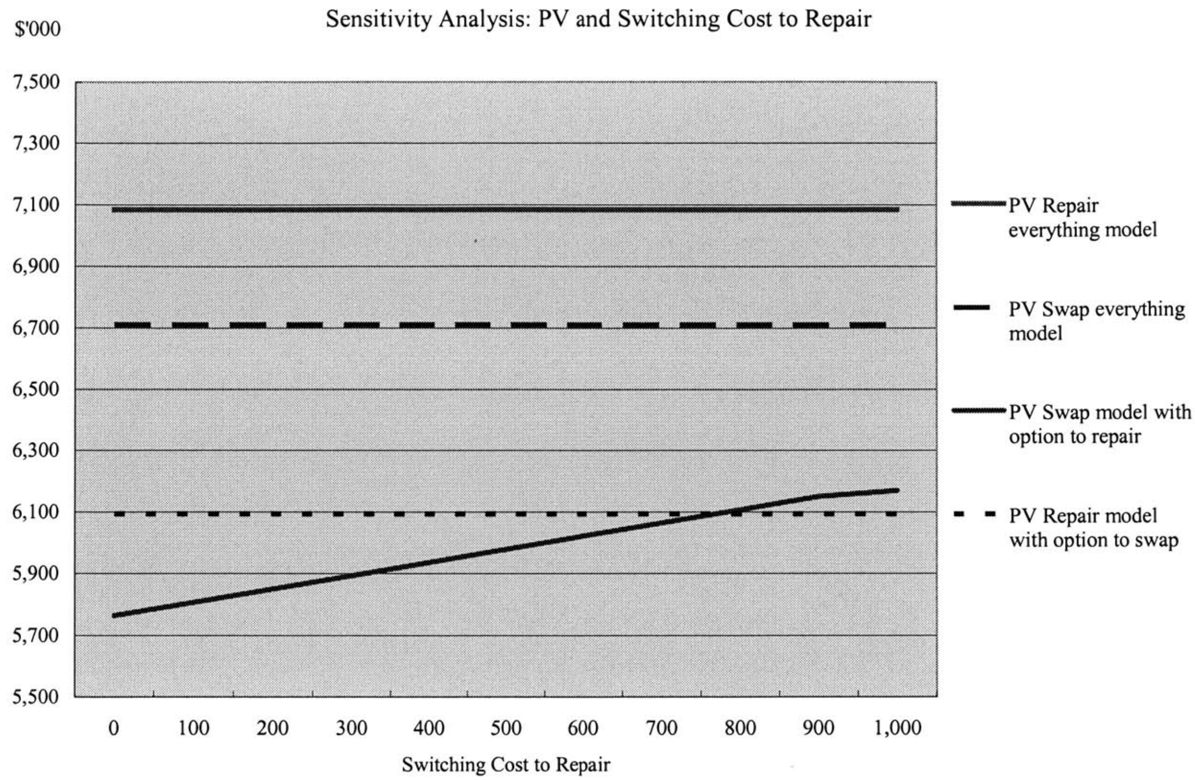
As the switching cost to swap increases, the value of option to swap decreases. When the switching cost is around $1 million, the option value almost disappears, as shown in Figure 11. Again, it should be noted that when PV increases in Figure 10, the cost is increasing. Meanwhile when the option value increases in Figure 11, the cost is decreasing.

Figure 11. Sensitivity analysis: option value and switching cost to swap



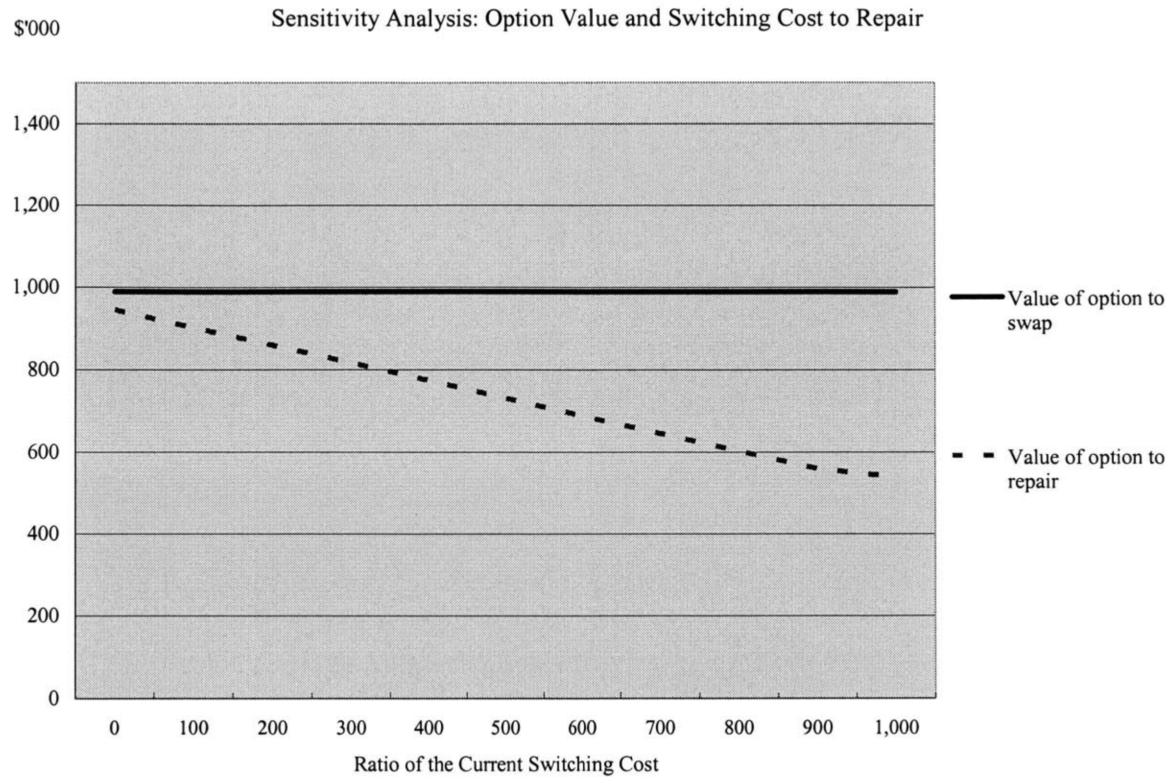
When the switching cost to repair changes (the case above shows the switching cost to swap), there is also a tipping point where the repair model with swap option becomes more optimal than the swap model with repair option. That is when the cost of the switching option to repair reaches $0.8 million as shown in Figure 12. The switching cost to repair can easily become more than $0.8 million because the repair overhead cost is $0.9 million. Without a contract with the repair outsourcing company, exercising the repair option may immediately incur full repair overhead costs.

Figure 12. Sensitivity analysis: present value and switching cost to repair



Similar to the switching cost to swap, the value of the repair option declines as the switching cost to repair increases. As the value of the option declines, the maximum cost to obtain the option decreases.

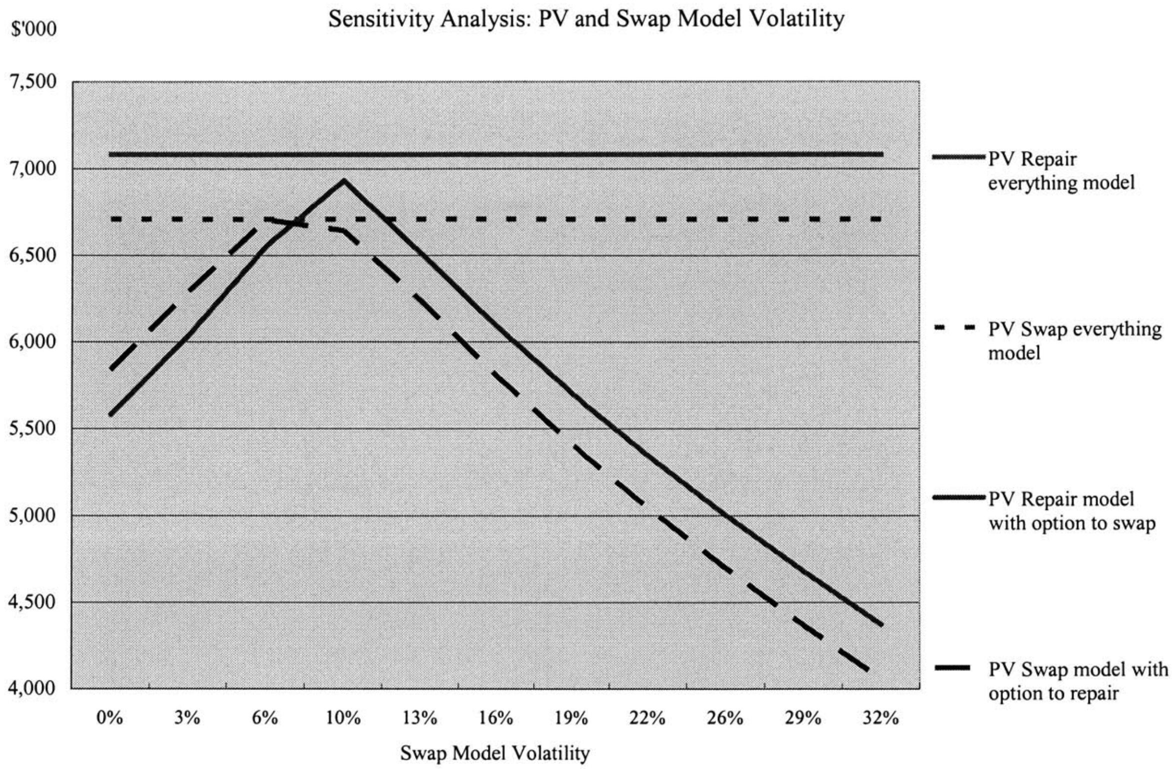
Figure 13. Sensitivity analysis: option value and switching cost to repair



B. Volatility

Figure 14 shows how the change in the swap model volatility affects the present value of different models. The range of change in the swap model volatility is between 0% and 200% of the base case volatility, which is 16%. In other words, the swap model volatility changes from 0% to 32%. The tipping point where the repair model with swap option becomes optimal is when the swap model volatility becomes 6.4% and the repair model volatility stays at 8%. Swap model volatility is driven by the product unit cost volatility and the repair model volatility is driven by the repair unit cost volatility. So when there is a steady increase in the product unit cost, the repair model with swap option can become more cost effective than the swap model with repair option.

Figure 14. Sensitivity analysis: present value and volatility of swap model



As the swap volatility becomes different from the fixed 8% of repair volatility, the value of both the swap option and the repair option increases. This is because the wider gap in the volatilities allows company A to take advantage of the upside opportunity, the difference in costs of the two models.

Figure 15. Sensitivity analysis: option value and volatility of swap model

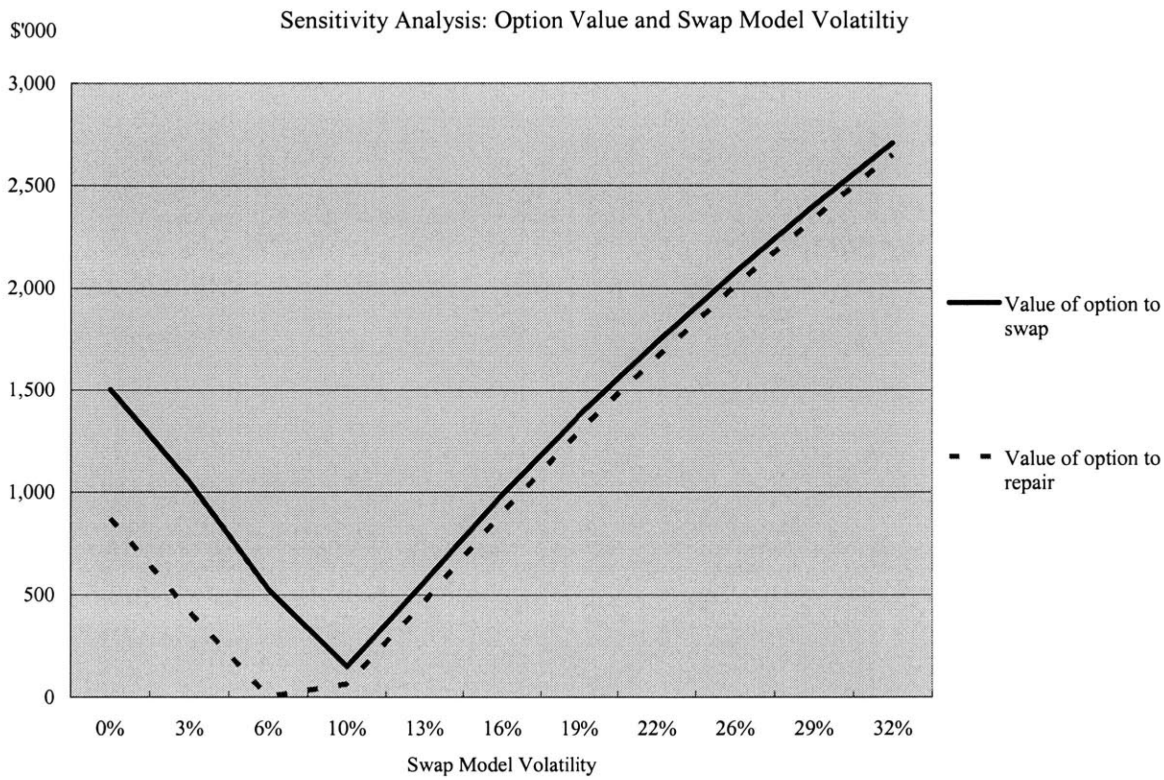


Figure 16 shows when the swap model volatility is fixed and the repair model volatility is varied. As you can see, the range of change in the repair model volatility is between 0% and 200% of the base case volatility, which is 8%. In this case, no tipping point can be found within the range between 0% and 16% in the repair model volatility. However, the PV of the swap model with repair option becomes very close to the PV of the swap everything model and the repair model with swap option. If there are some costs to obtain the repair option, it can be optimal to either abandon repair option or change to the repair model with swap option. Note that the base for the swap model volatility is 16% so as the repair model volatility approaches 16%, the option value diminishes.

Figure 16. Sensitivity analysis: present value and volatility of repair model

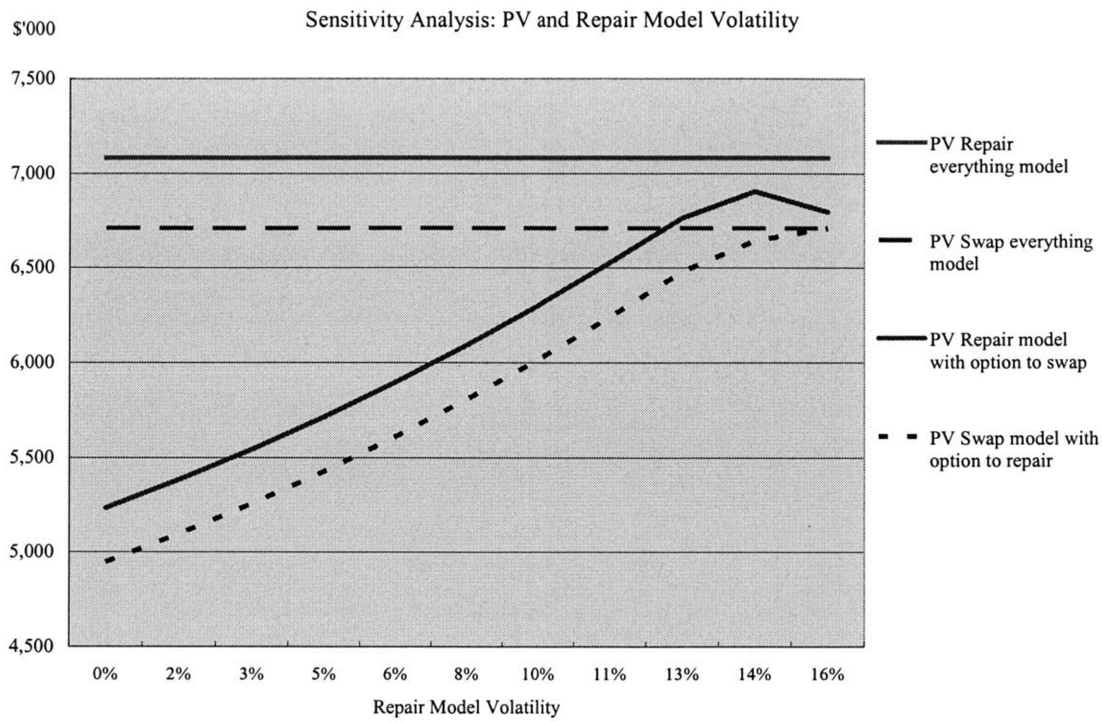
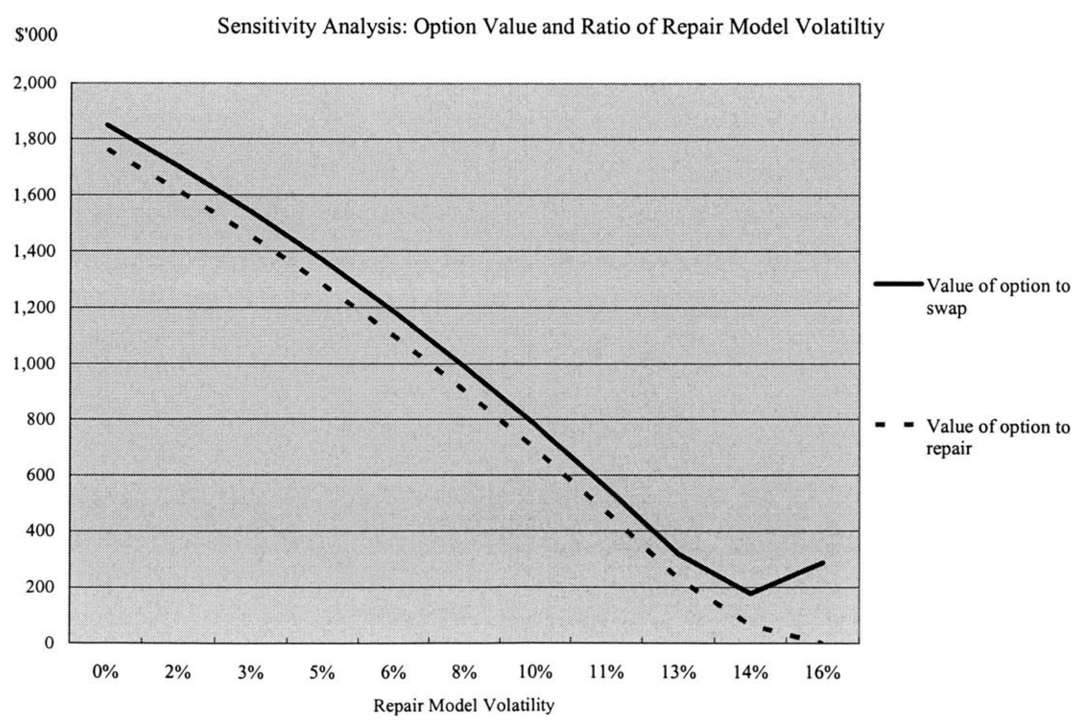


Figure 17. Sensitivity analysis: option value and volatility of repair model



Generally, the option value increases when the volatility becomes high. However, for the switching option, it is not that simple as discussed above. Because there are two kinds of volatility, it has to be viewed in a relative manner. When the two volatilities are similar (not necessarily the same because of other conditions such as difference in the present values), there is less room to take advantage of upside opportunity between the two models. This is why the option value diminishes when the swap model volatility and the repair model volatility becomes similar.

Therefore, it is important to monitor the product cost volatility, which drives the swap model volatility, and the repair cost volatility, which drives the repair model volatility. Specifically, the volatilities can be observed from the standard deviation of the trend of the product cost and the repair cost. For instance, if the product unit cost fluctuates more dramatically around the trend line than the repair cost, it is a good indication that not only the swap model with repair option becomes more valuable, but also the repair option itself becomes more valuable. In this case, company X can afford paying more to acquire the repair option. In the opposite case, the opposite happens. However, in order to ensure the cost optimality of models and the value of the switching option, the four steps of real options analysis should be taken each time, for it is not only the relative positions of the volatilities of the two models but also the present values of the two models that affect the value of switching options.

5.4.2. Other Sensitivities

The following are the variables that do not immediately change the optimality of the swap model with repair option. Conversely, if the key sensitivities above change and the repair model with swap option becomes optimal, the following variables will not affect the optimality of the repair model with swap option.

However, other sensitivities can change the present value and the option value. To repeat, when the repair option value becomes negligibly small, there is more incentive to abandon the option and move to swap everything model or change to the repair model with swap option. The repair option can be costly due to the repair overhead cost.

It should be noted that the value of options can be captured only when options are utilized at the right time. For example, at every product release, product cost and repair cost are compared and the decision to exercise options must be made and implemented immediately. If the process is mismanaged, such as incorrect cost data or slow implementation, the present value of the optimal model can be diminished and the option value can be reduced. This consideration can be reflected in the switching cost but having such flexibility is a fundamental assumption in switching option. If there is insufficient flexibility, the optimal solution may change.

A. Customer relationship ratio

When company X discards the cost of customer loyalty, the customer relationship ratio becomes zero. When company X considers customer loyalty to be extremely important, the relationship percentage becomes 100%. In both extremes, the swap model with repair option remains optimal. The option value improves as the percentage increases. In other words, the customer relationship ratio makes a relatively small impact on the optimal decision.

Figure 18. Sensitivity analysis: present value and customer relationship

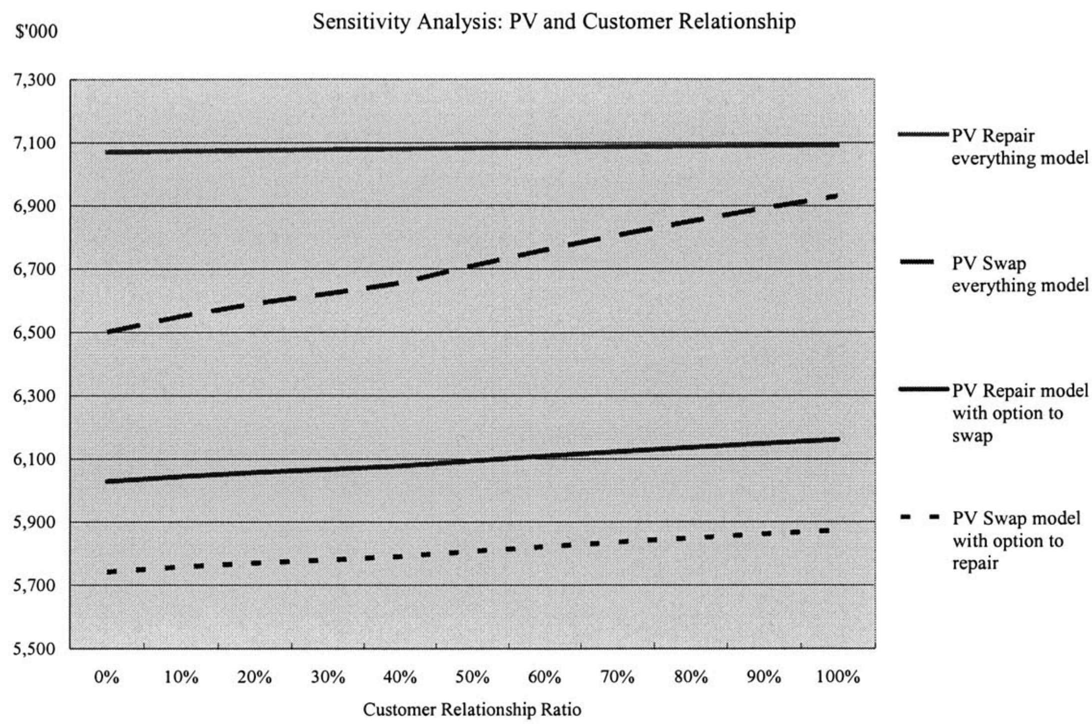
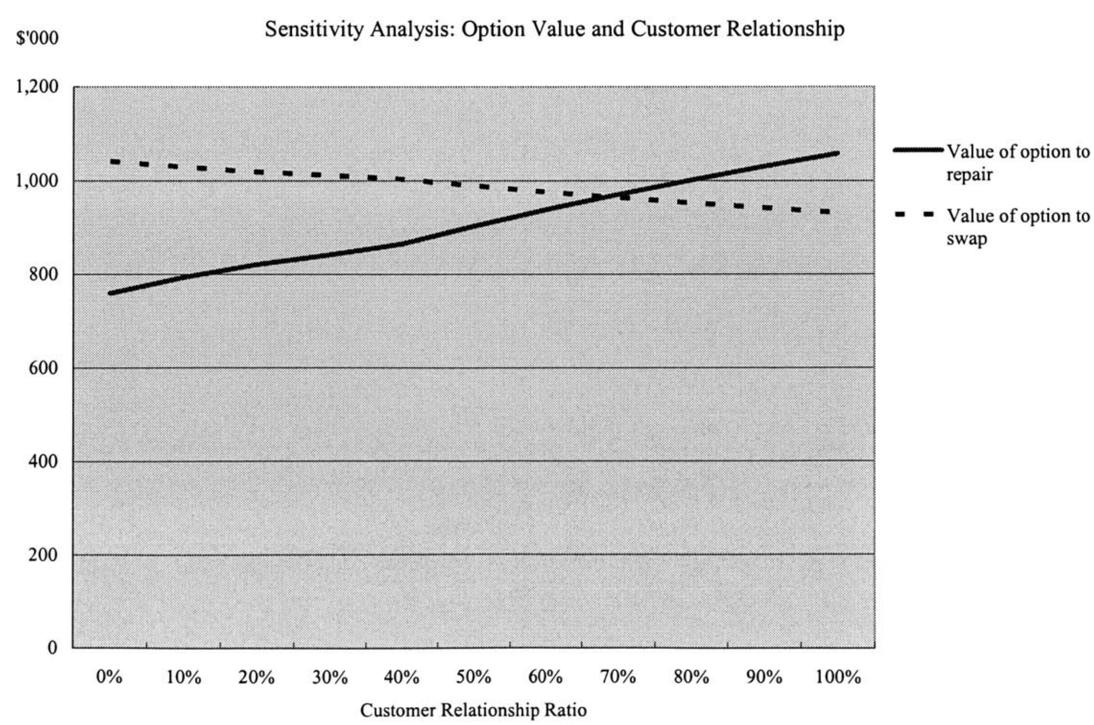


Figure 19. Sensitivity analysis: option value and customer relationship



B. Repair overhead cost

As Figure 20 shows, the swap model with repair option remains optimal when the repair overhead becomes zero because repair option is exercised more frequently to exploit the cheaper repair model. So the repair option value improves as the repair overhead cost decreases. This is under the assumption that the repair option is exercised at the right time. If not, the PV can jump closer to the highest PV of the swap everything model. So if company X has insufficient flexibility to switch to repair operation, the second best model, the repair model with swap option may make better sense when the repair overhead cost decreases. Let us call it "the law of the second best under inflexibility." This high inflexibility in switching to the repair option can be interpreted as a high switching cost to repair that can make a similar impact. The optimal solution changes from the swap model with repair option to the repair model with swap option, as pointed out in 5.4.1: Key Sensitivities.

Also, as the repair overhead cost increases and the repair option declines below the cost of obtaining the repair option, company X might want to abandon the repair option and move to the swap everything model or the repair model with swap option.

Similar results are observed when the repair unit cost changes because both the repair overhead cost and the repair unit cost essentially relate to the cost of the repair model.

Figure 20. Sensitivity analysis: present value and repair overhead cost

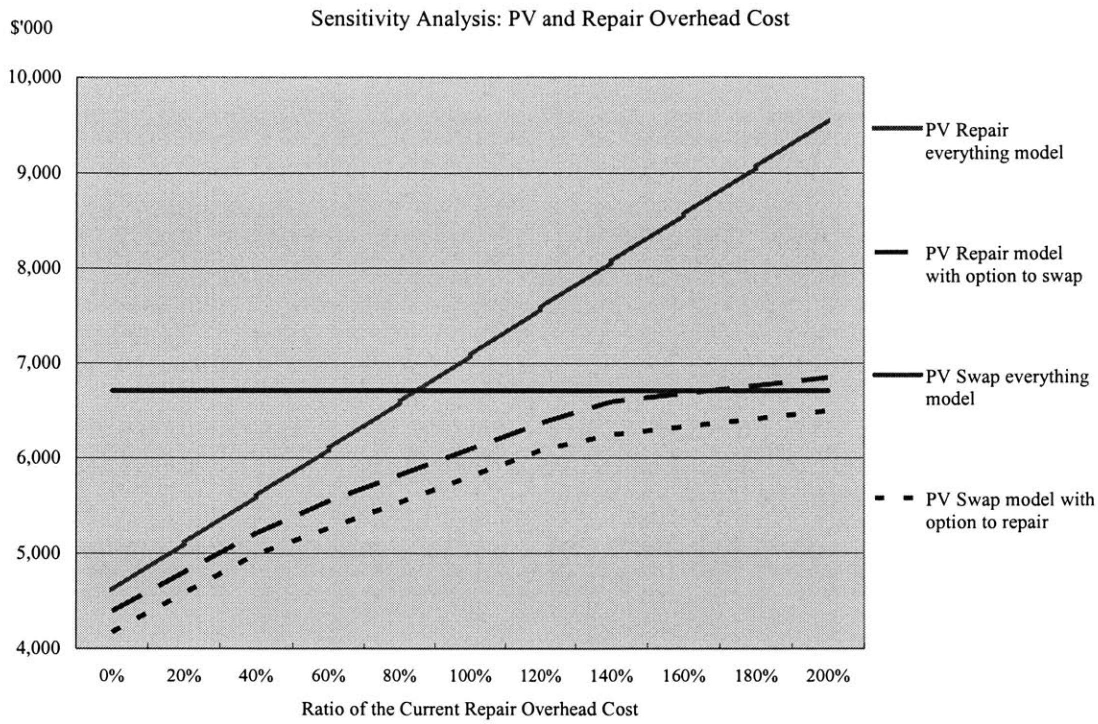


Figure 21. Sensitivity analysis: option value and repair overhead cost

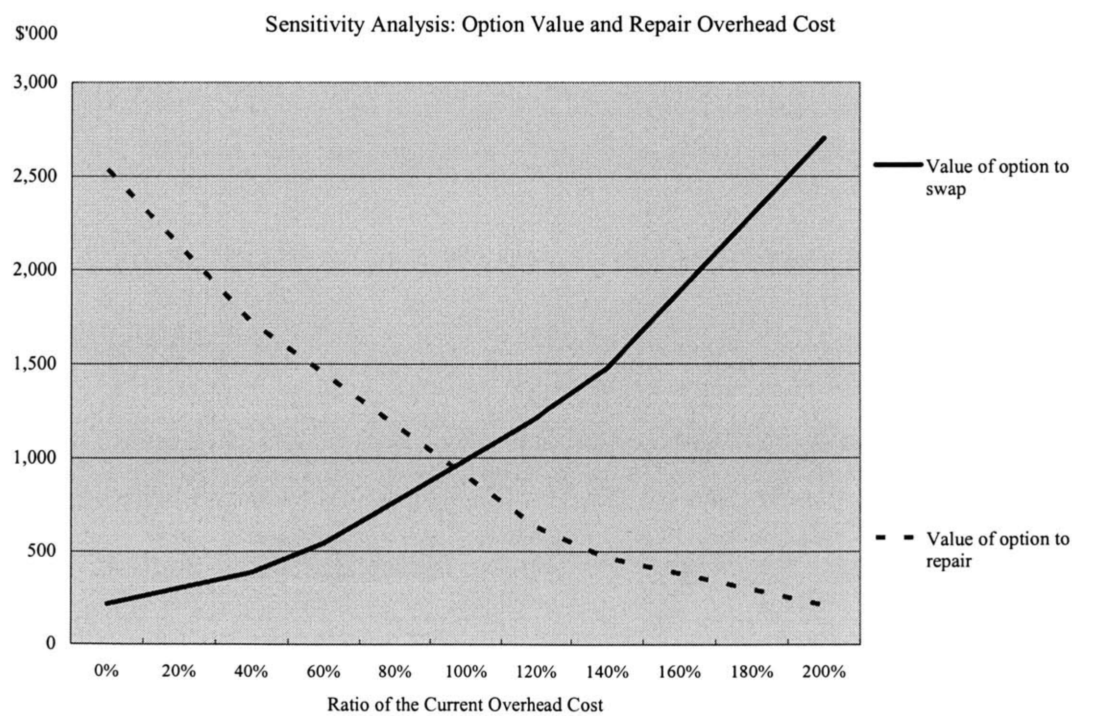


Figure 22. Sensitivity analysis: present value and repair unit cost

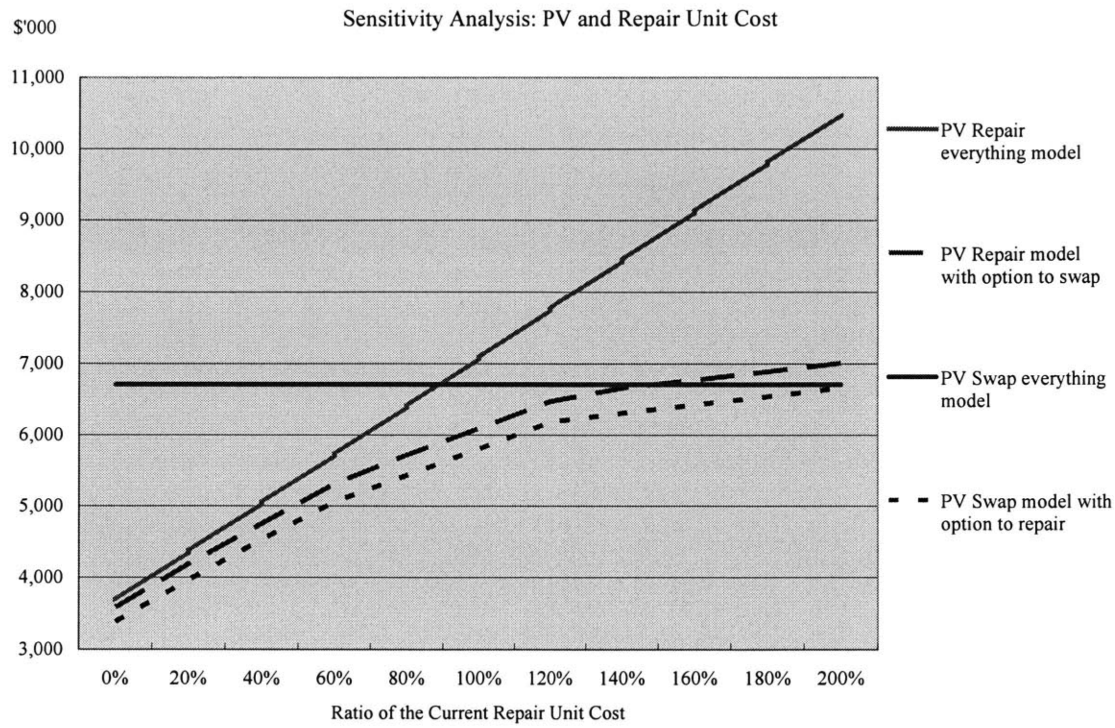
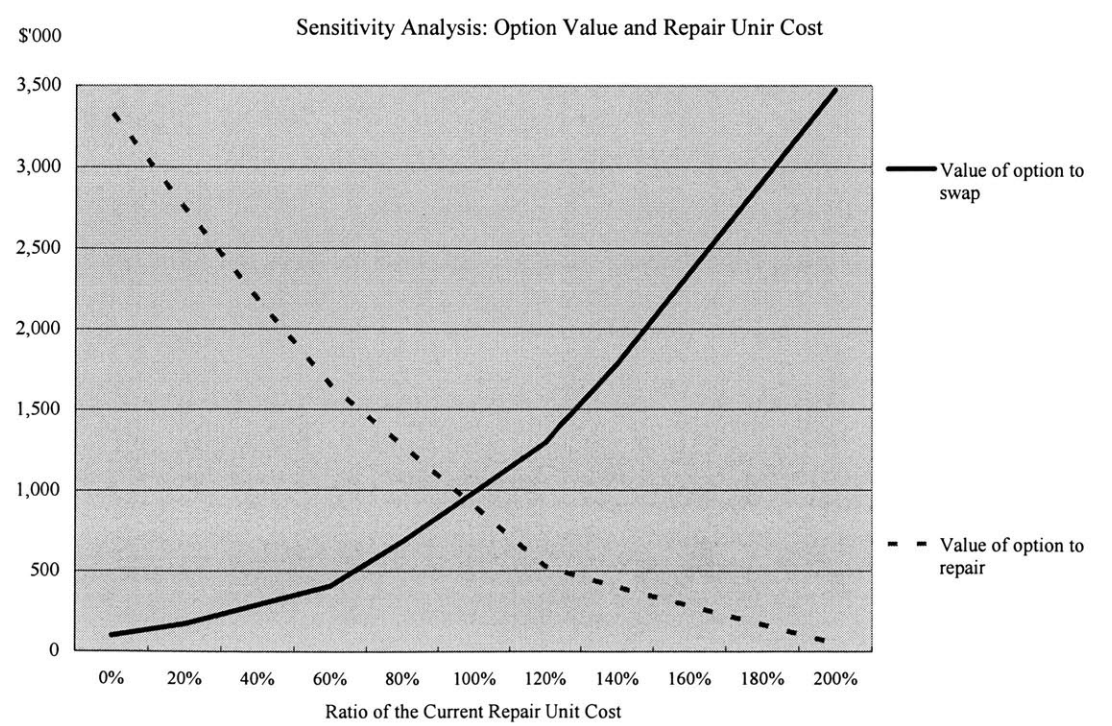


Figure 23. Sensitivity analysis: option value and repair unit cost



C. Product unit cost

Figure 24 shows that when the product unit cost becomes double that of the current level, company X may want to consider using the repair model with a swap option if it has insufficient flexibility. Also, as the product cost decreases closer to zero, company X may want to abandon the repair option as the option value disappears. Similar results can be obtained when the growth rate of product unit cost changes because the growth rate of product cost and the product cost itself both drive the cost of the swap model.

Figure 24. Sensitivity analysis: present value and product unit cost

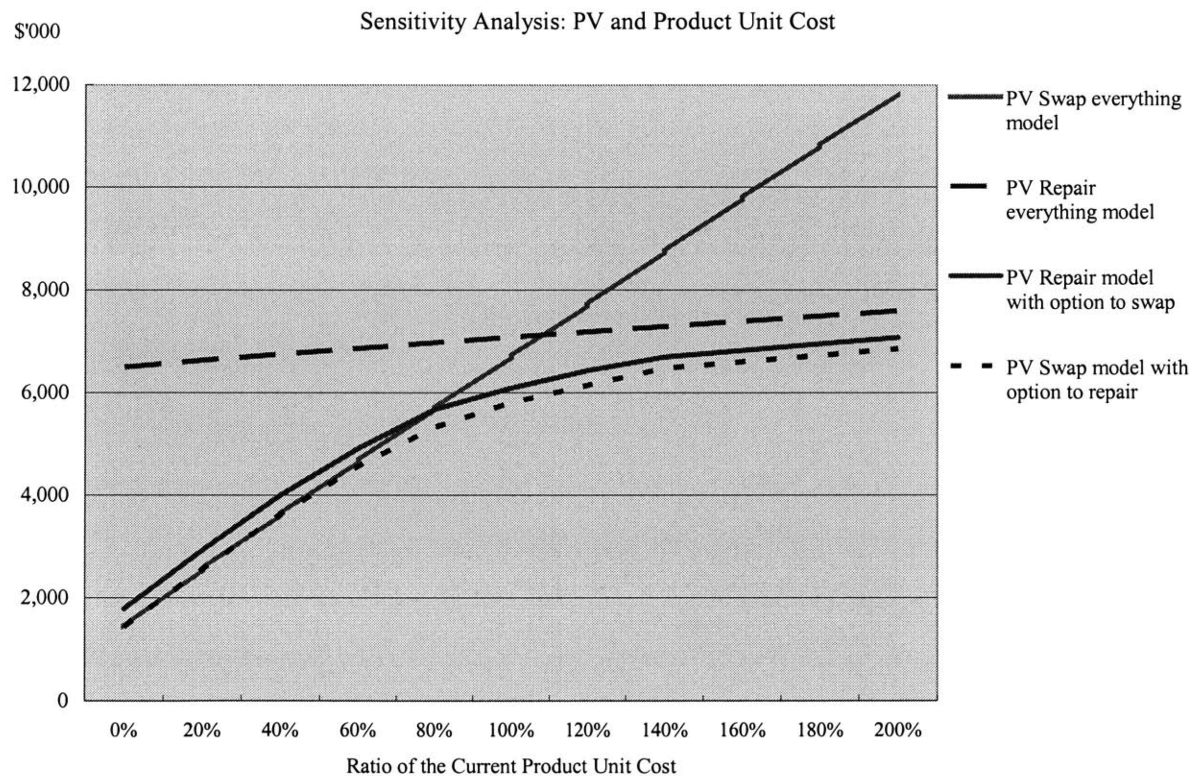
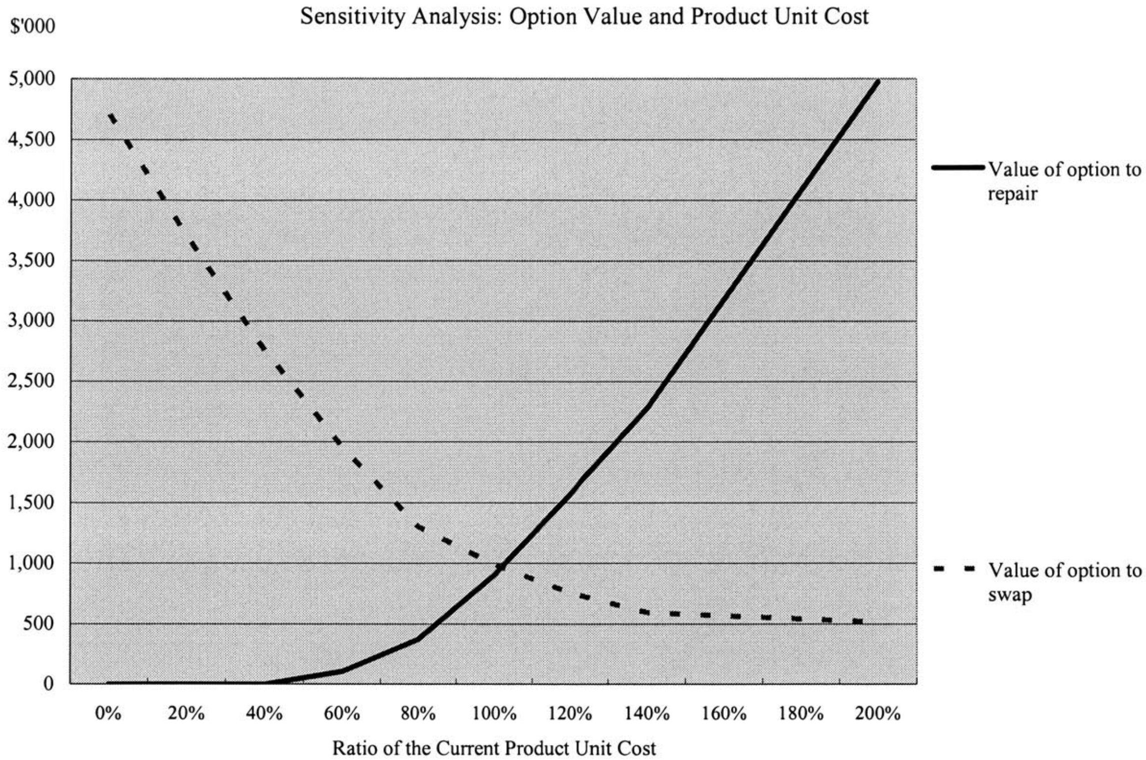


Figure 25. Sensitivity analysis: option value and product unit cost



D. Return demand

High return demand, as well as low repair cost, favors the repair model, so the law of second best under inflexibility can be applied.

The jump of the value of the swap option observed around 20% of the base line volume level is due to the low swap unit cost relative to the repair unit cost, which includes high overhead cost per unit basis when the repair volume is very small. As the volume increases, the repair overhead spreads out to the high volume and the repair unit cost declines. So the swap cost compared to the repair cost becomes high and the value of the swap option declines.

Figure 26. Sensitivity analysis: present value and return volume

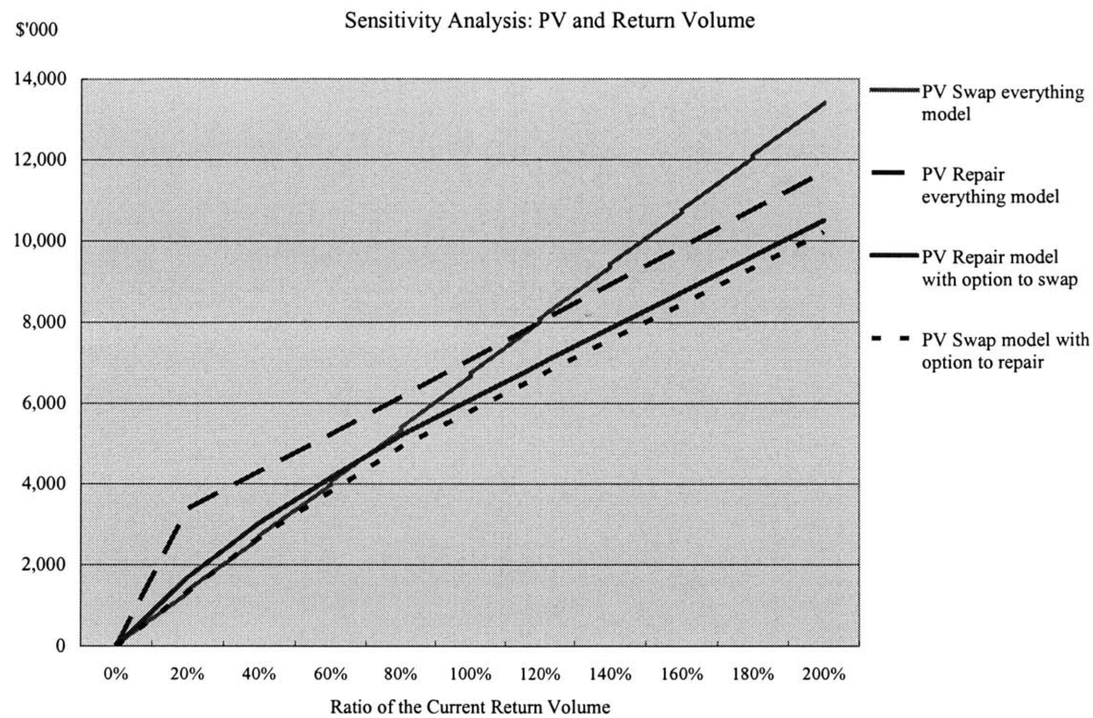
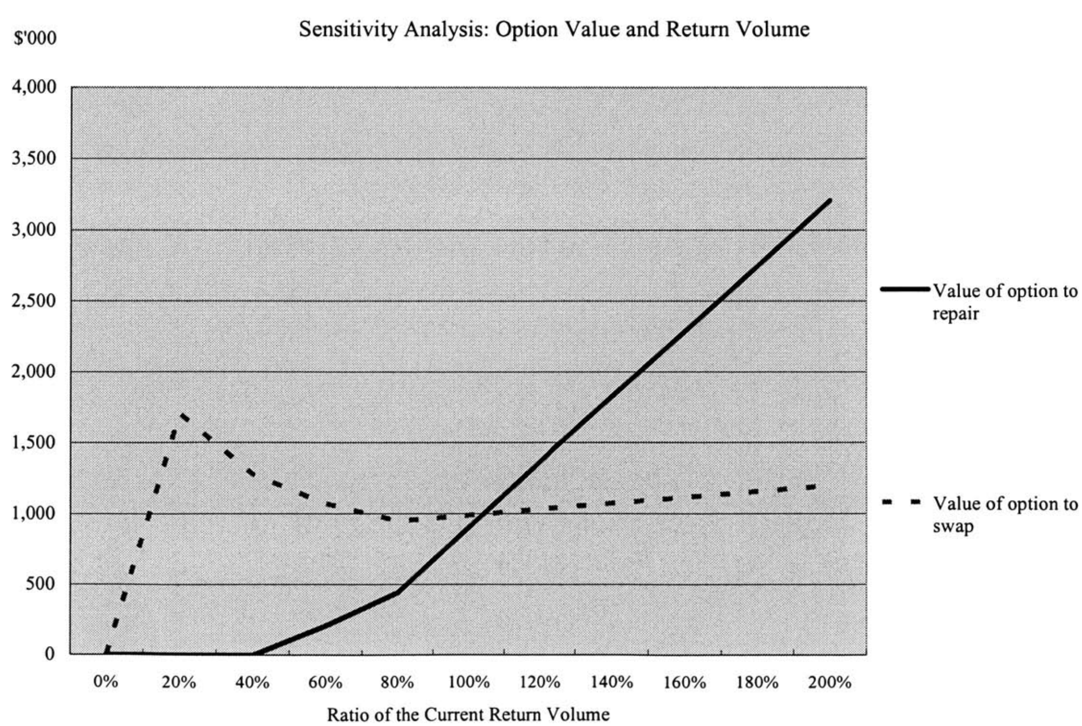


Figure 27. Sensitivity analysis: option value and return volume



5.4.3. Summary of Sensitivity Analysis

The summary of the sensitivity analysis is as follows.

Table 18. Summary of the sensitivity analysis around the optimal model

Variables	High		Low	
	Optimality of Swap Model with Option	Value of Option to Repair	Optimality of Swap Model with Option	Value of Option to Repair
Switching Cost to Repair	It can change optimal model to repair model with swap option	Decrease as repair option becomes more costly	Swap model with option becomes even more cost effective	Increase as repair option becomes less costly
Volatility of Swap Model	Swap model with option becomes even more cost effective	Increase as gap between volatilities increase	It can change optimal model to repair model with swap option	Decrease as the gap between volatilities decrease
Customer Relationship Ratio	Swap model with option is still optimal but becomes more costly	Increase because stock out becomes more costly	Swap model with option becomes even more cost effective	Decrease because stock out becomes less costly
Repair Overhead and/or Repair Unit Cost	Swap model with option is still optimal but becomes more costly	Decrease because repair option becomes relatively more costly	Optimality improves but the law of second best under inflexibility should be noted	Increase because repair option becomes relatively less costly
Product Unit Cost	Swap model with option is still optimal but becomes more costly	Increase because repair option becomes relatively less costly	Optimality improves but the law of second best under inflexibility should be noted	Decrease because repair option becomes relatively more costly
Return Demand or Return Demand Growth Rate	Optimality improves but the law of second best under inflexibility should be noted	Increase because of economies of scale that repair can provide	All models converge to smaller cost	Decrease because repair fixed cost becomes burdened with low volume

6. CONCLUSION

This chapter summarizes the result of the analysis above and evaluates how the cost to obtain the option and the cost to exercise the option affects the optimal solution. Additionally, the robustness and sensitivity of the optimal model are reviewed. Furthermore, strengths and weaknesses of the methodology used in this thesis are discussed. Finally, areas for further research are pointed out.

6.1. Result Evaluation

The following shows the cost efficiency and risks of different models of the reverse logistics process. It also discusses the robustness and feasibility of the optimal model.

6.1.1. Result Summary

When the results are evaluated, it is important to remember that the scope of this thesis is the depot operation in the U.S. The decision framework (a combination of the news vendor approach, discounted cash flow analysis, Monte Carlo simulation, and real options analysis) could be applied to the rest of worldwide operations so that the optimal model for each region can be identified and implemented. This is possible because each region operates fairly independently and there is no issue in global versus local optimizations. When this framework is rolled out worldwide, the impact can be much greater than the cost savings amount shown below because the worldwide volume is ten times as much as that of the U.S. depot operation.

Now that the results have been obtained, the costs and risks for each model are summarized as below.

Table 19. Summary of different models

all in $'000

Result Summary	Present Value (Present Cost)	Volatility	Best Case	Worst Case	Option Value
Repair everything model	$7,083	8%	$4,383	$11,447	NA
Repair model with option to swap	$6,094	10%	$2,669	$11,447	$989
Swap everything model	$6,710	16%	$2,569	$17,524	NA
Swap model with option to repair	$5,807	11%	$2,569	$11,547	$903

As the summary above shows, the swap model with the switching option to repair is the most cost efficient model. Cost saving can be achieved through the use of the cheaper swap model in basic operations: the downside risk, such as the product cost increase, is protected by the repair option. Specifically, the total present costs could be reduced by $1.3 million (including the option value of $0.9 million) or by 18% compared to the cost under the current model, while the volatility would only moderately increase from 8% to 11% in the next three years.

6.1.2. Costs of Obtaining and Exercising the Option to Repair

While the swap model with the repair option is determined to be optimal, there may be challenges in its feasibility. Obtaining the repair option can be difficult or costly because the repair outsourcing company may not accept little volume in an infrequent manner. If the cost to obtain the option exceeds the option value of $0.9 million, the option value will disappear. In fact, if the cost to obtain the repair option is $0.3 million, the present value of the swap model with the repair option becomes equal to the present value of the repair model with the swap option because the initial gap in the present values between the two models is only $0.3 million. The actual cost to obtain the repair option should be determined through negotiation with the repair outsource company.

Unlike the cost of obtaining the repair option, the cost of obtaining the swap option should be negligibly small because ordering new products from company X's factory does not incur substantial investment. In any case, it is recommended that company X conduct feasibility studies on both the repair and swap options so that it can refine the analysis above and make a more realistic decision.

The likelihood of a cheap swap option and an expensive repair option also applies to the switching cost, that is to say, the cost to exercise the option. This is because the swap option does not incur additional cost to order new products from the factory of company X, for the return volume is at best only 3% of total production. On the other hand, without a contract with a repair outsourcing company, exercising the repair option may immediately incur a cost equal to all or part of the repair overhead cost. That being said, if the repair outsourcing company handles more volume with other customers, the repair unit cost charged to company X can eventually become fully variable.

Therefore, after quantifying the cost of obtaining and exercising the options, it is possible that the repair model with the swap option becomes optimal. After all, the difference in cost saving is only $0.3 million. The repair model with the swap option can reduce the cost by $1 million, while the swap model with the repair option can reduce the cost by $1.3 million in the next three years.

Additional practical considerations are the following two points that apply to any real options analyses (Howell, et al., 2001):

- The availability and cost of information systems capable of providing the necessary data for the appropriate exercise of option.
- The availability of incentive systems capable of motivating managers to exercise flexibility in the interests of shareholders.

In the case of company X, the data on the product cost, the repair cost, and the volume need to be monitored at every product release. Then, company X needs to be able to switch to the cheaper model so that any cost savings opportunity can be exploited.

6.1.3. Sensitivity Issues

As discussed in Section 5.4: Sensitivity Analysis, it should be noted that the optimal model is sensitive to changes in the switching cost and the volatility. For example, if the switching cost to swap becomes zero or the switching cost to repair exceeds $0.8 million, the optimal model changes from the swap model with the repair option to the repair model with the swap option. Again because the switching cost to swap is likely to be insignificant and the switching cost to repair may be large due to the repair overhead cost, the repair model with the swap option becomes the optimal model. Similarly, when the swap model volatility drops to 6%, the repair model with the swap option becomes optimal. Consequently, it is important to monitor the switching cost and the volatility.

Other variables such as the repair cost, the product cost, and the volume can also change the result, though more indirectly than do the key sensitivities. The conclusion that the swap model with the repair option is optimal includes the assumption that the repair option is utilized whenever the data shows that the repair option is cheaper than the swap. In the case of repair cost decrease, product cost increase, or volume increase (all of these increase the relative cost of the swap model), if there is inflexibility in switching to the repair model, the cost of the swap model with the repair option may come closer to the very high cost of the swap everything model. If this is the case, the repair model with the swap option can be optimal. Additionally, when the value of the repair option declines or diminishes due to other sensitivities, there is an incentive to either abandon the repair option or move to the repair model with the swap option.

In order to ensure the cost optimality of models and the value of the switching option, the four steps of real options analysis should be performed when variables consistently deviate from the assumptions and the forecasts. It is not only the switching cost or the relative volatilities of the two models, but also the present values that affect the value of switching options.

6.2. Evaluation of the Methodology

The strength of the combined methodology of the news vendor approach, discounted cash flow analysis, Monte Carlo simulation, and real options analysis is that it considers inventory policy over a single period and multi product lines at a product level, and at the same time provides the present value of different models with options over multi-periods and multi-uncertainties at the aggregate level. To summarize:

- The news vendor approach provides optimal swap volume for the single period inventory replenishment.
- Using the swap volume, discounted cash flow analysis considers multi periods.
- Monte Carlo simulation can analyze the impact of simultaneous changes of multi uncertainties.
- Real options analysis provides a contingent strategy and the option value.

As you can see, these methodologies are complementary to one another.

A weakness of real options comes from the intrinsic difference between financial assets and real assets. For example, the no-arbitrage opportunity can be true in financial markets, for it is a publicly traded market. However, the no-arbitrage opportunity does not often apply to real asset projects because they are not publicly traded and there should be many arbitrage opportunities. An arbitrage opportunity emerges when there are differences among the returns of different projects. It is worth experimenting to use actual growth rate instead of the risk free rate.

Additionally, real options assumes that there is a maturity period. However, in the case of logistics systems, it is often the case that an option has no "maturity." As the system does not end at a certain time, it often tends to be an iterative process. For example, an air freight operation with a sea freight option does not have a maturity period, and whenever the sea freight option becomes more cost efficient, it should be exercised. This is probably why optimization has been the major methodology used in logistics systems. However, it is possible to gain a contract or agreed period to exercise options. For instance, a sea freight capacity option with a shipping line can be made valid for two years.

Finally, real options does not specifically address the timing of exercising the switching option. A binomial decision tree shows when to continue the base mode of operation and when to switch to the optional mode of operation. However, it does not predict that S becomes Su (or Sd). Though it is often mentioned that real options provides a strategic roadmap, it does not really show when to exercise an option. The timing should be obtained through basic arithmetic that compares the total cost of the basic mode of operation and the total cost of the optional mode of operation including the switching cost.

Though one strength and four weaknesses are mentioned, the conclusion should not be that real options analysis is an inferior methodology. It is a powerful and strategic tool with some room for improvement.

6.3 Further Research

There are four points left for further research. First, the fact that the volatilities of the two models and the switching cost, not the present values of the two models, determine the result contradicts intuition. The binomial approach calculates the present value with backwards recursion, so volatility and the switching cost, not initial present value obtained through DCF analysis, determine optimality. When the repair cost to the product cost declines dramatically, intuition suggests that the repair model should be the basis of the process, an assumption that cannot be explained with the binomial model. There could be some weakness in applying financial options to real assets or in using present value as an underlying asset.

Second, every time variables differ from the forecasted data, should real options analysis be reworked and the solution be changed? If the solution changes so frequently, there is little time to actually use the option, and the value of the option may end up being smaller than the cost to acquire the option. So it may be worthwhile to pursue the question of when it makes sense to change the long term solution produced by real options analysis.

Lastly, it would be interesting to see whether it is feasible to create an insurance market to pool different kinds of operational risks of many firms. Similar to the existing insurance system, the availability of correct data will be the key to create such a market as well as a sufficient number of participants.

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