Decision-making framework for justification of reverse logistics in the computer industry

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**DECISION-MAKING FRAMEWORK FOR
JUSTIFICATION OF REVERSE LOGISTICS
IN THE COMPUTER INDUSTRY**

TAN WEE KWAN, ALBERT

**SCHOOL OF MECHANICAL & AEROSPACE ENGINEERING
NANYANG TECHNOLOGICAL UNIVERSITY**

2005

**Decision-making Framework for
Justification of Reverse Logistics
in the Computer Industry**

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ABSTRACT

This research examines the viability of reverse logistics by developing a decision making model for manufacturers in deciding under what condition they should consider reverse logistics as a business where it can be performed to either minimize costs or maximize profit. It focuses on companies supplying computer products with actors consisting of the manufacturer, its suppliers, channels and repair depots to form the reverse logistics network.

As this is a new field in supply chain management especially in Singapore, an empirical study in Singapore is conducted to understand and evaluate the status of companies practicing reverse logistics to support their Asia Pacific operations. The survey findings confirmed that companies are implementing reverse logistics to minimize their costs or for warranty compliance. The next step is to determine key variables and inputs that are significant in developing a mathematical model is developed to assess profitability of reverse logistics operations. Two sub-models are developed: the first sub-model is for make parts where these parts are evaluated either for repair, repackage or scrap and the second sub-model is for buy parts where these parts are evaluated either for exchange or credit with supplier or simply scrap.

In extension to the mathematical model, a dynamic model is built to determine profitability of reverse logistics that takes into account other variables that are not possible in the prior model and validated using data from a computer company (Hewlett Parkard). Initial statistical analysis is performed on data collected from HP for their return volumes transacted over a period of two years. The results from this analysis have indicated that make parts are more profitable than buy parts in reverse

logistics and these parts can be categorized according to their transaction volumes (i.e. low, medium and high).

Both the mathematical and dynamic models have confirmed that reverse logistics is viable only for high quality and volume transaction, and decentralise reverse logistics is recommended for countries with high tariff for import and export of goods, in this case computer products and parts.

In conclusion, the models developed facilitate strategic analysis of reverse logistics as it incorporates important factors such as quality, return volumes and tariffs that have a significant impact on the profitability of reverse logistics. Thus, the model developed can enhance the decision making process for reverse logistics operations in the international context to either minimize the manufacturers' cost or maximize their profits.

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CHAPTER 1 INTRODUCTION

1.1 Background

Reverse Logistics is a process of planning, implementing and controlling the efficient, cost-effective flow of materials and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. It is a wide discipline, which can involve any of the following: re-cycling, re-use, recall and decomposition of packing material and products. However, it is not a new industry practice but has recently received growing attention as more companies are using it as a strategic tool in serving their customers.

Reverse logistics is commonly perceived to be identical to the traditional forward distribution. However, reverse logistics flows differ in several aspects from forward logistics flows (Stern et. al, 1996) in Figure 1.1;

a) Demand is relatively predictable in forward logistics flows but not so in the case of reverse logistics flows, where there is a high degree of uncertainty in supply both in terms of quantity and quality returned by the consumers (Fleischmann et. al, 1997). This is due to the difficulty in forecasting when a product will fail and which parts within the system need repair or replacement.

Forward versus Reverse Distribution

	<u>Forward Distribution</u>	<u>Reverse Distribution</u>
<i>Demand</i>	Predictable	Unpredictable
<i>Quantity</i>	Large lot size	Small Lot size
<i>Function</i>	Break Bulk	Make Bulk
<i>Unit Value</i>	High Value	Low Value
<i>Producers</i>	Few	Many

Figure 1.1 Comparison between forward and reverse distribution

b) The quantity of units produced by manufacturers is large and one of the functions of the forward channel is to assist in breaking the bulk quantity into smaller assortments so that they carry enough stocks to supply their immediate customers. In reverse logistics flow, quantities coming from consumers are small and the reverse logistics network is expected to make bulk to minimise transportation costs.

c) Unit value of electronics products is high and they are produced by a few manufacturers. However, in the case of reverse logistics, there are many consumers involved and the "book" value of these items would have depreciated to a much lower value. This is especially so in the PC industry where PC technology is changing so rapidly and the product life cycle is generally less than six months.

Some manufacturers have implemented reverse logistics because of heightened consumer interest in environmentally friendly products and practices, in addition to government legislation -- especially in Europe (Cooke, 1992). This has led to an increase in responsibilities of the supply chain members because they are now responsible for products they have sold to their customers and will have to

dispose them after their useful life is over. But the primary obstacle to reverse logistics is still in justifying its costs (Rogers and Tibben, 2001). It may be cheaper sometimes to replace the faulty part with a new part than to send it back to the manufacturers for repair.

1.2 Current issues and challenges in reverse logistics management

The following challenges and issues are prevalent in companies planning and managing reverse logistics operations based on the latest study by Rogers and Tibben (2001), Guide and Wassenhove (2000):

- The state of development of reverse logistics is analogous to that of inbound logistics of 10-20 years ago. The scope of reverse logistics has expanded from service parts management to include other areas (e.g. reuse, repair, remanufacturing, etc) and needs significantly more attention and development in the majority of the companies. The reverse logistics process has not been mapped in most companies under the enlarged scope of reverse logistics; thus, making it difficult for companies to properly plan, implement and control the process. Without a proper mapping of the reverse logistics process, the components and their relationships cannot be accurately determined. Company policies which prevent reverse logistics from operating effectively or efficiently were the second most commonly cited barrier to good reverse logistics. (Rogers and Tibben, 2001).
- Reverse logistics processes are always being managed within a single company or between a few companies, but seldom managed across a supply chain. The key

reason is due to lack of reverse logistics information systems (Rogers and Tibben, 2001). Few good reverse logistics management systems were found since few companies have successfully automated information relevant to the return process. Because information systems (IS) department resources are typically stretched to their limit, those resources are usually not available for developing reverse logistics applications.

- "Financial Justification" is considered the biggest barrier because companies assign reverse logistics a lower priority than other issues according to the survey done by Nanyang Technological University and National Computer Board (Tan, Ho and Yu, 2002). The greatest barrier to implementation of reverse logistics solutions is its importance relative to other issues (Rogers and Tibben, 2001). Nearly 40% of the respondents said that reverse logistics was not a priority for their firms. For many companies it has not been possible to justify a large investment in improving reverse logistics systems and capabilities.
- Most research efforts have focused on ways to minimize the loss associated with reverse logistics. This traditional view requires that the companies seek to create new markets for used products, but passively accept product returns. Few researches have focused on valuing the potential economic attractiveness of reverse logistics (Guide and Wassenhove, 2000). Despite the potential profitability of reverse logistics, there are no integrated decision frameworks to advise decision-makers about the economic viability of various reverse logistics options.

1.3 Needs and Motivation for this research

Looking at the current issues facing reverse logistics management, it is timely now to develop a framework to systematically evaluate the viability of reverse logistics and develop appropriate strategies and policies to optimize the reverse logistics network.

a. Needs for a decision-making framework to justify reverse logistics.

As indicated by the surveys in Singapore (Tan, Ho and Yu, 2002) and in USA (Roger and Tibben, 2001), most respondents felt that biggest barrier is to justify reverse logistics to their management as shown in Table 1.1.

Table 1.1 –Barriers to Reverse Logistics (Rogers et al. 2001)

BARRIERS TO REVERSE LOGISTICS

Barrier	Percentage of Respondents
Importance of reverse logistics relative to other issues	39.9%
Company policies	35.4%
Lack of systems	35.1%
Competitive issues	32.1%
Management inattention	27.3%
Personnel resources	19.3%
Financial resources	18.9%
Legal issues	14.1%

However, there is currently no method and framework available to help them develop a strong value proposition for reverse logistics and thus it is not given priority and attention. Therefore, to encourage more companies to practice and streamline reverse logistics operations, a decision-making framework to justify

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reverse logistics is essential to lower its barrier and to expand its development further.

b. Reverse logistics market is significant in Asia Pacific.

The growing concern for the environment, coupled with rapid increase in the introduction and use of new technology in the marketplace, has led to increased interest and focus in reverse logistics. According to Blumberg (1999), the compounded annual growth rate (CAGR) for repair service market in the Western Europe will reach 23.1% in 2000 while Asia Pacific will reach 19%. The latest estimate from Rogers and Tibben (2001) shows that reverse logistics is made up of 4% of the total logistics costs. Tables 1.2 and 1.3 show the repair service market forecast breakdown by areas and by market segments.

Table 1.2: Total Worldwide repair service market forecast by regions (Blumberg,1999)

(In Millions (US\$))

Region\Year	1994	1995	1996	1997	1998	1999	2000	CAGR
United States	3,936	4,527	5,229	6,000	7,107	8,109	9,293	14.6%
South America	241	275	31	357	407	473	549	16.15%
Western Europe	396	475	570	684	821	985	1,182	23.1%
Asia Pacific	289	344	409	487	579	689	828	19.0%
Rest of the world	275	324	283	452	533	639	765	19.8%
Total	5,137	5,945	6,904	7,980	9,447	10,895	12,617	15.8%

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Table 1.3: Total Worldwide repair service market forecast by market segment (Blumberg)

(In Millions (US\$))

Market Sector / Year	1994	1995	1996	1997	1998	1999	2000	CAGR
Process equipments	1,075	1,238	1,443	1,680	1,960	2,320	2,671	16.4%
Telecom	628	773	945	1,172	1,480	1,769	2,201	23.2%
Analytical instrument	567	687	780	921	1,041	1,176	2,201	23.2%
Computer / peripherals	1,054	1,161	1,323	1,480	1,700	1,922	2,140	12.5%
Medical equipment	235	299	358	455	568	672	851	23.9%

The market potential based on Blumberg's analysis suggests that there is significant growth for repair services (part of reverse logistics operation) in Asia Pacific especially in the high tech segment. Thus, the study on reverse logistics in the computer industry has its importance and significance to Asia Pacific as well as to Singapore economy as computer sector is one of Singapore's largest sectors within manufacturing industry according to the Economic Development Board of Singapore (EDB, 2002).

1.4 General Research Questions

Decision-making in reverse logistics operations involves a variety of logistical and management factors. These factors pose four key research questions on how they will affect reverse logistics operations, either singularly, or in combination with one another.

(1) Key question "Under what condition should one consider reverse logistics?"

- Is it to satisfy legislation requirement of specific countries or to maximize its profit margin for service parts distribution?
- Coupled with this question is to decide whether reverse logistics is determined at the item level or at the system or product level. At the system level, parts are grouped according to certain characteristics (by volume, value or engineering status) and decision is made based on such grouping. At the item level, parts are treated individually and decision is made based on each item attributes.

(2) Key question “Which type of reverse logistics treatment should be given for each item or for each group of items?” For example, some items are more economical for repairs or remanufacturing while others should be scrapped.

(3) Key question “Where is the ideal location to perform the repair or scrap, locally or centrally?” If the reverse logistics operation is to perform centrally, what is the preferred mode of shipment, air or sea mode?

(4) Key question “What is the right pricing for the repaired or re-manufactured parts to match against new parts?” This is to assure that these parts are equally demanded and form part of service part logistics.

These questions can be focused on individually, but studying how specific factors interact with one another provides a greater impact on understanding the overall reverse logistics system and is the main thrust of this study.

1.5 Research Objectives

The objectives of this research are as follows:

- To gather and gain an in-depth understanding of the existing methods of managing the reverse logistics of computer products and parts in this region.
- To develop a decision-making framework for justifying reverse logistics. The underlining decision is to determine,
  - Under what condition should manufacturers consider reverse logistics, and
  - How reverse logistics could be performed to minimize costs or maximize profit or both.
- To recommend optimal policies and best practices based on the simulation and validation to achieve maximum economic value. This will narrow the current gaps in planning and managing reverse logistics operations.

1.6 Scope of the research

The study will attempt to develop a decision-making framework for reverse logistics in this region focusing on the computer industry. The main actors are the manufacturer and its supply chain members (i.e. immediate suppliers, repair depots, immediate channels and logistics providers). The consumers will not be directly involved in this study, as shown in Figure 1.2. Dell Computer, which sells directly to consumer via the Internet, outsources their entire reverse logistics operations to a logistics provider (Image Microsystems: <http://www.imagemicrosystems.com>). Consumers send their computer to Genco for servicing and do not directly deal with Dell computer.

This study will focus on reverse logistics for products and parts and will exclude the recycling of packaging materials which numerous researches have already been done.

Figure 1.2. Scope of Research for Reverse Logistics

1.7 Research methodology

This study focuses primarily on companies supplying computer products with actors consisting of the manufacturer, its suppliers, its channels and repair depots to form the reverse logistics network. It is carried out in the following phases.

1. Conduct an empirical study in Singapore to understand the status of companies practicing reverse logistics to support their Asia Pacific operations. Compare the survey findings with those conducted overseas.

2. Identify key variables to develop a decision making model to maximize profitability for reverse logistics.
3. Simulate the model using HP data to evaluate its effectiveness in solving complex international reverse logistics operations in Asia Pacific.
4. Recommend optimal policies based on the results from the simulation to achieve maximum economic value.

1.8 Organization of this thesis

This thesis is made up of seven chapters. The Chapter 1 introduces the objectives for this research and the research methodology. It will also cover some of the key research questions and the scope of research work.

Chapter 2 summarises the key drivers in reverse logistics, past research works in reverse logistics and their limitations. These limitations are focused mainly in modeling for decision making.

Chapter 3 is a summary of a survey conducted in Singapore to assess the capabilities of our local companies in performing reverse logistics for Asia Pacific regions. This will help to set some baselines to determine their effectiveness in managing reverse logistics as compared to western countries as well as to surface challenges arises from Asian context, for example in term of custom duties, motivation, barriers, measurements, etc. These findings are crucial before embarking on a more elaborative study in reverse logistics.

Chapter 4 provides an explanation of a mathematical model developed to assess profitability of reverse logistics operations using key variables. One sub-

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model is for make parts where these parts are evaluated either for repair or repackaging or scrap. The other sub-model is for buy parts where these parts are evaluated either for exchange or credit with supplier or simply scrap. Linear programming is used to determine the maximum profitability using data from Dell Computer.

Chapter 5 provides an explanation of a dynamic model to determine profitability of reverse logistics. The dynamic model takes into account other variables that are not possible in the linear programming model in Chapter 4.

Chapter 6 discusses the application of the dynamic model to reverse logistics operations for Hewlett Packard Customer Service Centre in Singapore. Statistical analysis is performed on data collected from a computer company (Hewlett Packard) for their return volumes transacted over a period of two years to understand the behaviour of key variables. Based on the result obtained from the dynamic model, recommendations are made and some useful reverse logistics policies are suggested as a result.

Chapter 7 concludes the research and modeling efforts and highlights the research contributions for reverse logistics. Future research work is also included for other researchers to consider.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the relevant literature is reviewed. Literature that pertains to ‘decision making framework for reverse logistics’ can be classified under the following topics: Types of returns, driving forces for reverse logistics, decision making framework for reverse logistics, reverse logistics system modeling, information communication technologies to support decision making in reverse logistics. In this chapter, individual research papers are organised in tables as these areas are overviewed. This review is intended to provide information on the state of the art, determine what is lacking, and clarify the difference and similarities between the work in this thesis and the existing literature.

Section 2.1 examines the type and nature of returns for reverse logistics, while Section 2.2 reviews the key driving forces and motivations for reverse logistics. Section 2.3 provides an overview of a decision making framework and Section 2.4 covers the area of reverse logistics system modeling. Section 2.5 highlights specific ICT that provide relevant information for decision making in reverse logistics. Section 2.6 presents a summary and a general outlook on what exists and what is lacking in the current literature, and what the research in this thesis can add to the current literature.

2.1 Types of Returns

Reverse logistics can be defined as: *"the process of moving a product from the point of consumption to another point for the purpose of recapturing the remaining value, or for the eventual proper disposal of the product"* (Rogers and Tibben, 1999).

Figure 2.1 depicts the flow of products between the consumer, distribution channel and the manufacturer in reverse logistics while third party logistics can be performing the reverse logistics operations on behalf of the manufacturer. Even in the case of Dell Computer, the reverse logistics operations are outsourced to a third party logistics provider.

Figure 2.1: Reverse Logistics Flows

Reverse logistics is becoming an important aspect of supply chain management (Carter and Ellram, 1998). Many companies that previously did not devote much time or energy to the management and understanding of reverse logistics have begun to pay attention (Giuntini and Andel, 1995). Firms have begun to benchmark return operations against best-in-class operators (Stock, 1998). Third parties specializing in returns have seen the demand for their services greatly increased (Stock, 1998). Leading edge companies are recognizing the strategic value

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of a reverse logistics system to return the obsolete goods so that the goods on the retail shelf (and in the warehouse) are maintained in a fresh condition and hence in demand.

As shown in Table 2.1 below, that rate at which products are returned in some industries in the US can be as high as 20%.

Table 2.1: Percentage of product returns by industry (Rogers and Tibben, 1999)

Industry	Sample Return Percentages
Computers	10-20%
Automotive Parts	4-6%
Consumer Electronics	4-5%
Chemical	2-3%
Printers	4-8%

Generally, products are returned or discarded because they either do not function properly or their functions are no longer needed and they can be categorized under three main headings according to the supply chain stage in which they occur. Researchers have categorized the returns according to the usual supply chain hierarchy, starting with manufacturing returns, followed by distribution returns and consumer returns.

Manufacturing returns is defined as all instances where components or products have to be recovered in the production phase. This occurs for a variety of reasons. Raw materials may be left over, intermediate or final products may fail quality checks and have to be reworked and products may be left over during

production. De Brito, *et al*, (2002) have gathered a number of researches in this area and their impact on production and inventory planning and control.

Distribution returns refers to all those returns that are initiated by a supply chain actor during distribution after the product has been made (including the manufacturer). This involves product recalls, commercial returns and stock adjustments. Product recalls are products recollected because of safety or health problems with the products, and the manufacturer or a supplier usually initiates them. Commercial returns are all those returns where a buyer has a contractual option to return products to the seller. This can refer to wrong/damaged deliveries or to unsold products that retailers or distributors return to the wholesaler or manufacturer. Guide and Wassenhove (2000) have done numerous studies in this area for remanufacturing while Fleischmann, *et al* (1997) have gathered numerous works in optimising the distribution network for reverse logistics.

Consumer returns are those returns initiated by a customer or user as a result of consumption/use. There is a variety of reasons to return the products, namely: reimbursement guarantees, warranty returns, service returns (repairs and spare-parts), end-of-use, and end-of-life. Rogers and Tibben (2001) have conducted a survey in the US to study the behaviour of consumer returns and their motivation. Nagel and Meyer (1999) examine how customers can be more or less active concerning the returns, by sending back toner cartridges via mail, or by having refrigerators collected at home. Deposit fees and charity's contributions are some of the incentives used by companies to stimulate their own or other customers to bring/send back the goods they would like to recover (De Brito *et al*, 2002).

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In terms of product categories, the following research findings are contributed by the various investigators for specific industry sectors as shown in Table 2.2.

Table 2.2: Research on reverse logistics by industry sectors

Industry Sector	From Researchers	Year
Jet engines and airframes	Guide and Wassenhove	2003
Hazardous wastes	Hu, Sheu and Huang	2002
	Stock	1998
	Johnson	1998
Pharmaceuticals	Gooley	2003
	Teunter, et. al.	2000
Container remanufacturing	Guide and Wassenhove	2003
	Goh and Varaprasad	1986
	Kelle and Silver	1989
Tires	Rogers and Tibben-Lembke	1999
	Guide and Wassenhove	2003
Copy and Print Cartridge	Guide and Wassenhove	2003
	Krikke, et. al.	1999
	Rogers and Tibben-Lemke	1999
	Xerox	1999
Single-use cameras	Goldstein	1994
	Guide and Wassenhove	2003
	Kodak	1999

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Industry Sector	From Researchers	Year
Retailers	Gooley	1998
	Hamilton	2001
	Hoffman	1998
	J. C. Penney	2003
	Jedd	2000
	Rogers and Tibben	1999
Cellular telephones	Guide and Wassenhove	2003
Electronics and Computers	Autry, Daugherty and Richey	2000
	Knemweyer, Ponzurick and Logar	2002
	Krikke et al.	1999
	Linton and Johnson	2000
	Moyer and Gupta	1997
	Rogers and Tibben	1999
	Shih	2001
	Veerakamolmal and Gupta	1998

The electronics and computers industries are industries where new products and equipment become available very quickly. Computer that become obsolete are either land filled or have some parts of them recycled. The existing research on

recycling computers or computer parts is based on various practices in different parts of the world and has attracted many researchers due to its complexity.

2.2 Driving forces for reverse logistics

The following factors are also forcing companies to change their attitude towards reverse logistics according to numerous researchers and make reverse logistics a part of their strategic management:

- a. Government legislation,
- b. Shortening product life cycles,
- c. New direct channels of distribution,
- d. Market forces,
- e. Shifting of power within the supply chain, and
- f. Economic reasons (direct and indirect).

a. Government legislation: Waste reduction has received growing attention in industrial countries in view of the critical shortage of landfill and limitations in incineration capacity. Several countries have enacted environmental legislation that charges the producers with responsibility for the whole product life cycle. "Take-back obligation after use and eventual disposal" are typical legislative measures and a number of companies are actively exploring options for take-back and recovery of their product (Thierry, 1997).

Companies may get involved with reverse logistics as a strategic step to get prepared for future legislation. Legislation here refers to any jurisdiction indicating

that a company should recover its products or accept them back, e.g. packaging recycling quotas in Europe (EUROPA, online) and home shopping right to return in some countries as UK (Office for Fair Trading, online). They are preparing for the inevitable day when the producer will be made fully responsible for the disposal of the product at the end of its useful life. For example, Fuji Xerox in Asia is actively collecting used toners from laser printers for recycling as part of their reverse logistics program (Hiroaki, 2001). MacDonald (1996) presents a review of the solid waste management models while Caruso et al (1993) develop a location allocation model for planning the urban solid waste management system and a solution heuristics. Jacobs and Everett (1992) develop a model for optimal operation of landfills and recycling programs.

b. Shortening product life cycles: Product life cycles are being shortened as is evident in the computer industry. New designs are brought onto the market at an ever faster pace to persuade consumers to buy more often. While consumers have benefited from a greater variety and choice of products as well as improved performance, this trend inevitably results in more unsold products, more returns, more packaging materials, and more waste (Stock, 1998). Therefore, shorter product life cycles have increased both the volume to be dealt with by reverse logistics networks and also the cost of managing them.

c. New direct channels of distribution: New channels are being developed to provide consumers with easier and quicker ways to purchase products. Direct channels

such as e-commerce increase the likelihood of returned products, such as items damaged in transit. Dell in Asia is selling its PCs online and is expecting between 10% and 15% of its products to be returned to it via third party logistics providers using their website “e-support direct” (Ng, 2001).

As direct channels serve customers not only locally but also globally, managing returns will become increasingly complicated and expensive. Thus, direct channels will add pressure on reverse logistics networks. In fact, a company or an organization is sometimes compelled to become responsibly engaged with reverse logistics. For instance, Paul Farrow, the founder of Walden Paddlers, Inc. was concerned with “the velocity at which consumer products travel through the market to the landfill” which pushed him to an innovative project of a 100-percent-recyclable kayak (Farrow et al., 2000).

d. Market forces: Reverse logistics can also be used to replace customers' obsolete or slow moving inventories with newer goods. If existing parts held by the dealers are not selling well, companies such as Caterpillar Asia give their dealers a generous return allowance to exchange for new parts that their customers really need. Caterpillar Asia has an e-commerce program for their dealers to return their existing parts in exchange for parts in new products (Fites, 2000).

In face of competition, a company may perform reverse logistics to prevent other companies from getting their technology or from preventing them from entering the market. Or the company may want to present a good (environmental) image with the customer or building a better relation with customer. Thus, having a green line of

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products can be part of a customer relationship strategy, especially due to the increased environmental consciousness by society as a whole.

e. Shifting of power within the supply chain: Increased competition has enabled customers to become more powerful in the supply chain. A recent survey conducted in Singapore among logistics service providers confirms that meeting customer demands are rapidly becoming the most important driver of logistics management (Sum and Teo, 1999). Offering a greater variety of logistics services is considered crucial as more logistics companies in Singapore are transforming themselves into third party logistics providers. Third-party logistics providers are expected to provide a complete set of solutions for the collection and transportation of products, as well as other value-added services such as repair and re-manufacturing.

More and more manufacturers are producing goods based on the actual customer demands rather than on forecasts, so as to avoid flooding the channel with unwanted inventory (Tan, 1999). They are forced to manage these inventories more effectively to maintain their competitive edge.

Manufacturers' strategic use of reverse logistics capabilities increases the switching costs of customers so that they will not patronize from another supplier. Adopting and implementing reverse logistics policies is one of the means of developing linkages with suppliers (Ritchie, Burnes, Whittle and Hey, 2000). Information support is another mean to develop such linkages to achieve efficient reverse logistics operations (Daugherty, Myers and Richey, 2002). By providing prompt and accurate information, logistics managers will be equipped with enhanced

visibility of the products that will be returned and can, therefore, process the receipt and return of the products more efficiently.

f. Economic reason (direct or indirect): Economics relates to all recovery actions where the company has direct or indirect economic benefits. The profit from recovery actions include abating costs, dwindling on the use of materials, or obtaining valuable spare parts. The market potential based on EDB of Singapore analysis (EDB, 2002) suggests that there is a significant growth for repair services (part of reverse logistics operation) in Asia Pacific especially in the high tech segment.

2.3 Decision Making Framework for reverse logistics

Decision making for Reverse Logistics can be categorised into three levels: strategic, tactic and operational by using the taxonomy of Ganeshan et al. (1999) and of Schmidt et al. (2000). This is illustrated in Table 2.3. However, a company does not necessarily have to follow the decision hierarchy step by step especially in the presence of legislation as it has no choice.

Table 2.3: Different levels of decision making in reverse logistics

Level	Type of Decision Making
Strategic	• Recovery Strategy • Product Design • Network Capacity and Design

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Tactical	• Production Planning • Distribution Planning • Inventory Planning • Marketing
Operational	• Production Scheduling and Control • Information Management

At the strategic level, decisions are long-term since they are hard to change. For example, decision of whether or not to do recovery and if so which type of recovery are long-term in nature. The return reason, together with the inherent product characteristics, give an idea whether high value recovery is, or not, possible. In this way, a spectrum of the return option pyramid can be created and be taken into account during the design of the product. In fact as some decisions become fixed, other decisions become further constrained given that one would like to maintain efficiency. Therefore, every decision has a bearing on the impact of other decisions. Network can be re-designed since recovery can be merged with an already existing supply network. The issues here are to locate warehouses, re-distribution plants and so on and at the same time allowing for enough future capacity. Fleischmann, *et al* (1997) has gathered numerous works in optimising the reverse logistics network.

At the tactical level, one has to integrate product returns with the overall organization. In particular, the transport, handling and the warehousing of returns have to be dealt with. One of the issues is for procurement to take into account product returns leading to decision on which forecasting techniques to employ. Some

companies may consider outsourcing (partially) return operations and new coordinating mechanisms have to be set. Furthermore, there are typical production planning and inventory management decisions to take into account product returns and recovery. Guide and Wassenhove (2000) have done numerous researches in this area for production, inventory planning and control.

At the operational level, one needs to make decision on production scheduling & control to manage the disassembly and reassembly operations. More detailed schemes to monitor, share and control information have to take place at this level. Supportive IT system has also to be thoroughly thought about. Stock (1998) has mapped out some basic processes for reverse logistics and how information is used to make operational decisions. Rogers and Tibben (2001) has proposed some key attributes for a reverse logistics system to support its operations.

2.4 Reverse Logistics Systems Modeling

Reverse logistics system design and modeling has gained tremendous importance for the competitive position of manufacturing companies in today's global market. Most reverse logistics models are found in the operations research literature. Researchers have tried different mathematical modeling and solution approaches such as heuristics or modifications on existing algorithms to manage models with return flows. Table 2.4 summarizes some of the key work in this area.

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Table 2.4: Examples of reverse logistics systems modeling

Authors	Objectives	Type of Model	Deterministic / Stochastic	Single Period / Multiple Periods
Fleischmann et al. 1997	Surveying the field of reverse logistics for management of return flows	Different quantitative models which are usually modification of facility location problems.	Both	Single period
Spengler et al. 1997	Set up and control of environment friendly production technologies	A mixed integer programming model	Deterministic	Single period
Realff et al. 1999	Designing a reverse production system	A mixed integer programming model	Deterministic	Single period
Fleischmann 2000	Decision in reverse logistics	Distribution management and inventory management models	Stochastic	Multiple periods
Toktay et al. 2000	An ordering policy to minimise total procurement, lost sales and inventory costs	A queuing network model	Deterministic	Multiple periods
Shih 2001	Minimise total costs	A mixed integer programming model	Deterministic	Single period
Klausner and Hendrickson 2000	Estimating the buy back price	A mathematical model	Deterministic	Single period
Guide Jr. V.D.R., R.H. Teunter & L.N. van Wassenhove 2001	Match Supply and Demand to Maximize Profits from Remanufacturing	A mathematical model	Deterministic	Single period

Fleischmann et al. (1997) present a review of quantitative models for reverse logistics. These are usually modifications of facility location problems. They analyze the management of return flow from the users back to the producers. These flows are generated by reuse of products, parts, or materials, and effort to minimize material wastage. There are uncertainties such as quality and the quantity of what can be collected back. They discuss distribution planning, inventory control, and production planning respectively. There are both stochastic models and deterministic models. They consider inventory, collection, transportation, and operation costs. They have demand constraints, limits on the number of facilities. They concluded that modifications and extensions are necessary.

Splengler et al. (1997) present development of operations research models for recycling of industrial by-products and dismantling and recycling of products at the end of their lifetime. They apply mixed integer linear programming technique to model the real life industries such as demolition of buildings, and iron and steel.

Realf et al. (1999) developed a mixed integer programming model for reverse production system design. The model is validated with a case study for carpet recycling industry. The results show that the volume of carpet recycled is a very important factor for economical justification. Similarly, Shih (2001) developed a mixed integer programming model for infrastructure design of recycling systems for computers and other electronic products in Taiwan. The model minimizes the total cost consisting of transportation costs, operating costs, facility costs, disposal costs, and landfill costs. Numbers and locations of storage and recycling sites are obtained for different scenarios.

Fleischmann (2000) develops distribution management and inventory management models for reverse logistics. The analyses are applied to a case for IBM using Arena, a commercial simulation software package. Toktay et al. (2000) analyze inventory management of re-manufacturable products by developing a closed queuing network.

From an economic perspective, only some (related) research is available. Klausner and Hendrickson (2000) present a mathematical model that might be used for estimating the buy back price. Guide et al (2001) present a mathematical model to determine the optimal acquisition price for products from the field as well as the selling price of these products. All the models assume a steady state situation.

2.5 Information & Communication Technology (ICT) to support decision making in Reverse Logistics

Information is needed in decision making and ICT helps to capture and present the information for managerial decision. ICT can help to track the returns, planning and optimization of returns for recovery, and information gathering. Table 2.5 below lists the kind of ICT applications and respective implications in handling return logistics.

Table 2.5: Examples of ICT applications for Reverse Logistics

Type of Applications	Objectives	Type of Decision Making
DSS for end-of-use; (Nagel and Meyer, 1999)	Information on operations' costs & recycling revenues	Cost optimization, facilities location, vehicle routing, etc.
Computer's configuration	Information on	Setting buy-back price

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reader (Nagel and Meyer, 1999)	operations' costs & recycling revenues	
Software specialized on return handling (Meyer, 1999)	Product's expiration data, damage check	Recovery-related Decisions
DSS for remanufacturing (Linton and Johnson, 2000)	In-depth Information on processes	Remanufacturing-related Decisions
DSS for warehousing (Landers et al., 2000)	Real-time data on orders, information on capacity restrictions	Inventory control, transportation's choices, etc.
DfX, remote maintenance, etc. (Maslennikova & Foley, 2000)	Extensive data-base on products	Recovery options, environment's sustainability, and so forth.

ICT for tracking of product returns

Information relating a product return with a past sale can support forecasting of product returns and is therefore helpful for inventory management (de Brito and Dekker, 2001). Landers et al. (2000) highlight the importance of tracking component's orders in the case of reverse logistics. The authors use a concept called "virtual warehousing" where real-time information feeds expeditious algorithms to support decisions. The use of ICT leads to an improvement in stock levels, routing and picking processes when compared with the pre-ICT scenario. Xerox (Maslennikova and Foley, 2000) uses bar code labels to track packaging material with the aim of achieving resources' preservation. One can use ICT to know the location of items in the chain (tracking) and also to know their historic path through

the chain (tracing) (van Dorp, 2002). The focus of tracking and tracing has mainly been on the outbound flows (Gurin, 1999). Regarding the application of tracking and tracing in the (reverse) supply chain there is research taking into account the use of ICT to elaborate on inventory and purchasing policies (Toktay et al., 2000).

ICT for planning and optimization of returns for recovery

Commercial software specifically designed for planning purpose is not available (Caldwell, 1999). While some specialists have suggested logic extensions of packages such as MRPII (McNeill, 1991) many firms are pushed to develop their own tailor-made software. Fraunhofer IML has developed software to embed data on recovery processes as reported in Nagel and Meyer (1999). The authors consider two chains in Germany: the national refrigerator and the computer recycling networks. Costs could be minimized with the optimization of the location of facilities, vehicle routing and operations' scheduling supported by the software. For the case of the German computer-recycling network, transport volume (in tons per km) could be reduced by almost 20%. Estée Lauder is another company that has developed specialized software to handle product returns (Meyer, 1999). The system checks the cosmetic items for expiration date and damages and then makes recovery related decisions. Estée Lauder recovers its investment on ICT within one year. In the case of Nortel Networks, a Decision Support System (DSS) was developed to assist remanufacturing (Linton and Johnson, 2000). The tools establish interrelations between the production and the remanufacturing of products allowing both processes to be better planned and controlled with limited resources.

ICT for process optimization of disassembly

There is also literature on how to use information and new technologies to improve processes in the reverse logistics, in cases where products and equipment need to be disassembled. For example, Mok et al. (1997) develop criteria for the disassembling process. They take into consideration different degrees of technological effort, which can be employed in a specific situation and illustrate their methodology with the disassembly of an automobile. In particular, Xerox (Maslennikova and Foley, 2000) has an integrated solution for reverse logistics from product creation to eventual disposal. ICT is indeed a supportive tool that can be used through the whole life path of a product with benefits for reverse logistics. In the context of recovery, one will find the needs in the reverse end: products have to be torn apart and thus designed to ease of de-manufacturing (Dfx). Besides this, disassembled parts may have to be re-assembled in re-manufactured products. As the case of Xerox shows, an integrated Dfx is a critical factor for a sustainable development. Some studies take into account the impact of product design on the supply chain logistics (Krikke et al., 2001).

ICT for information gathering

Finally, information gathering is another critical factor. The ICT tools are very demanding with respect to information for all parties involved in reverse logistics. Moreover, Nagel and Meyer (1999) declare that the lack of information can be a bottleneck, which results in difficulties for the management of recycling systems. On the Nortel Networks case, the DSS could not be designed as desired due to a short

of data on customer's returns (Nagel and Meyer, 1999). Data are of utmost importance in the Xerox's case (Maslennikova and Foley, 2000). It is evidenced that data rather than technology is the critical factor with respect to ICT applications for reverse logistics.

2.6 Summary

Most of the decision making models for reverse logistics were built on operations research (OR) theory comprising a disparate collection of mathematical techniques, such as linear programming, queuing theory, Markov chains and dynamic programming. The common theme running through all these tools is their suitability for the solution of man-made problems. Although not strictly modeling techniques, their consideration here is warranted by virtue of their widespread use in industry.

The first observation to be made is that different methods are suited to different problems. No single technique is likely to prove a panacea in this field. OR tools have their place at a tactical level in the design of supply chains. They constitute the only analytical approach examined here that is able to solve batch sizing and job sequencing problems. Yet they fail to throw much light on the dynamic behaviour of the supply chain as a whole. Qualitative phenomena like demand amplification can only be investigated and hence combated by methods based on the dynamics of the system.

Further, the implications of strategic design on supply chain performance can only be discovered by using simulations based on the dynamics of the system. The OR optimization techniques examined provide little insight into how system

parameters affect the solution. However, it must be conceded, that little actual sensitivity analysis has been carried out with any of these methods. Therefore, while OR techniques are useful in providing solutions to local tactical problems, the impact of these solutions on the global behaviour of the whole supply chain can only be assessed using dynamic simulation.

The model developed in this thesis incorporates a system approach to analyze reverse logistics. This comprehensive approach is lacking in current models in the literature. Separate analysis of these systems result in different decisions than when analyzed as a combined system. Instead of analyzing reuse, remanufacturing, recycling separately, this model will include all these options to make holistic judgement.

Most models in the literature are using mixed integer programming models for single period computation. The model in this thesis is using system dynamics model. This will facilitate analysis of dynamic behaviour for reverse logistics over multiple periods and how each variable interact with one another over time. The model can be positioned at strategic level for decision making using the taxonomy of Ganeshan et al. (1999) and of Schmidt et al. (2000).

Most of the models treat all returns similarly, especially those works in the electronics and computer sectors but this is not true in reality. The model in this thesis will treat different type of parts (make part or buy part) differently for reverse logistics. Furthermore, most models in the literature considered return volumes, return quality, tariffs and other factors as constant. The research in this dissertation

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captures fluctuation in a design and analysis of experiments with the selected low and high values of some factors to be more realistic.

Overall, a comprehensive decision making model for reverse logistics is lacking to address the complexity of the computer industry. This research addresses the gap by developing a model, a case study for validation and a dynamic approach to justify reverse logistics for international needs. In fact, the dynamic model can be developed into an ICT application later which is lacking currently to enhance the decision making process for reverse logistics in the computer industry.

CHAPTER 3

SURVEY OF REVERSE LOGISTICS OPERATIONS IN ASIA PACIFIC

3.1 Introduction

Reverse logistics is a relatively new arena and is even unheard of in many parts of Asia-Pacific regions. This survey was the first to describe an empirical study of companies based in Singapore with reverse logistics operations supporting their Asia-Pacific market (Tan and Arun, 2003). This is a crucial step in this research to provide a preliminary insight on reverse logistics in this region and more fundamentally, confirming if there are companies implementing reverse logistics before more in-depth research is carried out. It will also provide useful inputs to identify critical variables (both endogenous and exogenous) for modeling the reverse logistics operations.

In July 1999, a 12-page survey was sent to 179 companies. A response rate of 15.7% was achieved. The respondents were from different industrial sectors, namely: semi-conductor, consumer electronics, telecommunications, computer, data storage, machinery, chemical and medical equipment supplies.

The objectives of this study were:

1. To evaluate the various reverse logistics practices amongst the key industries to support their operations in the Asia-Pacific region and compare the results with similar study in the US (Rogers *et al.*, 2001).
2. To analyze the types of product and component returns for exchange or repair.
3. To study the various methods of managing the reverse logistics operations.

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The data collected identified some of the current general practices and barriers, and revealed a number of important facts for reverse logistics in Asia. Although this study is an initial step to uncover and understand the reverse logistics practices in the Asia Pacific region, the feedback from the survey did show that there are a number of companies in Singapore implementing reverse logistics for various reasons.

3.2 Research Method

With the help of the National Computer Board (Singapore), 179 companies were selected from a list of 200 companies based on their presence in Asia Pacific. The survey form consisting of three main sections were mailed to the CEO of each company, to request that the questionnaire be completed by a Logistics/ Material/ Distribution Manager, with knowledge of reverse logistics operations within Asia-Pacific.

A self-addressed envelope was also provided (by the National Computer Board), and respondents were requested to return the entire survey package should they not wish to participate. In order to effectively track each participant, each survey form was deliberately labeled with its assigned serial listing. This proved to be useful in identifying the respondents who returned their forms without disclosing their identity.

To facilitate a higher return rate for the survey, it was made known that participating companies would be given a summary of the survey results. As

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logistics executives are very busy throughout the working hours, the survey form with full details in appendix A was designed with the following considerations:

- a. Limiting the form to 10 pages of questions,
- b. Using multiple choice format for all questions, and
- c. Defining “Reverse Logistics” as done in the beginning of survey as shown in appendix.

Of the total 179 survey forms mailed, only 56 were returned, of which 34 were invalid (due to change of address) and 22 were properly completed, thus constituting a 15.17% response rate. The majority of the respondents (15 out of 22, or 68%) are from the Computer or Electronics based manufacturing companies with the rest from telecommunication and medical supply companies.

Over 75% of the respondents indicated that returns from the Asia Pacific region are less than 25% of worldwide returns in term of both shipment value and shipment volume. This indicates that: either the companies here are just beginning to practice reverse logistics, or the sales volume here is low compared to Europe and USA.

Most of the respondents have less than 100 employees. 23 respondents (or 59%) have no logistics departments tasked to plan, organize or design reverse logistics system for their business. We can infer that most of the respondents do not have a department dedicated to the planning, organizing and designing of reverse logistics systems for their organization. Thus, some of the reverse logistics operations could actually be merged with the forward logistics group or managed by other departments such as marketing which is very common in Singapore.

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3.3 Result finding from the Study

There are many possible reasons why a product might require reverse logistics. As shown in Figure 3.1, returns due to quality or warranty claims are the key reasons for returns amongst these 22 respondents. The next highest ranked reason for returns is due to stock recall, end-of-life (EOL) or obsolescence.

Figure 3.1 – Top 3 Reasons for Returns

Warranties are formal statements of expected product performance by the manufacturer, and whether expressed or implied, are legally enforceable. Products under warranty can be returned to the manufacturers or designated repair centres for repair, replacement, or refund. Based on the survey, it seems that quality related reasons (be it defective or good ones but treated as defectives) is the prime factor for returns in Asia-Pacific. By “defective”, this refers to products found defective by the retailers or by the customers. In many cases, a company will inform the suppliers of

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the defects and the suppliers in return will compensate the retailers either with a new product or refund him with a cheque or a credit.

A number of the respondents (13 out of 22) have liberal conditions for returns, allowing return of products with less than six months from their dates of purchase. 11 respondents (i.e., 50%) have no definite target or limit on percentage of returns allowed per sales transaction, while 8 respondents (or 36%) allow between 1% and 5% of return per sales transaction.

Given the liberal return policies and that some returns may be of high value, the returns should be accounted for in their financial books in a timely manner. However, some companies may choose to use actual values while others may choose to use salvage values for the items reclaimed. Thus, one needs to be careful when assessing the value of the return goods before comparing or benchmarking them with others.

The typical product life cycles for products manufactured by these 22 respondents fall mainly under two categories: 6 to 12 months and more than 24 months. Those with 6 to 12 months are mainly for the computer industry, while those with more than 24 months are mainly for the electronics components industry.

The survey shows that both resellers/distributors and intra-corporate are the most common sources of returns (close to 30%). The former may be due to the current supply chain structure of most computer and electronics manufacturing companies in Asia-Pacific. Traditionally, these companies distribute primarily through resellers and distributors to expand their networks (Martin, 1998; Rogers, 2001).

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Intra-company supply is another common practice amongst these industries, relying on component or peripheral parts supplied by its sister business units. Returns in this case are possible among different business units within an organization. Returns from the End-user/Consumers is also a growing trend, especially with computer manufacturing companies as more are using electronic commerce for direct factory-to-end-user distribution to emulate Dell's successful business model.

Most return disposition decisions are made by in-house service centres or regional distribution centres as opposed to national distribution centres. Service centres are the ideal place for quality and defective screening and hence, decisions on disposal should be made there as well. Regional Distribution Centres are another commonplace for return disposition decisions. This relates back to the previous result that most returns come from these centres due to the distribution supply chain structure of these industries. Third Party Logistics Service Providers are not given much authority to decide the fate of returns.

Figure 3.2 shows that majority of the respondents (14 out of the 22) would scrap or destroy their returns. Retailers in the reverse logistics system primarily dispose of their products through: return to vendors, or sell with a discount. Manufacturers, however, have many different options. Manufacturers can choose to recondition, refurbish, remanufacture, repackage or recycle a product for re-sale later in the market.

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Figure 3.2 – Returns Disposal

“Scrap or Destroy” seems to be the most common disposal method. This may be due to the fast changing and obsolescence of technology, making it uneconomical to repair, refurbish or reuse the products. Some of the returns disposal actions (e.g. re-sell or re-packaging) are partly initiated by retailers. When returns are due mainly to “quality” related reasons, quite often they are repaired, refurbished, or repackaged before returning to the market for re-sale, if the product life cycle is not expired yet.

“Replenishment” happens mainly with electronics component manufacturers, where components with expired shelf life need to be restocked with “fresher” ones. Such returns are known as “Stock Rotation” in most industries (Cohen and Lee, 1996). The survey results have confirmed that electronics component manufacturers also resort to “Scrap or Destroy” as components with expired shelf life can no longer be recycled, reused or resold. On the other hand, PC manufacturers and medical equipment suppliers tend to perform “recondition/ refurbishing”, “repackaging”, and “resell” due to the higher value of the products.

The survey results have confirmed that many companies have a relatively long turnaround time for returns. Most of the respondents have returns with 5 or more days

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for turnaround time and are aware of the transit time measurement for reverse logistics, in the same way as the forward logistics (Figure 3.3). This is similar to the survey conducted in the US where 60% of the respondents have returns of 5 or more days for turnaround time (Rogers, 2001).

Figure 3.3 – Reverse Logistics Performance Metrics

However, very few companies have considered seriously the financial perspective of the reverse logistics. Performance measurements such as the Distribution Overhead which includes storage and labour costs, Percent of Dead-On-Arrival (percentage of products found defective upon arrival) and Percentage Sales Return, which offer financial insight on how well a company performs in terms of controlling the level of returns, are not in use by most of the respondents.

Not all companies can execute reverse logistics smoothly. The existence of many barriers, internal or external, may hinder these companies' effort in one way or another. As indicated by the respondents, “Competitive Issues”, “Financial Justification” and “Legal Issues” are three key barriers to successful reverse logistics implementations (Figure 3.4).

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Figure 3.4 – Top 3 Barriers to Success in Reverse Logistics

“Competitive Issues” such as the environment hamper reverse logistics efforts. The use of green marketing strategies that defines how a company performs reverse logistics may have significant impact on how a company wishes to employ its reverse logistics practices. Indeed, as discussed previously, not many companies have dedicated teams employed to effectively manage reverse logistics. In fact, many companies are outsourcing most or all of their logistics activities (National Computer Board, 1999). This is evident from 50% of the respondents who have outsourced reverse logistics operations to 3rd party providers.

"Financial Justification" is a barrier because companies assign reverse logistics a lower priority than other issues. Table 1.1 shows the result from the US survey that biggest barrier is that reverse logistics was not a priority for their companies and thus, it has not been possible to justify a large investment in improving reverse logistics systems and capabilities (Rogers, 2001).

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"Legal Issues" appear as a major barrier over the last few years. Apart from economic reasons, most companies practice reverse logistics primarily to comply with government regulations or pressure from environmental agencies. In fact, the growing concern of ozone layer depletion has resulted in many companies embarking on green marketing. For example, the recycling of ink cartridges for desktop printers and the recycling of metal wastes are some of the common practices in Asia Pacific industries.

3.4 Summary of the Study

The objective of this study was to gain preliminary insights of companies in Singapore practicing reverse logistics operations to support their Asia Pacific market and compare the results with similar study in the US.

The data collected revealed a number of important facts for reverse logistics in Asia: First, the impact of shorter product life cycles has resulted in respondents using air transportation to cut down the transportation time. In addition, most returns are scrapped or destroyed as they may have become obsolete. Second, since most of the respondents do not deal directly with end consumers but with distributors and retailers, it is logical that most returns are from the channels and the channels make consolidation as well as disposal decisions, similar to the US study. Finally, the biggest barrier to reverse logistics is financial justification as confirmed by both the respondents and from the US study. With growing pressure to control financial bottom-lines, more and more companies are forced to scrutinize their

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reverse logistics practices, in order to trim excessive losses due to inefficient reverse logistics operations.

This study is an initial step in this research to understand the reverse logistics practices in the Asia Pacific region and reconfirm the need to further investigate opportunity for a company to effectively manage and use reverse logistics to minimize costs or maximize profits. Some of the factors (e.g. type of disposal, cycle time, time delay, etc) identified in this study are important considerations that need to be included in the decision making model.

CHAPTER 4

DECISION MAKING MODEL FOR REVERSE LOGISTICS

4.1 A decision making model for justifying reverse logistics

Previous models (Krikke et al. (1999), Linton and Johnson (2000), Moyer and Gupta (1997), Shih (2001), Veerakamolmal and Gupta (1998)) use a single part for simulation without considering different characteristics of individual part that warrant different mode of reverse logistics treatment. Another limitation of past models for reverse logistics is to model recycling or repair or repackaging operation separately and not considering them within a system. (Recycling - Splengler et al. (1997), Realff et al. (1999), Remanufacturing - Toktay et al.(2000), Reuse - Klausner and Hendrickson (2000)). The main reason is that returns can be treated differently under different state of return quality.

Furthermore, there are a few critical decisions that one has to make in reverse logistics. These decisions are currently based on intuitive judgement than on some scientific grounds. Figure 4.1 is an outline of the decision making model recommended for reverse logistics that adopts a more systemic and rigor approach in reaching the final decision which will overcome the limitations built by past models as mentioned.

Chapter 4 Decision making model for reverse logistics

Figure 4.1: Decision making model for Reverse Logistics

The model will help decision makers in the following situations.

Situation 1: What price should one set so that it can recover its reverse logistics costs as well as making it a profitable business? In order to compute the price, one has to take into consideration the quality of returns as well as the costs to returns. This model should maximize the profit by setting the right selling price.

Situation 2: Where should the recovery process (reuse, repair, scrap) be performed and where should these products be stored after the recovery process or exchanging with suppliers. This model should minimise the recovery costs in order to maximize the profit for reverse logistics.

4.2 Decision Making Framework for Reverse logistics

Figure 4.2 shows the decision making framework to effectively maximize the profitability of reverse logistics. The decision tree tests all possible types of parts for return, including:

- a. Parts that are in excess and good condition;
- b. Defective parts that are in repairable condition; and
- c. Defective parts that are under supplier warranty.

The steps for making the return decision are as followed:

1. Is this part at the end of life cycle (EOL)?
  - If this part is at EOL, it is scrapped; otherwise, proceed to the next step.
2. Is it a make part or a buy part?
  - Make part flows through steps 3 while Buy part flows through steps 4 and 5.
3. What is the condition of this make part?

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- If this part is in good condition, it is directly sent to good part inventory for storage.
  - If this part is in poor condition, it is directly sent to scrap.
  - If this part is serviceable, it is sent for repair or remanufacturing
4. Is this buy part under supplier warranty?
    - If this part not under warranty, it is directly sent to scrap.
    - If this part is under warranty, go to step 5.
  5. Can this part be credited from supplier without returning to the supplier?
    - If this part can be credited, it is sent to scrap. Otherwise, the part is sent to supplier for exchange and return to good parts inventory for storage.

This decision process has two outcomes: (i) Return the part for storage and (iii) Simply scrap it.

Figure 4.2: Decision making framework for reverse logistics

4.3 Equations to compute reverse logistics profitability

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Using the framework from Figure 4.2, two set of equations for reverse logistics can be developed for the computer industry:

- Type 1 Return: Parts that are manufactured internally,
- Type 2 Return: Parts that are purchased from suppliers and OEMs.

4.3.1 Equations for manufacturing parts

For Type 1 Return (parts manufactured internally), the profitability of reverse logistics can be computed using the Equation 4.1

$$\text{Max} \sum_{p=1}^n \text{Net\_profit} = \left[\sum_{p=1}^n \text{Rqty\_reuse}_{ijp} \times \text{Profit\_reuse}_{jp} + \sum_{p=1}^n \text{Rqty\_repair}_{ijp} \times \text{Profit\_repair}_{jp} + \sum_{p=1}^n \text{Rqty\_scrap}_{ip} \times \text{Profit\_scrap}_{ip} - \sum_{p=1}^n \text{Cost\_revlog}_{ijp} \right] \quad \text{Equation (4.1)}$$

Subject to

$$\sum_{p=1}^n \text{Net\_profit} \geq 1 \quad p = 1, 2, \dots, n \text{ Make Parts}$$

Rqty_reuse_{ijp} , Rqty_repair_{ijp} and Rqty_scrap_{ip} are non negative for all i and j ,

where

p refers to each part number within a set of manufacturing parts,

ij refers to the movement from collection point i to facility j ,

Rqty_reuse_{ijp} , Rqty_repair_{ijp} and Rqty_scrap_{ip} are number of part p for reuse, repair

and scrap collected at i and sent to designated facilities j for

processing,

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$Profit\_reuse_{jp}$ is the unit profit generated for reusing part p from repackaging facility

j and can be calculated using the Equation 4.2

$Profit\_reuse_{jp} = Price\_reuse_p - Cost\_reuse_{jp}$ (4.2)	Equation

where

$Price\_reuse_p$ is the unit price for selling repackaged part p , and

$Cost\_reuse_{jp}$ is the unit cost of repackaging part p at the designated facility j .

$Profit\_repair_{jp}$ is the unit profit generated for repairing part p at repair facility j and

can be calculated using the Equation 4.3

$Profit\_repair_{jp} = Price\_repair_p - Cost\_repair_{jp}$	Equation (4.3)

where

$Price\_repair_p$ is the unit price for selling repaired part p , and

$Cost\_repair_{jp}$ is the unit cost of repair for part p at the designated facility j .

$Profit\_scrap_{ip}$ is the unit profit generated from scraping part p at the collection point

i and can be calculated using the Equation 4.4

$Profit\_scrap_{ip} = Price\_scrap_p - Cost\_scrap_{ip}$ (4.4)	Equation

where

$Price\_scrap_p$ is the unit price for selling part p ,

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$Cost\_scrap_{ip}$ is the unit cost of scrapping part p at the collection point i as it does not make economic sense to ship part p to another location for scrap,

$\sum_{p=1}^n Cost\_revlog_{ijp}$ is the total reverse logistics costs associated with all the returns (excluding repair, reuse and scrap costs) from collection point i to the destination j and can be calculated using Equation 4.5.

$$\sum_{p=1}^n Cost\_revlog_{ijp} = \sum_{p=1}^n \left[Rqty_{ijp} \times Cost\_handling_{ijp} + Rqty_{ijp} \times Cost\_freight_{ijp} + Rqty_{ijp} \times Cost\_custom_{ijp} + Rqty_{ijp} \times Cost\_storage_p + Rqty_{ijp} \times Cost\_acquisition_p \right]$$

Equation (4.5)

where

$Rqty_{ijp}$ is the number of part p shipped from collection point i to designated facility j ,

$Cost\_handling_{ijp}$ is the average handling and administrative cost per part p from collection point i to designated facility j ,

$Cost\_freight_{ijp}$ is the freight or shipment cost per part p from collection point i to designated facility j ,

$Cost\_custom_{ijp}$ is the total custom duty or levy paid per part p from collection point i to designated facility j ,

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$Cost\_storage_p$ is the storage cost per part p , and

$Cost\_acquisition_p$ is the cost to acquire or trade-in a single unit of part p .

4.3.2 Equations for purchasing parts

For Type 2 Return (parts purchased from suppliers or OEMs), the profitability of reverse logistics can be computed using the Equation 4.6

$$Max \sum_{p=1}^n Net\_profit = \left[\begin{aligned} & \sum_{p=1}^n Rqty\_exchange_{ijp} \times Profit\_exchange_{ijp} \\ & + \sum_{p=1}^n Rqty\_credit_{ip} \times Revenue\_credit_{ip} \\ & + \sum_{p=1}^n (Rqty\_scrap_{ip} + Rqty\_credit_{ip}) \times Profit\_scrap_{ip} - \sum_{p=1}^n Cost\_revlog_{ijp} \end{aligned} \right] \quad \text{Equation (4.6)}$$

Subject to

$$\sum_{p=1}^n Net\_profit \geq 1 \quad p = 1, 2, \dots, n \text{ buy or purchase Parts}$$

$Rqty\_exchange_{ijp}$, $Rqty\_credit_{ijp}$ and $Rqty\_scrap_{ip}$ are non negative for all i and j

where

p refers to each part number within a set of buy / purchase parts from suppliers,

ij refers to the movement from collection point i to supplier location j ,

$Rqty\_exchange_{ijp}$, $Rqty\_credit_{ip}$ and $Rqty\_scrap_{ip}$ are number of part p for exchange,

credit and scrap collected at i and sent to either supplier j for

exchange or to scrap,

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$Profit\_exchange_{ijp}$ is the profit generated from exchanging part p under warranty from collection point i to supplier location j and can be calculated using the Equation 4.7

$$Profit\_exchange_{ijp} = Price\_exchange_p - Cost\_exchange_{ijp} \quad \text{Equation (4.7)}$$

where

$Price\_exchange_p$ is the unit price for selling part p exchanged from supplier,

$Cost\_exchange_{ijp}$ is the unit cost of exchanging part p from collection point i to supplier j .

$Revenue\_credit_{ip}$ is the price credited from supplier without returning part p to them. $Rqty\_credit_{ip}$ is added to the scrap quantity as these quantities are not required to be shipped back to the suppliers for exchange.

$Profit\_scrap_{ip}$ is the profit generated for scraping part p with no warranty and can be calculated using the Equation 4.8

$$Profit\_scrap_{ip} = Price\_scrap_p - Cost\_scrap_{ip} \quad \text{Equation (4.8)}$$

where

$Price\_scrap_p$ is the unit selling price for part p as scrap,

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$Cost\_scrap_{ip}$ is the unit cost of scrapping part p at the collection point i as it does not make economic sense to ship part p to supplier for scrap.

$\sum_{p=1}^n Cost\_revlog_{ijp}$ is the total reverse logistics costs associated with all the returns (excluding exchange and scrap costs) from collection point i to the supplier location j and can be calculated using Equation 4.9.

$$\sum_{p=1}^n Cost\_revlog_{ijp} = \sum_{p=1}^n \left[Rqty_{ijp} \times Cost\_handling_{ijp} + Rqty_{ijp} \times Cost\_freight_{ijp} + Rqty_{ijp} \times Cost\_custom_{ijp} + Rqty_{ijp} \times Cost\_storage_p + Rqty_{ijp} \times Cost\_acquisition_p \right]$$

Equation (4.9)

where

$Rqty_{ijp}$ is the number of part p shipped from collection point i to supplier location j ,

$Cost\_handling_{ijp}$ is the average handling and administrative cost per part p from collection point i to supplier location j ,

$Cost\_freight_{ijp}$ is the freight or shipment cost per part p from collection point i to supplier location j ,

$Cost\_custom_{ijp}$ is the total custom duty or levy paid per part p from collection point i to supplier location j ,

$Cost\_storage_p$ is the storage cost per part p , and

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$Cost\_acquisition_p$ is the cost to acquire or trade-in a single unit of part p .

4.4 Case Study using Dell Computer

For verification and validation purposes, a case study is provided to test the framework and decision making model. Dell Computer was selected for this purpose as they are aggressively in pursuing reverse logistics (Aberdeen Group, 2003). Necessary data for the model parameters were collected to build and test the model. Linear programming (LP) is the most suitable technique to build this model as it permits the computation of the optimum (maximum or minimum) of a linear function, in this case net profit for reverse logistics subjected to a set of constraints defined by linear equations and in equations involving numerous cost variables. LP has been successfully used in similar modelling of large variety of supply chain optimization:

- Production from scarce resources (optimal allocation of resources)
- Logistics (many aspects of transportation and resource deployment)
- Scheduling (assignment of people and machines to tasks).

The model is solved by using Excel Solver (Microsoft Office product), which provides mixed integer programming capability. Results and insights are presented for maximizing the profitability of reverse logistics in the computer industry.

4.4.1 Dell Reverse Logistics Model

Dell has many customers all around the world and can be classified into businesses, consumer market, government and institutions. It has an Asset Recovery Service (ARS) provided to all their customers as part of the reverse logistics program

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(http://www.dell.com/downloads/global/services/ds_ars.pdf). Services under ARS include the following services:

- Value Recovery Services - When an organization has reason to believe that its used equipment has some residual value, it will choose this option. Dell sells an asset and returns to the customer money from that sale according to a pre-published schedule of value. The cost is US\$59 per system unit (a two-piece bundle containing, for example, a PC and a monitor) when a customer has pre-packed the device or US\$69 per system unit if the client elects to have Dell program manage the whole operation.
- PC recycling Services - When equipment has little or no value — as is common in assets more than four years old — customers choose this option. For US\$49 per customer-packaged system or US\$59 per Dell program-managed system, Dell removes and recycles used equipment.

Both services include transportation of the equipment, flexible logistics in which the customer chooses the approach, equipment disposition, and detailed reports about data security and compliance with environmental requirements.

The reverse logistics network for Dell consists of suppliers, manufacturing facilities, customers and secondary markets. Customers return their products through a logistics provider and these products are sorted depending on their condition. Some are remanufactured, some are repaired, some are sent back to suppliers for exchange if their warranties are still valid, and the rest are either scrapped or sold to secondary market. Figure 4.3 illustrates Dell reverse logistics network which will be used in the model.

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Figure 4.3: Dell reverse logistics network

Data is gathered through Dell website (<http://www.dell.com>) and related sites as well as from past articles in industrial journals. Estimations for some of the model parameters were necessary for the model inputs. The LP model is built using the following data

- 3 manufacturing facilities, one in Penang (Malaysia), one in Singapore and a centralised one in Austin, USA
- 1 logistics provider
- Customers from South East Asia
- Dell desktop computer that can be recycled, repaired, reused or scrapped.

Basic data for the model is tabulated below.

Table 4.1: Basic data from Dell Computer for modeling

Retail Price of Dell Desktop Computer	S\$1,870
Average Weight of Dell Desktop Computer	10 kg
Sales of repaired PC to secondary markets	20% of retail price
Sales of repaired PC to consumers	80% pf retail price
Recovery costs in Penang, Malaysia $Cost_{reuse_{jp}}$, $Cost_{repair_{jp}}$ and $Cost_{scrap_{ip}}$	Repackaging - \$100 Repair - \$250 Scrap - \$100

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Recovery costs in Singapore $Cost\_reuse_{jp}$, $Cost\_repair_{jp}$ and $Cost\_scrap_{ip}$	Repackaging - \$100 Repair - \$400 Scrap - \$100
Recovery costs in Austin, USA $Cost\_reuse_{jp}$, $Cost\_repair_{jp}$ and $Cost\_scrap_{ip}$	Repackaging - \$150 Repair - \$500 Scrap - \$200

In order to compute the reverse logistics costs ($Cost\_Revlog$) using Equation 4.5, several cost elements are required. The freight rate ($Cost\_freight_{ijp}$) can be obtained using online freight estimation from Fedex website (www.fedex.com.sg) based on the average weight of PC (@10 kg) and the custom charges ($Cost\_custom_{ijp}$) are gathered from IE Singapore Tariffs handbook. Handling charges ($Cost\_handling_{ijp}$), acquisition costs ($Cost\_acquisition_p$) and storage costs ($Cost\_storage_p$) are provided by a logistics provider using their standard charge rate for clients.

Table 4.2: Cost of reverse logistics for modeling

Type of costs (ij)	Within Penang	Singapore -Penang	USA – Penang	Within Singapore	Penang - Singapore	USA – Singapore	Within USA	Penang - USA	Sing-USA
Freight	\$0.00	\$102.00	\$140.00	\$0.00	\$102.00	\$152.00	\$0	\$140.00	\$152.00
Custom	\$0.00	\$0.00	\$20.00	\$0.00	\$47.00	\$47.00	\$0.00	\$15.00	\$15.00
Handling	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00	\$38.00
Acquisition	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00	\$30.00
Storage	\$15.00	\$15.00	\$15.00	\$20.00	\$20.00	\$20.00	\$30.00	\$30.00	\$30.00
Total Cost	\$83.00	\$185.00	\$243.00	\$88.00	\$237.00	\$287.00	\$98.00	\$253.00	\$265.00

Quantities of PCs returned for reuse, repair and scrap are entered into the spreadsheet for each country (10,000 PCs are returned in Singapore and Penang, 20,000 PCs are returned in Austin based on their annual financial report) and the model generates the most profitable options using linear programming. Constraints

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are introduced into the model to ensure non-negative values and other variable dependency. The model assumes that all returned PCs are sold completely after processing. Thus, the net profit generated from the model will be much higher than anticipated and is computed by using Equation 4.1

$$Max \sum_{p=1}^n Net\_profit = \left[\sum_{p=1}^n Rqty\_reuse_{ip} \times Profit\_reuse_{ip} + \sum_{p=1}^n Rqty\_repair_{ip} \times Profit\_repair_{ip} + \sum_{p=1}^n Rqty\_scrap_{ip} \times Profit\_scrap_{ip} - \sum_{p=1}^n Cost\_revlog_{ip} \right] \quad \text{Equation (4.1)}$$

we have,

$$\begin{aligned} \text{Net Profit} = & (\$1,496.00 - \text{Cost of repair}) \times \text{quantities sold after repaired} + (\$1,496.00 \\ & - \text{Cost of reuse}) \times \text{quantities sold after reuse} + (\$374.00 - \text{Cost of scrap}) \\ & \times \text{quantities sold for scrap} - (\text{Cost of freight} + \text{Cost of customs} + \text{Cost of} \\ & \text{handling} + \text{Costs of acquisition} + \text{Cost of storage}), \end{aligned}$$

where \$1,496 is 80% of retail price (\$1,800) and \$374 is 80% of retail price.

4.4.2 Summary from the case study

The following figures 4.4, 4.5 and 4.6 summarized the results obtained from this case study.

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Figure 4.4 : Cost breakdown for reuse in each country

Figure 4.5 : Cost breakdown for repair in each country

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Figure 4.6 : Cost breakdown for scrap in each country

From figure 4.4, it is obvious that product returns meant for reuse is cheaper to be processed within the country than overseas. The freight costs are higher than the reuse cost in this case. For product returns meant for repair (figure 4.5), returns from USA and Singapore are still cheaper to be repaired in Penang as the cost of freight contributes to a lower percentage than the repair costs. As for product returns meant for scrap (figure 4.6), it is logical to scrap locally as the freight costs are higher than the scrap cost.

The recommendations from the LP model exhibits similar behaviour as listed in Appendix B.

CHAPTER 5

DYNAMIC MODEL FOR DECISION MAKING IN REVERSE LOGISTICS

5.1 Introduction to system dynamics

Equations (4.1) to (4.9) from chapter 4 are useful in determining the quantity of processing to be done for each location with the minimum cost and hence maximum profit assuming price is fixed and does not decrease. However, the linear programming model is useful only for companies with mild fluctuation in return volume over time and there are negligible delays in their reverse logistics operations. These limitations can be overcome by using system dynamics modeling which allows one to simulate volume fluctuation with delays under various return quality conditions when needed.

In this chapter, system dynamics modeling will be used to simulate alternative approaches to optimise decision making in reverse logistics and to enhance the mathematical model presented in the previous chapter.

System dynamics techniques will be used to gain insights into the dynamics of reverse logistics network and how rules and constraints interplay based on various issues through simulation. This is because in most reverse logistics networks there will be ‘leads and lags’ - in other words, the response to an input or a change in the network may be delayed. For example, the presence of a warehouse or stock-holding intermediary in the distribution channel can cause a substantial distortion in the demand at the factory. This is due to the ‘acceleration effect’ which can cause self-generated fluctuations in the operating characteristics of a network. Taking concepts such as the acceleration effect and the interrelationships within complex business

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systems, Forrester (1958) has developed the notion of ‘Industrial Dynamics’, which he defined as:

“The study of the information feedback characteristics of industrial activity to show how organisational structure, amplification (in policies) and time delays (in decisions and actions) interact to influence the success of the enterprise. It treats the interactions between the flows of information, money, orders, materials, personnel and capital equipment in a company, an industry or a national economy.”

Delays in reacting to variations in market demand for different aspects of supply chain performance have long been studied. The seminal works here are those of Forrester (1958, 1961), who investigated the effect of changes in market demand on a four-level supply chain. Forrester incorporated delays in both the physical structure of his supply chain as in the managers’ decisions and policies governing inventory adjustment. Forrester found that these delays were responsible for much of the oscillatory behaviour of many supply chains. He found that the nature of the managerial policies concerned could modify these delays and the resulting instabilities of supply chains considerable. His model was later on converted into the well-known “Beer Game” (Sterman 1989), in which these policies and delays generate well-known supply chain dynamics such as the Bull-whip effect (Lee *et al.* 1997a, 1997b, Fransoo and Wouters 2000).

5.2 Model Objectives

The objective of the model is to examine how quality of returns, return volumes and other cost elements affect the profitability of reverse logistics over a period of time.

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More specifically, it is to study the complexity and interdependence of these key factors which impact on the profitability of reverse logistics in a multi-national company environment operating in Asia, and thus enable these companies to craft reverse logistics policy effectively. This objective is addressed through the development of a number of tightly coupled system dynamics sub-models, as outlined in Figure 5.1.

5.3 Applied methodology

The literature presents a number of formal methodologies, in the form of step by step procedures, for developing system dynamics models. The approach to model this system is as follows:

1. Define the dynamic problem to be solved and its scope,
2. Identify the variables involved and their relationship,
3. Draw the causal loop diagram,
4. Select a software suitable to model the system,
5. Construct the stock and flow diagram,
6. Simulate the model, and
7. Verify and validate the model

The whole process is divided into 2 phases: the first phase is the qualitative analysis of the system. During this phase, a causal loop diagram is built which is then transformed into a flow diagram. The second phase is the quantitative analysis of the system. During this phase, the flow diagram is translated to a simulation program

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using Vensim software (Vensim) which is then verified and validated using a case study. The program is executed for what-if scenarios and the results are analysed.

This process is iterative in nature since there is no template upon which to base the model structure. This process evolves over time as more information becomes available which is fed as critical decision points into the system. During the modeling process, it is very important for the model to distinguish between perceived and actual information as actual information is almost never available to act on immediately, and so decisions must be made on perceived values. The model is fine-tuned through successive iterations to better approximate real-world behaviour.

In order to develop a system dynamics model to study the dynamics of reverse logistics network, it requires identifying the key decision points in the system. These decision points form the basis of sub-models in that they may be developed and tested in relative isolation. Once each of the sub-models is close to accurately capture the real-world decision processes, the next main task is to capture the feedback between the various decision points or sub-systems.

To simulate the competitive nature of the computer industry with numerous variables and constraints, Vensim software is used to expand the model to allow for multiple scenario and countries. In this way, the decision-making structures can be presented in a graphical way to facilitate better understanding of the complex dynamics of the system behaviour.

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5.4 Model structure

The model structure in Figure 5.1 captures the overall model construct from acquisition of returns to the sales and distribution of recovered products (products after repaired or re-manufactured or re-use) or in exchange with suppliers (Tan and Arun, Forthcoming).

Figure 5.1. Model structure for reverse logistics

In order for the system dynamics model to compute the profitability of reverse logistics, it will need information pertaining to the costs of reverse logistics, the type of parts involved, the revenue for selling the returns and the treatment for these returns.

Costs of reverse logistics can be broken down into two components:

- Fixed costs - transport cost, custom duty, acquisition cost and handling cost,
- Variable costs - storage cost, repair or reuse costs or scrap cost.

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Some of these costs are linear while others are non-linear which pose challenges during modeling.

There are 2 major groups of returns, one group is the make parts that can be repackaged, repaired or scrapped and the other group is the purchase parts that can be exchanged with suppliers or for credit and scrap. The return volume is not a constant but commonly exhibits a normally distributed probability distribution based on the 2 years data from HP. The Vensim software has a feature to generate stochastic inputs based on a given mean value and standard deviation value.

The quality of returns is critical in determining the proportion of parts for repair, reuse, exchange, credit or scrap and thus impacting the profitability of reverse logistics. Higher quality returns result in simple repackaging or repair while lower quality returns result in scrap. The quality of returns will be simulated in the model using the three conditions, namely best quality condition, average quality condition and worst quality condition where:

- Best quality condition represent situation where the quantity of scrap is zero,
- Average quality condition represent situation where the quantities of parts for repair, reuse and scrap are the same, and
- Worst quality condition represent the quantity of parts for repair and reuse is zero, and scrap is 100%.

Lastly, the resale price and attractiveness of resale parts are important inputs to determine the demand for returns and hence its profitability. The resale price cannot be higher than the price of new parts and this is a constraint that the model needs to address. In Dell Computer case, the resale price is 80% of its retail price.

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The markets for these parts are the consumers themselves for update, or it could be the secondary markets (e.g. dealers, resellers, and OEMs)

5.5 Causal loop diagram

Figure 5.2 shows the causal-loop diagram for reverse logistics network in the computer industry. The arrows represent the relations between each variable. The direction of the arrow is the direction of the effect while the signs (+) and (-) at the end of the arrow shows the sign of the effect. When the sign is (+), the variables change in the same direction and it is known as a reinforcing loop if all the signs in the loop are (+) or it has even number of sign (-). Otherwise, the variables change in the opposite direction and it is known as balancing loop if it has odd number of sign (-).

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Figure 5.2. Causal loop diagram for reverse logistics

There are five balancing loops and four reinforcing loops in this model. They are as follows:

An increase in the attractiveness of resale parts or products after being serviced will trigger an increase in the demand for used PCs, servers or component parts and this will lead to an increase in their selling price (Loops R1 and R3) and result in an increase in acquisition cost to trade-in their PCs, servers or parts, as customer is only willing to part them at a higher price as they had bought them at a

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higher price (similar to property brokerage). Increasing the acquisition cost or trade-in cost for used PCs, servers or component parts will lead to an increase in the supply of these products or parts for repair, reuse or exchange with supplier (Loops R2 and R4). Furthermore, computer companies are more willing to give higher trade-in value for computers with more recent technologies than those with older technologies.

In terms of scrap, an increase in the demand for returns will cause an increase in the price for scrap which will trigger an increase in acquisition cost for scrap to make it more attractive for parts to be scrapped (Loop R1). This is similar to the second hand car industry where an increase in demand for scrap car will cause an increase in the price of scrap car to attract more car owners to scrap their cars.

Reinforcing loops

R1	Demand for returns --> Price of Scrap --> Profitability of Scrap --> Demand for returns
R2	Demand for returns --> Selling price of returns --> Acquisition cost of returns --> Profitability of reverse logistics --> Demand for returns
R3	Demand for returns --> Selling price of returns --> Demand for returns
R4	Demand for returns --> Price of Scrap --> Demand for returns

The cost to repair or reuse will increase with increasing volume but it is also affected by the quality of returns. Better quality of returns will increase the volume of parts for repair or reuse leading to an increase in the cost of repair or reuse (loops B2, B3 and B4) but will decrease the cost of scrap since the scrap volume is

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decreased (loop B1). For example, printers sent for servicing in HP are first diagnosed to determine if they need simple repair or overhaul due to serious problems. Those with simple repair will be sent to repair workshop while those with serious problem will be scrapped. Thus, if most of the returns are of higher quality involving simple repair, then the cost of repair will increase due to the increase in quantity for repair.

Similarly, better return policy with suppliers will decrease the cost of exchanging with suppliers since suppliers would agree to credit the price of return without having to return the parts to them. This will mean that the scrap cost will increase as these parts will need to be scrapped instead of returning to the suppliers, especially bulky monitors that will cost more money to transport than to scrap them.

An increase in the demand for returns will cause an increase the supply of scrap and an increase the cost of scrap as in loop B1 while increasing the selling price of scrap will increase the profitability of scrap as in loop R1. So, the strength of reinforcing loops R1 and R4 to offset the strength of balancing loop B1 will ultimately determine the profitability of scrap.

Balancing loops

B1	Demand for returns --> Price of scrap --> Acquisition cost for scrap --> Supply of Scrap part --> Cost of Scrap --> Profitability of scrap --> Demand for returns
B2	Demand for returns --> Selling price of returns --> Acquisition cost of returns --> Supply of repair part --> cost of repair --> Profitability of reverse logistics --> Demand for return
B3	Demand for returns --> Selling price of returns --> Acquisition cost of returns --

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	> Supply of reuse part --> cost of repackaging --> Profitability of reverse logistics --> Demand for return
B4	Demand for returns --> Selling price of returns --> Acquisition cost of returns -- > Supply of supplier exchange part --> Cost of exchanging part with supplier -- > Profitability of reverse logistics --> Demand for return
B5	Demand for returns --> Selling price of returns --> Acquisition cost of returns -- > Profitability of reverse logistics --> Demand for return

In summary, increasing the cost of repair or reuse or exchange will reduce the profitability of reverse logistics as in loops B2, B3 and B4 while increasing the selling price will increase the profitability of reverse logistics as in loop R2. Thus, the strength of reinforcing loops R2 and R3 to offset the strength of balancing loops B2, B3, B4 and B5 will ultimately determine the profitability of reverse logistics.

5.6 Model description for reverse logistics

The stock and flow diagram is shown in Figure 5.3. The diagram is constructed using variables categorised as levels represented by box, flows represented by valve and constant. Level variables represent accumulations in the system while flow variables are the rate of change in level variables and they represent those activities which fill in or drain the level variables. Delays are levels that introduce the time delay in material or information flow. Although delays exist in all the flows, only the significant ones are included in this model. Single line arrows are information flows while double line arrows are material flows in the model. Alternately, single dotted and solid lines can be used.

The model is built under the following general configurations:

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- Time horizon: 2 years.
- Time unit: Week.
- Time step: 1 week.

The model employed 92 variables and can be grouped under level, flow and constant.

The key level variables in this model are as followed:

- a. *Returns* - Total quantity of returns collected
- b. *Manufacturing returns* - Total quantity of make parts returned for processing
- c. *Supplier Exchange stocks* - Total quantity of buy part return for exchange or credit with suppliers
- d. *Repair return stocks* - Stocks cumulated for repair
- e. *Repaired stocks* - Total number of parts repaired and ready for sales
- f. *Reuse return stocks* – Stocks cumulated for repackaging
- g. *Reuse stocks* - Total quantity of parts repackaged and ready for sales
- h. *Scrap stocks* - Total quantity of parts for scrap or cannibalization
- i. *Recovered stocks* - Total quantity of parts recovered after processing and exchanging with suppliers.

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Figure 5.3 Dynamic model for Reverse logistics network

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The initial return stock *Returns* accumulate its returns stock from the flow variable *acquisition rate*. Since this rate is not a constant but randomly distributed within a range of numbers, it is generated by inputting the maximum rate, mean and standard deviation of each part return history to simulate real-time situation.

Acquisition Rate =

ACTIVE INITIAL ((RANDOM NORMAL (0, Max acquisition, Mean acquisition, STD Dev for acquisition , 0))/Collection time, Mean acquisition)

Returns(t) =

$$\int_0^t [\text{Acquisition Rate}(t) - \text{Return Rate for Manufactured Stocks}(t) - \text{Return Rate for Scrap}$$

$$\text{Stocks}(t) - \text{Return Rate for Supplier Stocks}(t)] d(t) + \text{Returns}(0)$$

,where t is the last period of the time horizon.

The *Returns* stocks are then sorted into buy or make or scrap parts for processing using three constants, *buy part return ratio*, *make part return ratio* and *scrap ratio*. Since a part can either be a make part or buy part, either *buy part return ratio* or *make part return ratio* will be set to zero in each simulation. The *scrap ratio* is computed as followed:

Scrap ratio=

IF THEN ELSE (Buy parts return ratio > 0, 1-Buy parts return ratio, 1-Make parts return ratio)

For buy part, the stocks are accumulated in the variable *Stock Exchange Stocks* and are either send back to supplier for exchange using the flow variable *Stock Exchange Rate to Supplier* or send to scrap using the flow variable *Stock Credit Rate*

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for *Supplier* if the supplier is willing to credit the quantity without returning the stocks to them. The exchanged part is then flow into the variable *Recovered Stock* where it is ready for resale.

$$\begin{aligned} \text{Supplier Exchange Stocks}(t) = & \int_0^t [\text{Return Rate for Supplier Stocks}(t) - \text{Stock Exchange Rate to Supplier}(t) - \text{Stock Credit} \\ & \text{Rate for Supplier}(t)] d(t) + \text{Supplier Exchange Stocks}(0) \end{aligned}$$

,where t is the last period of the time horizon.

For make part, the stocks are accumulated in the variable *Manufactured return* and later split for repair or reuse using the constant, *Reuse versus Repair ratio*. Parts for repair will accumulate in the variable *Repair return stocks* before sending to repair and then accumulated in the variable *Repaired stocks*.

$$\begin{aligned} \text{Manufactured return}(t) = & \int_0^t [\text{Return Rate for Manufactured Stocks}(t) - \text{Return Rate for Repair Stocks}(t) - \text{Return Rate} \\ & \text{for Reuse Stocks}(t)] d(t) + \text{Manufactured return}(0) \end{aligned}$$

,where t is the last period of the time horizon..

Some of the repair parts may not be repairable and are sent for scrap. Parts for reuse will accumulate in the variable *Reuse return stocks* before sending to repackaging and then accumulated in the variable *Reused stocks*. Both stocks from *Reuse return stocks* and *Reused stocks* are accumulated at the variable *Recovered stocks* where they are ready for resale.

$$\text{Recovered Stocks}(t) =$$

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$$\int_0^t [\text{Delivery Rate for Repaired Stocks}(t) + \text{Delivery Rate for Reuse Stocks}(t) + \text{Stock Exchange Rate to Supplier}(t) - \text{Sales Rate for Recovered Stocks}(t)] d(t) + \text{Recovered Stocks}(0)$$

,where t is the last period of the time horizon.

The costing for reverse logistics is represented in Figure 5.4. The components of fixed costs are made up of custom duty, transport cost, acquisition cost and handling cost similar to Equation 4.5 from chapter 4. Each of these costs is computed as followed:

$$\text{Custom Duty} = \text{Duty Percent} * \text{Item resales price}$$

$$\text{Transport Cost} = \text{Item Weight} * \text{Air Freight cost per kg}$$

$$\text{Acquisition cost} = 0$$

$$\text{Handling Cost} = \text{Labor cost per hour} * \text{Number of hours per transaction}$$

To compute the total cost for each type of reverse logistics (repair, reuse, scrap, or exchange), their operation cost and storage cost are added into the total similar to Equations 4.2, 4.3 and 4.4 from chapter 4.

$$\begin{aligned} \text{Total Reverse logistics costs} = \\ \text{Total Exchange Cost} + \text{Total Repair Cost} + \text{Total Reuse Cost} + \text{Total Scrap Cost} \end{aligned}$$

Where,

$$\text{Total Exchange Cost} =$$

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Supplier Exchange Stocks*((Storage Cost*Delay from supplier) + Fixed Costs)

Total Repair Cost=

Repaired Stocks*(Average Cost to Repair per piece + (Storage Cost*(Delay in repair +Delay in transportation)))+Fixed Costs)

Total Reuse Cost=

Reuse Stocks*(Average Cost to Repackage per piece+(Storage Cost*(Delay in transportation + Delay in repackaging)))+Fixed Costs)

Total Scrap Cost=

Scrap Stocks*(1-Ratio of Cannibalization to scrap disposal)*(Average Cost to Scrap per pc + (Storage Cost*Delay in scrapping stock) + Fixed Costs)

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Figure 5.4: Costing of reverse logistics

The total gross profit for reverse logistics will include profits generated from exchanging with suppliers, from repair, from reuse and from scrap. Details of all the equations for this model can be found in Appendix C.

Total Gross Profit=

Gross Profit from Exchange Stock + Gross Profit from Repair Stock + Gross Profit from Reuse Stock + Gross Profit from Scrap Stock

This is similar to the original Equations 4.1 after subtracting the total reverse logistics costs.

$$Max \sum_{p=1}^n Net\_profit = \left[\sum_{p=1}^n Rqty\_reuse_{ijp} \times Profit\_reuse_{jp} + \sum_{p=1}^n Rqty\_repair_{ijp} \times Profit\_repair_{jp} + \sum_{p=1}^n Rqty\_scrap_{ip} \times Profit\_scrap_{ip} - \sum_{p=1}^n Cost\_revlog_{ijp} \right]$$

Equation (4.1)

5.7 Experiment design for simulation

In order to test the model under different scenarios, it is important to design an experiment for the simulation. In this case, the model is tested on three dimensions; return volume, custom duty and quality of returns to determine its profitability as shown in the Table 5.1. The return volume can be segmented into low, medium and high volumes while the quality of returns can be sub-divided into 3 groups, high quality, average quality and low quality similar to the conditions applied in the mathematical model from the previous chapter. Similarly, the custom duty can be segmented into country with low or no tariff and country with high tariff. The

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reverse logistics profitability is calculated by subtracting the revenue earned through reselling the recovered parts from the total cost of reverse logistics.

Table 5.1: Experiment design for simulating the dynamic model

Return Volume	Return Quality	Country with Low Tariff	Country with High Tariff
High Volume $1 < \text{volume} < 99$	High Quality Average Quality Low Quality	<i>Profit Margin for each condition</i>	<i>Profit Margin for each condition</i>
Medium Volume $100 < \text{volume} < 999$	High Quality Average Quality Low Quality	<i>Profit Margin for each condition</i>	<i>Profit Margin for each condition</i>
Low Volume $\text{volume} > 1000$	High Quality Average Quality Low Quality	<i>Profit Margin for each condition</i>	<i>Profit Margin for each condition</i>

5.8 Summary of the dynamic model

The dynamic model will allow one to simulate volume fluctuation with delays under various return quality conditions. In order to verify and validate the dynamic model, the computer industry is chosen for the case study because many computer industries are multi-national companies and they practice products take-back for their products after consumer use.

CHAPTER 6

APPLYING THE DYNAMIC MODEL TO A CASE STUDY

6.1 Introduction to HP Asia Pacific

HP (Asia Pacific) Customer Services was selected for this case as they have a large reverse logistics operation in Asia Pacific and the manager in charge was willing to provide the data for this study (Tan, Yu and Arun, 2003). HP (AP) is a regional customer support service division whose core function is to supply spare parts to facilitate repair operations for products that are under warranty or with a service contract in Asia Pacific. As and when a customer contacts the company for repair services, the company will courier the relevant spare parts to the required site. The assigned Customer Engineer will diagnose the problem and replace the defective part or parts. Upon completion of the repair, the Engineer will return the defective parts, except obsolete ones, to the service store, which will then ship them back to its US headquarters in Palo Alto for repair or refurbishment depending on how much work is needed to rectify the defective parts. The repaired or refurbished parts are, subsequently, stored in the Central Stocking Pool which is located in a different state. If the parts cannot be repaired or refurbished, they will be scrapped or disposed.

HP (AP)'s Traffic Manager estimated that, at any one time, the total value of spare parts in the logistics transit pipeline amounted to an estimated \$7 million. This comprised:

- 50% Transit inventory – good spare parts being shipped out from its (OEM) suppliers;

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- 30% Return inventory - used or defective parts being returned to the suppliers or the US headquarters, and
- 20% Overstocks - good spare parts to facilitate stock rotation.

A study was commissioned by HP focusing on reducing the cost and improving the efficiency of the Return inventory and Overstocks in the reverse logistics pipeline, estimated to cost \$3.5 million. The scope of this study covered the reverse logistics operations in fourteen (14) countries within Asia. Data are gathered over a period of eighteen (18) months, from August 1999 to February 2001 pertained to processes in the forward distribution of new spare parts from the company's US headquarters to the reverse logistics operations of defective spare parts back to its US Central Stocking Pool. The study also examined the on-going IT implementation issues in the company and their impact on the reverse logistics operations if any.

Statistical analysis is performed on a Hewlett Packard product family (high-end server) with its full bill-of-materials to understand and analyze the reverse logistics operations of the components. Four assemblies are randomly chosen from the product family and their components' return transactions to the US head office is collected over 24 months for this study (since the average product life cycle of a computer is less than 24 months).

There are 2 types of parts in the bill-of-material, make parts and purchase parts. The make parts are generally core parts that HP will make internally using their most advanced technology and know-hows (e.g. motherboard). In the case of purchase parts, they are products easily available from the market where price is very competitive (e.g. disk drive). Thus, it is logical to split the data into make parts and

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purchase parts to understand their characteristics as the starting point. Table 6.1 shows the ratio of gross profit margin over product cost for four assemblies from the product family and we can infer that make parts generally have similar or higher profit margin than purchase parts.

Table 6.1: Comparison of gross profit margin between Make parts & Purchase parts

	Assembly 1		Assembly 2		Assembly 3		Assembly 4	
	Make part	Purchase part	Make part	Purchase part	Make part	Purchase Part	Make part	Purchase part
No. of part	22	123	20	64	23	77	21	97
Total Costs (\$)	2674	26039	3497	2656	2772	8141	1797	8915
Gross Profit Margin* (\$)	21746	81907	8419	6680	14224	19867	8448	42460
Gross Profit Margin* / Cost	8.1	3.1	2.4	2.5	5.1	2.4	4.7	4.8

Gross Profit Margin* refers to retail price minus cost

Table 6.2 shows that the percentages of active returns are less than 50% of the total number of components. The rest of the parts would either be scrapped or not returned after warranty has expired. Due to this limitation, the return transaction analysis will focus on the active parts instead of the full BOM since the other inactive components have no return transaction history.

Table 6.2: Percentage of active returns over the total number of components.

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	Assembly 1	Assembly 2	Assembly 3	Assembly 4
No. of components with active returns	32	26	26	26
Total no. of components	85	101	119	146
Percentage of active returns over total no. of components	38%	26%	22%	18%

6.2 Return transactional behaviour of make parts and purchase parts

The returns of components are traced back to their parent assembly so that a regression analysis can be performed between the server and its components.

The costs taken to compute the parts for Table 6.3 are as follows:

- Repair or remanufacturing cost for make parts and
- Purchase cost for purchase parts.

Table 6.3: Characteristics of Make parts versus Purchase parts

HP High-end server	Make parts	Purchase parts
Number of parts	22 (15%)*	123 (85%)
Total cost of each group (\$)	\$2,674 (9%)	\$26,039 (91%)
Total profit margin for each group (\$)	\$21,746 (21%)	\$81,907 (79%)
Ratio of Total Profit Margin to Total Cost	8.1	3.14

* % refers to percentage of parts over total number of parts

More Cost and price details of each part can be found in Appendix D.

From Table 6.3, the percentage of cost for make parts over total cost for all parts (9%) is lower than its part composition (15%). The reverse is true for purchase parts where the percentage of cost for its parts over total cost of all parts (91%) is higher than its part composition (85%). In terms of average ratio of gross profit

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margin to cost, repair or re-manufacturing parts are more profitable than purchase parts (8 times to 3 times).

In Figure 6.1, profit margin for make parts exhibit non-linear distribution with minimum profit margin at \$71 and maximum profit margin at \$1,165. 20 out of 22 parts (91%) have profit margin greater than \$100. In the case of purchase parts (Figure 6.2), the distribution is linear initially while the tail end increased sharply, implying that only a small fractions of purchase parts have high profit margins as compared to make parts.

Figure 6.1: Cumulative profit margin for make parts (sorted from lowest to highest margin)

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Figure 6.2: Cumulative profit margin for purchase parts (sorted from lowest to highest margin)

Only 23 out of 97 parts (24%) have profit margin greater than \$100 as compared to 91% for make parts using the 80/20 rule.

In order to segment the parts based on return volume, it is useful to group the parts into 3 equal segments for comparison. Using the 4 assemblies from Table 6.1, it is found that almost equal number of parts can be grouped for parts under 100 transactions and for parts between 100 and 1000 transactions, with the remaining few exceeding 1000 transactions (resembling 80/20 rule). Thus, it is appropriate to segment the parts with cumulative volume less than 100, cumulative volume between 100 and 1000, and cumulative volume greater than 1000 for analysis. From Table 6.4, we can infer that higher volume return transaction generates smaller coefficient of variation and vice versa for lower volume return transaction.

Table 6.4: Comparison of return behaviour for different group of parts

Category of parts	Total Vol. over 24 mths	Mean	Standard Deviation (s.d.)	s.d. / Mean (Coeff. Of Variation)

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Low Vol. parts	> 100	29	8	0.29
Mid Vol. parts	Between 100 to 999	135	27	0.20
High Vol. parts	> 1000 per mth	390	66	0.17

Table 6.5 shows the return volumes from a product assembly and we can infer again that coefficient of variation is smaller as the return transaction increases. This implies that the volume for low volume parts tends to fluctuate more than those high volume parts as their coefficients of variation are smaller.

Table 6.5: Returns volume sorted in ascending order

Part-Num	Total Vol. Return	Standard Deviation (s.d.)	Mean Vol. per month	s.d. / Mean
46020-60001	25	1.6	1.1	1.5
A2084-62014	29	2.1	1.3	1.7
8120-1378	29	3.0	1.3	2.4
A4022-60006	29	1.0	1.3	0.8
46021-60418	48	1.6	2.1	0.8
A1658-69023-r	60	3.2	2.6	1.2
A2084-69012-r	77	1.8	3.3	0.5
A2084-60010	78	2.4	3.4	0.7
25567-69004-r	86	1.5	3.7	0.4
C1429-60401	97	2.5	4.2	0.6
A2094-60011	98	2.4	4.3	0.6
98236-69524-r	108	3.9	4.7	0.8
A2084-62004	112	2.5	4.9	0.5
A2084-69005-r	121	2.8	5.3	0.5
A2084-69511-r	140	2.7	6.1	0.4
A2084-69510-r	199	3.1	8.7	0.4

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46021-60401	230	3.9	10.0	0.4
A2084-69019-r	242	3.4	10.5	0.3
C1536-69201-r	254	3.3	11.0	0.3
A2084-69001-r	255	5.3	11.1	0.5
A2575-69001	312	4.5	13.6	0.3
C2300-60005	413	5.5	18.0	0.3
A2335-69222-r	730	7.0	31.7	0.2
0957-0253	1290	18.6	56.1	0.3
1150-1922	2510	25.7	109.1	0.2
1420-0314	5164	55.8	224.5	0.2

6.3 Seasonality analysis

In term of seasonality, there are 4 peaks observed in Feb, May, August and November over the 24 months. These peaks are consistent for parts with low return volume to high return volume as shown in Figures 6.3, 6.4 and 6.5. Staff from HP has verified that the possible reason for such peaks is due to the quarterly closing of financial book where offices in each country try to return as much as possible to reduce their inventory holding. Since the quarterly closing are in March, June, September and December, most offices would return their parts one month before the closing to reflect their inventory adjustment. This also confirms that most offices in each country do not return their parts promptly but accumulate them till quarterly closing so that they can consolidate their shipment for better freight discount.

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Figure 6.3: Return Volume for high volume parts (< 1000 per year)

Figure 6.4: Return Volume for medium volume parts (100 < and < 1000 per year)

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Figure 6.5: Return Volume for low volume parts (> 100 per year)

6.4 Serial correlation and trend analysis

The graphs in appendix E show the estimated autocorrelations between values of each part at various lags. The lag k autocorrelation coefficient measures the correlation between values of each part at time t and time $(t - k)$. Also shown are 95.0% probability limits around 0.0. If the probability limits at a particular lag do not contain the estimated coefficient, there is a statistically significant correlation at that lag at the 95.0% confidence level. In this case, none of the 24 autocorrelations coefficients are statistically significant, implying that the time series may well be completely random. Out of 26 parts, only 1 part exhibits serial correlation that is significant at lag 1. (i.e. 1 month lag).

Appendix F shows each step of the seasonal decomposition. The trend-cycle

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column shows the results of a centred moving average of length 3 applied to each part. The seasonality column shows the data divided by the moving average and multiplied by 100. Seasonal indices are then computed for each month by averaging the ratios across all observations in that month, and scaling the indices so that an average month equals 100. The data are then divided by the trend-cycle and seasonal estimates to give the irregular or residual component. This component is then multiplied by 100. The data cover 24 time periods and a seasonality of 3 is used to offset the 4 peaks to remove seasonal effects. Almost all the parts show increasing trend on return volume except for 2 parts.

6.5 Current issues facing HP reverse logistics operations in Asia

HP realized certain inefficiencies in the management of its reverse logistics operations. For example, some overseas offices were returning their near-worthless spare parts back to the US, thereby incurring unnecessary logistics expenses. In view of the continued launch of new products in Asia and the shortening of product life cycles, HP anticipated an increase in volume returned in the near future if the return process is not rectified. To improve its reverse logistics management, it established a task force.

The objectives of the task force were:

- (a) To critically examine the reverse logistics flow, pertaining to defective spare parts, in HP (AP) Customer Services, and
- (b) To recommend a set of policies and strategies that would improve the efficiency of its reverse logistics operations in Asia Pacific and, thus, reduce its operating costs.

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According to the project leader of the task force, the ideal and optimal reverse logistics system would be one which could manage variability to an acceptable degree in the return pipeline, and which would offer a high degree of inventory visibility. In addition, it was also the opinion of the project leader that the reverse logistics system should entail processes that were simple, inexpensive to install and operate, and scalable throughout the Asia-Pacific region.

At present, each of HP's overseas offices manages its own spare parts return process. This involves the handling of a large volume of spare parts, which are returned to the suppliers or to the US for refurbishment, repair or disposal, as illustrated in Figure 6.6. A third-party logistics provider will pick up these parts for consolidation before shipping them to the US. At the US headquarters, all the returned parts are sorted out prior to deciding on repair or disposal.

Figure 6.6: HP existing part return process to the US head offices

Good spare parts are then sent to the Central Stocking Pool for reuse while defective ones are repaired or refurbished before being returned to the Central

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Stocking Pool. One of the reasons for returning good spare parts is to facilitate stock rotation. This will replace slow-moving spare parts or those with little or no demand from each warehouse with newer parts so that they can support new HP models. Defective parts are also returned to the suppliers for replacement or credit. This has helped HP in reducing its cost of servicing customers without service level being compromised since it does not need to expand its warehouses and yet maintain a current inventory of parts closer to its customer base to support newer models..

Table 6.6 shows the percentage of spare parts in good condition originated from countries in the Asia-Pacific region that were shipped to the US headquarters over a 6-month period. Three countries, namely Japan, Australia, and South Korea, were more active in returning good spare parts to the US headquarters for credits as compared to other countries. Others recorded low return rates as a result of the low sales volumes in their respective markets. For example, Vietnam recorded a spare parts return of 0.3%. India and China have relatively high sales volume but the return volume is surprisingly small (at less than 1%) against the region's total returns. This can be attributed to HP valuing all defectives at zero costs (book value) and the fact that India's and China's export Customs charge high tariffs based on product cost. As such, returning the spares did not make economic sense. This resulted in having to store the defective spare parts in large warehouses or to undertake the repair or re-manufacturing locally. However, not all repairs can be done in these countries due to lack of specialized skills and equipment that can only be found in the US.

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Table 6.6: Percentage of volume return (in good condition) by individual country
versus Total volume Return in the Asia Pacific

Country	Volume % per month
Japan	27.4%
Australia	20.7%
South Korea	16.5%
Thailand	6.9%
Singapore	5.7%
Taiwan	4.7%
Hong Kong	4.1%
Indonesia	3.4%
New Zealand	3.2%
Philippines	2.6%
Malaysia	2.2%
China	1.5%
India	0.8%
Vietnam	0.3%

The estimated logistics cost in returning a spare part is about \$100. This is the amount that third-party logistics providers, such as DHL and Air Express International, are charging HP for most shipments from any part of Asia to the US repair centre. The shipment of very heavy items, which constitutes less than 10% of total return volume, such as monitors weighing more than 10kg, is an exception. The \$100 charge per part includes freight, shipment consolidation, customs clearance, sorting, warehouse handling, systems updating, and spare parts administration. HP wants to avoid returning spare parts in cases where the product cost is less than its reverse logistics cost. In its opinion, these low-cost parts should be scrapped at the country's site, rather than sent back to the US headquarters. Therefore, the focus of the study is not on the expensive spare parts, but on the low-cost parts costing less than \$100.

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The results from the study are presented by the project team in Table 6.7. It can be seen that Australia, India and Taiwan recorded significant return of parts costing less than a dollar while more than 20% of the total returns of five countries involved spare parts costing under \$10. Only four countries (China at 58%, Hong Kong 55%, Japan 58%, and Philippines 60%) recorded more than 50% returns of spare parts costing above \$100. None of the fourteen countries in the Asia-Pacific region achieved 80% or more returns of spare parts costing above \$100.

Table 6.7: Percentage distribution of product cost for good and defective spare parts returning to the US from the Asia pacific countries

Country/Parts' cost \$	less than \$1	\$1< x < \$10	\$10< x < \$25	\$25< x < \$50	\$50< x < \$100	above \$100
Australia	26%	12%	19%	7%	11%	24%
China	0%	7%	1%	9%	25%	58%
Hong Kong	1%	5%	6%	13%	20%	55%
India	20%	54%	9%	3%	11%	3%
Indonesia	0%	72%	10%	3%	6%	8%
Japan	0%	1%	7%	15%	18%	58%
Korea	4%	29%	22%	13%	7%	25%
Malaysia	1%	1%	6%	5%	38%	49%
New Zealand	0%	3%	6%	22%	26%	42%
Philippines	0%	0%	9%	10%	20%	60%
Singapore	1%	4%	15%	25%	15%	41%
Taiwan	20%	38%	13%	7%	9%	12%
Thailand	10%	22%	11%	27%	14%	16%
Vietnam	18%	8%	19%	27%	18%	10%
Overall %Returned	8%	14%	13%	13%	14%	37%

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As HP's headquarters in this region, Singapore achieved below 50% of the total returns in the category where spare parts costing above \$100. Australia, being one of the highest volume contributors to parts return in the region, also fell below the 24% mark in this category. In fact, Australia topped the category of less-than-\$1 spare parts return in this study (at 26% contribution), a situation that is almost identical to its above-\$100 category. It is surprising that 49% of the total returns involve the return of parts below \$50 despite the existing return policy that mandates a minimum return limit of \$100. One reason could be the varying interpretation of this minimum return limit by different countries. Some countries interpret the \$100-limit as one which is based on market price while others based the limit on transfer price instead of product cost.

In fact, many offices in the Asia-Pacific countries do not have a standardized decision-making process for spare parts disposal. Figure 6.7 shows the current decision flow for spare parts return to the US head office. The decision tree tests all possible types of spare parts for return, including:

- a. Parts that are in excess and good condition;
- b. Defective parts that are in repairable condition; and
- c. Defective parts that are no longer needed in the stocking pool.

The procedure for making the return decision is based on a series of questions, namely:

1. Is this part needed?

If this part is not needed, it is recycled or scrapped; otherwise, proceed to the next question.

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2. Is this part in good working condition?

If it is not in good working condition, proceed to the next question; otherwise, proceed to question 5.

3. Is this part repairable?

If this part is not repairable, it is recycled or scrapped; otherwise, proceed to the next question.

4. Is this part worth repairing (e.g. above \$100 product cost)?

If this part is not worth repairing, it is recycled or scrapped? Otherwise, it will be sent for repair and stored in the US central warehouse.

5. Is this part needed or demanded in Asia Pacific?

If so, is it stored in a local warehouse? Otherwise, proceed to the next question.

6. Is this part worth returning to the US?

If this part is not worth returning to the US, it is scrapped or recycled? Otherwise, it is sent to the US central warehouse.

This decision process has three outcomes: (i) Return the part to Asia Pacific, (ii) Return the part to the US and (iii) Simply scrap or recycle the part locally.

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Figure 6.7: Decision making process in HP for reverse logistics

Even though this decision making process looks logical, there are some limitations in it. It treats all incoming returns equal without considering (a) their degree of serviceability as some returns require minor repair while others may require major overhaul, (b) its volume as higher volume can leverage on economies of scale, and (c) import tariff which have an impact to profitability.

6.6 Simulating HP reverse logistics using the dynamic model

Since the return volumes fluctuate over time and there were delays in shipping the returns for repair, using system dynamics modeling will allow one to understand the behaviour in a reverse logistics network better as well as providing a guide to management action to overcome these effects. It will be challenging using linear programming as described in the previous chapter to model the fluctuation. Analysis from Table 6.5 has confirmed that return volume fluctuates more with lesser transactional volume. Furthermore, Figures 6.3, 6.4 and 6.5 have indicated that there are 3 months delays in returning products back for repair or exchange with supplier. Thus, the model must be capable to include the delay time factor to mimic HP operations.

Based on the design for experimentation defined in Chapter 5, Table 6.8 is constructed to simulate the different configuration for analysis. Countries are sorted by return volume and custom duty. Since return volume exhibits a normal distribution probability curve, the mean volume, maximum volume and standard deviation are used to generate the return volume during simulation. This distribution

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behaviour is confirmed from the results obtained in Appendix E that none of the 24 autocorrelations coefficients are statistically significant, implying that the time series may well be completely random.

China has low return volume with zero tariffs while India has low return volume but with slightly higher tariff. Japan and South Korea have high return volume while Thailand has the highest tariff for imported goods. The tariff rates are extracted from custom directory of each country using Harmonized Standard code 8472 meant for computer products. The air freight rates are standard rates used by HP as these are rates charged by its freight forwarders.

Table 6.8: Data used as inputs to simulate returns from each country

	China	India	Taiwan	Thailand	Japan	South Korea
Supply and cost parameters	Low Vol.	Low Vol.	Med Vol.	Med Vol.	High Vol.	High Vol.
Mean acquisition volume (pcs)	7	7	34	34	98	98
Max acquisition volume (pcs)	10	10	50	50	120	120
Std Dev. for acquisition (pcs)	2	2	7	7	17	17
Air freight cost per kg (\$/pcs)	2	1.4	2.5	0.6	1.6	1.6
Custom Duty for import (\$/pcs)	0	0.15	0	0.4	0	0.08

To simulate the different quality of returns, Table 6.9 is constructed and incorporated into each simulation run. Quality is grouped into inferior quality, average quality and superior quality beside differentiating make part from buy part since their profit margin are significantly differently as illustrated in Table 6.3. For superior quality involving make parts, the *make part versus scrap ratio* is set to 1 to

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ensure zero scrap and the *reuse versus repair ratio* is set to 1 where all returns are reused. For superior quality involving buy parts, the *buy part versus scrap part ratio* is set to 1 to ensure zero scrap and the *credit versus exchange ratio* is set to 1 so that all the parts are credited without having to ship to supplier for exchange. For parts with inferior quality, all the ratios are set to zero to maximize scrap quantities.

Table 6.9: Data used as inputs to simulate returns with different quality

Quality parameters	Make Parts			Buy Parts		
	Inferior	Average	Superior	Inferior	Average	Superior
<i>Make part versus scrap ratio</i>	0	0.66	1	0	0	0
<i>Reuse versus repair ratio</i>	0	0.5	1	0	0	0
<i>Repair failure rate</i>	0	0	0	0	0	0
<i>Buy part versus scrap ratio</i>	0	0	0	0	0.66	1
<i>Ratio of credit versus exchange</i>	0	0	0	0	0.5	1
<i>Ratio of cannibalizing to disposal</i>	0	0.5	1	0	0.5	1

6.7 Results from the simulation

Based on experimental design in Table 5.1, the following results are obtained in Table 6.10. The volume of returns is grouped into countries with low volume, medium volume and high volume versus countries with high tariff and low tariff. The demand of the resale part is simulated using the market attractiveness factor. The market attractiveness factor can be used to simulate the trends of increasing return volume based on the trend analysis results in Appendix F. Higher attractiveness of the market will cause a higher demand for resale part.

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Table 6.10: Profitability analysis from the simulation

Return Volume	Return Quality	Countries with low tariff and less attractive resale market	Countries with low tariff and more attractive resale market	Countries with high tariff and less attractive resale market	Countries with high tariff and more attractive resale market
High Volume Countries volume > 1000 Japan and South Korea	High Quality	High Profit	High Profit	High Profit	High Profit
	Average Quality	Moderate Profit	High Profit	Moderate losses	High Profit
	Inferior Quality	Moderate losses	Moderate losses	High losses	High losses
Medium Volume Countries 100 < volume < 999 Taiwan and Thailand	High Quality	High Profit	High Profit	Low losses	High Profit
	Average Quality	Moderate Profit	Moderate Profit	Moderate losses	Low losses
	Inferior Quality	Low losses	Low losses	Moderate losses	Moderate losses
Low Volume Countries 1 < volume < 99 China and India	High Quality	Low Profit	Low Profit	Low Profit	Low Profit
	Average Quality	Low Profit	Low Profit	Low losses	Low Profit
	Inferior Quality	Low losses	Low losses	Low losses	Low losses

Please note that High profit or losses refer to > \$10,000, Moderate profit or losses refer to between \$1,000 and \$9,999 and Low profit or losses refer to between \$0 and \$999.

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From Table 6.10, we can deduce the following behaviour for profitability of reverse logistics:

- a. Inferior quality returns will generate losses regardless of volume size, tariff amount and market attractiveness. Higher volume will generate more losses as shown in Figure 6.8 where Japan and South Korea which have the highest return volumes among the countries exhibit the worst losses. This supports the mathematical model developed in Chapter 4 Equation 4.1 where *Net_profit* in the model is directly proportional to the return volume and thus supporting the dynamic behaviour in which higher return volume will generate higher losses.

Figure 6.8: Profitability of each country for returns with inferior quality

In contrast, higher profitability can be achieved if the return volume is high and return quality is superior. As can be seen from Figures 6.9 and 6.10, South

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Korea and Japan which have the highest transaction volumes are exhibiting almost double their profit by comparing in terms of average return quality versus superior return quality. This behaviour is again supported by the mathematical model in Equation 4.1.

Figure 6.9: Profitability of each country for returns with average quality

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Figure 6.10: Profitability of each country for returns with superior quality

- b. High tariff generates higher losses for high volume and inferior quality returns. From Figure 6.11, Thailand which has the highest import tariff among the countries exhibits the worst losses.
- c. Market attractiveness does not create significant impact to the profitability for reverse logistics. From Figures 6.11 and 6.12, all the countries show slight improvement in their profitability when the market attractiveness is shifted from low to high. Thailand exhibits losses under low attractiveness and is slightly profitable under high attractiveness.

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Figure 6.11: Profitability of each country with low market attractiveness

Figure 6.12: Profitability of each country with high market attractiveness

6.8 Model validation

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The system dynamics literature stresses the importance of model validity. Specifically, in order to determine the validity of a model, and to develop confidence in it as a useful tool for system understanding and policy evaluation, a number of validity checks are performed here. These checks include repeatable, transparency, dimensionality, system construct, process reliability, time step and behaviour reproduction tests.

- a. Repeatability – All model variables are documented and their results in the form of output graphs and tables are readily reproducible. However, some variables such as return volume are programmed to produce random output to make it more realistic.
- b. Transparency – Meaningful variable names are given to ensure that the feedback and decision structure are transparent in the model. For example, repair return stock is used to represent return stocks waiting for repair while repaired stock is used to represent stocks that have been repaired and ready for sales.
- c. Dimensionality – All units are checked for dimensionally consistency and the Vensim software has a feature to perform the check before each simulation.
- d. Process reliability – Materials are conserved throughout the flows. All return materials are converted into scrap or recovered stock and exit from the system once they are sold. All level variables are prevented from going negative and division by zero is avoided using IF THEN statements.
- e. Time step – In order to avoid integration errors, the literature recommends a time step of less than half of the smallest time constant in the model. In this case, the return volume is reported monthly but the processing time for repair is in days. To compromise, the time step used is in week.

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f. Behaviour Reproduction Test – The model is validated by using inputs from two different sets of inputs, HP raw data and the simulated data. Profits generated from each set of input are compared using measure of fit R^2 and R Pearson coefficient. The R^2 value can be interpreted as the proportion of the variance in HP raw data attributable to the variance in the simulated data. If the model replicates exactly the actual series, $R^2 = 1$ and if the model output is constant, $R^2 = 0$. R^2 is the square of the correlation coefficient, r , which measures the degree to which two series converge. The R^2 obtained from 5 different part transactions in Table 6.11 confirmed that the simulated input generate is very close output to actual raw inputs as their value is 0.9 or above.

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Table 6.11: Results obtained in validating raw inputs against simulated inputs

Part No	C1536-69201-r			1420-0314			A2335-69222-r			1150-1922			0957-0253			
	INPUTS		OUTPUTS	INPUTS		OUTPUTS	INPUTS		OUTPUTS	INPUTS		OUTPUTS	INPUTS		OUTPUTS	
Time	HP Raw	Sim	Raw	HP Raw	Sim	Raw	HP Raw	Sim	Raw	HP Raw	Sim	Raw	HP Raw	Sim	Raw	
0	0	0	0	0	0	0	0.00	0	0	0.00	0	0	0.00	0	0	
1	11	331	331	224	7420	7420	13	1060	397	72	3577	397	61	1855	1987	
2	18	591	591	355	13232	13232	39	1890	709	86	6380	709	78	3308	3544	
3	13	1173	1226	234	25420	26268	31	3594	1460	96	12294	1460	70	6249	7089	
4	12	1941	1959	270	40612	41106	30	5766	2326	79	19642	2326	63	10065	11134	
5	8	2552	3029	333	53256	62131	33	7600	4529	100	25793	4529	105	13070	15878	
6	10	2872	3871	223	60979	77258	23	8777	6664	95	29666	6664	62	14561	20009	
7	6	3030	4472	218	65266	90138	26	9490	8494	64	31874	8494	69	15074	23071	
8	9	3367	4693	254	72109	104032	36	10510	10159	132	35244	10159	59	18922	27573	
9	11	3587	4831	205	76654	111093	34	11186	11048	108	37446	11048	48	21550	29956	
10	11	4105	4706	275	86663	114163	29	11377	11664	98	42193	11664	70	22468	31535	
11	9	4222	4638	229	88957	117076	32	11812	12096	92	43320	12096	58	24876	32067	
12	13	4310	4708	201	91029	117019	20	12574	12828	68	44388	12828	44	24610	31504	
13	12	4536	4832	185	95597	119379	34	13028	13348	130	46538	13348	59	24368	31686	
14	14	4639	4859	187	97336	120113	39	13407	13881	150	47401	13881	51	25115	31539	
15	7	4678	5054	184	98610	118575	41	14349	13729	120	48035	13729	56	24999	30521	
16	12	5003	5249	271	104371	115355	39	15280	14034	140	50728	14034	73	27485	30023	
17	13	5578	5529	218	110912	111841	33	15103	14772	93	53777	14772	53	28306	29381	
18	16	5990	5447	239	108580	108405	33	14883	15729	128	52689	15729	58	29851	29007	
19	12	5812	5480	151	105895	109972	32	15092	16577	123	51441	16577	35	32452	29691	
20	5	5605	5612	168	110437	110756	37	14883	16970	130	51791	16970	36	34185	29706	
21	13	5779	5933	266	113905	112228	37	15149	17123	132	50895	17123	39	32442	29692	
22	14	5889	6092	152	112354	109184	37	15065	17102	129	51667	17102	25	30526	28448	
23	5	5748	5792	122	113434	105383	22	15049	17272	145	51233	17272	18	31118	26849	
	Simulate			Simulate			Simulate			Simulate			Simulate			
	Std Dev			Std Dev			Std Dev			Std Dev			Std Dev			
	3.3			55.79			6.95			26			19			
	Mean			Mean			Mean			Mean			Mean			
	11.04			224.52			32			109			56			
	Max			Max			Max			Max			Max			
	18			355			41			150			105			
Results	R2 R		R2 R		R2 R		R2 R		R2 R		R2 R		R2 R		R2 R	
	0.93 0.96		0.89 0.94		0.96 0.98		0.96 0.98		0.96 0.98		0.96 0.98		0.83 0.91		0.83 0.91	

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6.9 Summary of the case study

Table 6.12 compares the results obtained from the linear programming model and system dynamics model. It is clear that the both models exhibited similar results even though one is based on static simulation and another is on dynamics simulation.

Table 6.12: Comparison of results from Linear Programming & System Dynamics models

Countries with			Profits / Losses generated	
Return Vol.	Return Quality	Tariff	Linear Programming	System Dynamics
High	High	High	High Profit	High Profit
High	Low	High	High Losses	High Losses
High	Low	Low	Moderate Losses	Moderate Losses
High	High	Low	High Profit	High Profit
Low	High	High	Low Profit	Low Profit
Low	Low	High	Low Losses	Low Losses
Low	High	Low	Low Profit	Low Profit
Low	Low	Low	Low Losses	Low Losses

Based on the results obtained from both models, the following policies are recommended to maximize manufacturer's profitability for reverse logistics in Table 6.13.

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Table 6.13: Recommended Policies for reverse logistics in the computer industry

Countries with			Recommended Policy		
Return Vol.	Return Quality	Tariff	Centralize Processing	Decentralize Processing	Outsource To 3PLs
High	High	High	√		
High	Low	High		√	
High	Low	Low		√	
High	High	Low	√		
Low	High	High			√
Low	Low	High			√
Low	High	Low		√	
Low	Low	Low			√

CHAPTER 7

CONCLUSIONS AND FUTURE RESEARCH

7.1 Conclusions

This thesis provides methods and ideas on how reverse logistics can be positioned as a profitable business. The mathematical model is able to accommodate issues and challenges faced in a global MNC setting. It is solved by using linear programming and system dynamics modeling. The results from both modeling methods are consistent and validate one another.

Returns volume and their quality have confirmed to have the most impact on the profitability of reverse logistics. Return volumes must be sufficiently high to achieve higher profitability due to economies of scale. The overheads involved in setting up the repair facilities will only be justified by higher return volume. This is demonstrated in the linear programming model and the system dynamics model.

Higher quality returns (e.g. repair, reuse, exchange or credit with supplier) are recommended for reverse logistics. The costs incurred to service these high quality returns are much lower and thus giving higher profit margin. This is again demonstrated from both the models.

The import and export custom charges are another important factor that has an impact on the profitability of reverse logistics. Higher custom charges will make reverse logistics unattractive for centralized reverse logistics due to the high costs incurred for customs.

Chapter 7 Conclusions and future research

Based on the results obtained from both linear programming and system dynamics models, there is a strong case that most of the parameters in the mathematical model are essential in determining the profitability of reverse logistics in the global context. This is because most of the logistics problems have similar components as compared to the ones considered in this thesis.

In conclusion, managing reverse logistics in a global context involves more international issues as compared to a managing reverse logistics within a country. Therefore, the parameters to consider are more complex and need more sophisticated methods (e.g. linear programming, system modeling, etc) to solve them.

7.2 Contributions

The contributions of this research are as follows:

- The research provides a decision making model incorporating important factors such as quality, volumes and custom duties that have significant impact on the profitability of reverse logistics. As of this writing, the author is not aware of any published models close to this model which is a better representation in today's context.
- This research also addresses a fundamental assumption in all previous works that model reverse logistics discretely either in recycling process or repair process or repackaging process but not all the processes at the same time. This assumption is no longer valid in today's context.
- This research provides a basis for comparing different market attractiveness in evaluating profitability of reverse logistics. It is noted that previous models

Chapter 7 Conclusions and future research

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assumed that resale price as a constant throughout the product life cycle. This assumption is no longer valid in today's context.

- This decision making framework will assist manufacturing companies to evaluate their viability as well as providing opportunities for third party logistics companies to evaluate reverse logistics opportunities. By changing some of the parameters, the third party logistics companies can evaluate the various factors over a period of time before deciding to offer reverse logistics services.
- The analysis using this model draws attention to and develops insights for international issues such as custom duties and international freights and their strategic importance for reverse logistics. This model is expected to improve the decision making process for companies to evaluate the profitability of reverse logistics to support its international operations.

7.3 Suggestions for future work

Suggestions for future work based on the research in this thesis are as follows:

- The current dynamic model is developed from the manufacturer's point of view in computing profitability. However, this model can also be used to represent a third party logistics (3PL) offering reverse logistics services. This can be accomplished by setting the acquisition cost to a non-zero since there is a need to purchase those faulty parts and it varies according to the quality of returns. With more 3PLs offering reverse logistics, it is logical to expand this model to examine their business viability.

Chapter 7 Conclusions and future research

- Exchange rates can be introduced to capture currency fluctuations over time in the dynamic model. This is especially true in Asia where each country has its own currency which fluctuates with time.
- Design of experiments can be performed with other variables that have not been analyzed in this thesis such as delays in transportation, duration for repair or repackaging and other cost elements.
- The dynamic model can be applied to other industries to determine its fitness. For example, in the consumer goods, chemical, and automotive industries. Due to environmental and economic factors, together with the deadline from Waste Electrical and Electronic Equipment Directive (WEEE) in August 2005, these industries are facing growing pressure to recycle their products after end of usage. Penalties and fines are introduced in some countries and these are additional cost elements that can be introduced into the dynamic model for further research.

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APPENDIX A

Survey Form for Reverse Logistics Study

SURVEY ON REVERSE LOGISTICS OPERATIONS IN ASIA-PACIFIC

The National Computer Board and the Nanyang Technological University are jointly conducting this survey to evaluate the various Reverse Logistics practices amongst the key industries within and across the Asia-Pacific. This survey will facilitate benchmark comparison and observations of best practices amongst companies of similar industry. In addition, we hope to identify the IT gap in supporting reverse logistics operations across the different industries.

Ideally, a Logistics/Material/Distribution Manager should complete this questionnaire. Please direct your enquiry to Associate Professor Yu Wei Shin (Tel: 790-5519, NTU), Associate Professor Kam Booï Chung (Tel: 790-5581, NTU), Professor Rajesh Piplani (Tel: 790-5601, NTU) or Mr Albert Tan (Tel: 778-2211, NCB).

All information provided will be kept in strictest confidence, and only aggregate information will be released. Please send the completed questionnaire to NTU by post using the self-addressed postage envelope provided by **16 July 1999**.

If you would like to receive a copy of the survey aggregate findings, please provide us the following particulars.

Job Title:	_____
Company:	_____
Division:	_____
Department:	_____
Company Address:	_____ _____

1 of 12

Please tick (✓) as appropriate. In some questions, you may be required to tick more than one choice.

Part 1: Company Profile

Questions in this section allow us to gather profile information about your organization and the extent of Reverse Logistics employed by your organization.

1. Select the type of Industry your organization belongs:

☐
Medical
Equipment
Supplies

☐
Automotive /
Engineering

☐
Telecommunication

☐
Aircraft
Supplies

☐
Computer /
Electronics

Others (Please specify) _____

2. Select the typical product life¹ cycle of your organization's product:

☐
< 6 mths

☐
6-12 mths

☐
13-18 mths

☐
19-24 mths

☐
> 24 mths

3. Rank the top 3 reasons for returns in your organization.
(Rank 1 to 3: "1" = most important reason; 3 being the least important reason):

☐
Money-Back
Guarantee

☐
Quality
Assurance /
Warranty

☐
Stock
Rotation³ /
Replacement

☐
Dead-On-Arrival

☐
End-of-Life² /
Obsolescence

☐
Government
Regulation

☐
Environmental
Reasons

☐
Channel
Inventory
Management

☐
Recapture
Value

☐
Stock
Recall⁴
(Engineering)

Others (Please specify) _____

¹ **Product Life Cycle** - Refers to the market life of a product.

² **Obsolescence (End-of-Life)** - Where a product has reached beyond its useful life.

³ **Stock Rotation** - The return of inventory stocks as a result of expired shelf date.

⁴ **Stock Recall** - A return process triggered usually by a quality related problem.

4. Specify percentage of Asia-Pacific return shipments against the total returns shipment worldwide (*1st tier customer and/or direct customer*) back into your organization/entity.

	☐	☐	☐	☐
By Total Returns Shipment Value:	< 25%	25-50%	51-75%	> 75%
	☐	☐	☐	☐
By Total Returns Shipment Volume:	< 25%	25-50%	51-75%	> 75%

5. Rank (by volume) the Top 3 regions where the returns are coming to your organization).
(Rank 1 to 3: 1 = "*Highest volume*"; 2 = "*Second Highest volume*"; 3 = "*Third Highest volume*").

☐	☐	☐
S.E. Asia	Pacific	North Asia

6. Value of goods transacted in returns shipment per month:

☐	☐	☐	☐
< US\$50,000	US\$50,000-US\$200,000	US\$200,001-US\$500,000	> US\$500,000

7. Specify the number of *full-time* employees (within Singapore) in your company accordingly:

Total Number of Employees:	____
Total IT Staff:	____
Total Logistics Staff:	____

8. State whether there is a department in your organization tasked to plan, organize and design Reverse Logistics model:

☐	☐
Yes	No

9. Indicate the number of days allowed for goods to be returned after delivery.

☐	☐	☐	☐	☐
≤ 6 mths	7 mths - 1 year	1-3 years	4-5 years	> 5 years

10. Indicate the percent of return allowed per sales transaction.

☐	☐	☐	☐	☐	☐
1-5%	6-10%	11-20%	21-50%	> 50%	None

Part 2: Reverse Logistics Process

Questions in this section allow us to understand the mode of employment of Reverse Logistics in your organization.

1. Specify the average expected turn-around time (from point of service order taking to final delivery) for the returns process (single lap only) in your organization:

☐

< 1 day

☐

1-2 days

☐

3-4 days

☐

5-7 days

☐

> 7 days

2. Indicate the source/s of your organization's returns. (Please tick all that applies)

☐End-User /
Consumer☐

Retailer

☐Reseller /
Distributor☐Distribution
Center☐

Intra-Corporate

Others (Please specify) _____

3. Where in the supply chain are decisions made about what is to be done with a returned item?
Where appropriate, this may include Third-Party Logistics Provider⁵.

In-HouseThird-Party

At Retailer / Distributor (or point of customer contact)

☐☐

At Regional Distribution Center

☐☐

At National Distribution Center

☐☐

At Field Stocking Center

☐☐

At Service Center

☐☐

Others (Please specify) _____

⁵ Third-Party Logistics Provider – Vendor employed to run logistics function for a non-logistics firm.

4. Specify the disposal of goods involved in the Reverse Logistics process. (Please tick all that applies)

Replenishment ⁶	☐	Send to central processing facility	☐
Recycle ⁷ (materials reclaim)	☐	Resell to broker / other outlets	☐
Remanufacture ⁸	☐	Scrap / Destroy	☐
Repackage ⁹	☐	Fire-Sale ¹⁰ to staff / customer	☐
Recondition / Refurbish ¹¹	☐	Others (Please specify) _____	

5. State facility used to consolidate goods prior to actual returns.

	<u>In-House</u>	<u>Third-Party</u>
Factory	☐	☐
Central Collection Centers / Warehouse	☐	☐
Remote Field Stocking Centers	☐	☐
Service and Repair Centers	☐	☐
Spare Parts Center	☐	☐
Distribution Centers	☐	☐
Others (Please specify) _____	☐	☐

6. Rank the top 3 barriers to successful Reverse Logistic activities in your organization.
(Rank 1 to 3: 1 = "Biggest barrier"; 2 = "2nd Biggest barrier"; 3 = "3rd Biggest barrier").

Company policy	☐
Competitive issues	☐
Financial justification	☐
Personnel resources	☐
Lack of proper information systems	☐
Legal issues	☐
Lack of management attention	☐

⁶ Replenishment – To fill up with fresh or new supply.⁷ Recycle – When a product is reduced to its basic elements, which are then re-used at a later stage.⁸ Re-manufacture – Similar to "recondition / refurbish", but requires more extensive work; often requiring complete disassembling of the product.⁹ Repackage – The re-boxing or re-containerization of a product.¹⁰ Fire-Sale – Same as "Salvage", where a product is sold to a broker or some other low-revenue customer.¹¹ Recondition / Refurbish – When a product is cleaned and repaired to return to a "like new" state.

7. Mark the levels of Reverse Logistic activities out-source or perform by Logistics Service Provider:

	<u>Current</u>	<u>Future</u>
Order Management / Order Processing	☐	☐
Call Response Center	☐	☐
Warehousing	☐	☐
Inventory Management	☐	☐
Transportation	☐	☐
Repair / Engineering Services	☐	☐
Materials Disposal (Scrap, destroy, etc)	☐	☐
Others (<i>Please specify</i>) _____	☐	☐

8. Specify the average weight of returns shipment involved in Reverse Logistics:

☐ < 1Kg
 ☐ 1 – 2Kg
 ☐ 3 – 5Kg
 ☐ 6 – 10Kg
 ☐ > 10Kg

9. Indicate if any of these were considered in the Reverse Logistics process:

Returns Management Authorization (RMA)¹² ☐
 Duty Drawback¹³ ☐
 Duty Avoidance¹⁴ ☐

¹² **Returns Material Authorization (RMA)** – Authorization to return a product.

¹³ **Duty Drawback** – The duty avoidance practice of recovering duty levied on a good re-entering a country after repair, rework and/or re-pack.

¹⁴ **Duty Avoidance** – The avoidance of paying “double duty” for the same good on re-entry to a country after repair, rework and/or re-pack.

10. Select the Reverse Logistics performance measurement/s used in your organization:

Delivery Transit-Time	☐	Field Inventory Fill Rate (FIFR) ¹⁵	☐
% Sales Returns	☐	Returns Distribution Overheads (DOH)	☐
% Dead-On-Arrival (DOA) ¹⁶	☐	End-Of-Life Exposure (EOL)	☐
Others (Please specify) _____			
* No measurement at all		☐	

11. Rank the transport mode/s used in returns shipment.

(Rank 1 to 3: 1 = "Most Common mode"; 2 = "2nd Common mode"; 3 = "3rd Common mode").

☐	☐	☐
Land	Air	Sea

12. State the average number of times a particular item is allowed to return.

☐	☐	☐	☐
Once	Twice	Thrice	No limit

¹⁵ Field Inventory Fill Rate (FIFR) – Refers to number of inventory turns to maintain order fulfillment.

¹⁶ Dead-On-Arrival (DOA) – Refers to any non-conformance as a result of functional or physical defect at point of goods arrival.

APPENDIX B

Results obtained from the linear programming model

Qty of returns entered into the model   Qty of returns recommended by the model

	Reuse	Repair	Scrap		Reuse	Repair	Scrap	Net Profit
Penang Singapore	10,000		0		0	10,000	0	\$49,670,000
USA	0	10,000	0		10,000	0	0	
	20,000	0	0		20,000	0	0	
	30,000	10,000	0		30,000	10,000	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	10,000	0		0	10,000	0	\$49,670,000
USA	10,000	0	0		10,000	0	0	
	20,000	0	0		20,000	0	0	
	30,000	10,000	0		30,000	10,000	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	10,000	0		0	20,000	0	\$47,220,000
USA	0	10,000	0		10,000	0	0	
	20,000	0	0		10,000	0	0	
	20,000	20,000	0		20,000	20,000	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	10,000	0	0		0	20,000	0	\$47,220,000
USA	10,000	0	0		10,000	0	0	
	0	20,000	0		10,000	0	0	
	20,000	20,000	0		20,000	20,000	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	10,000	0	0		13,333	0	0	\$45,313,333
USA	10,000	0	0		13,333	0	0	
	20,000	0	0		13,333	0	0	
	40,000	0	0		40,000	0	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	10,000	0	0		0	30,000	0	\$44,770,000
USA	0	10,000	0		10,000	0	0	
	0	20,000	0		0	0	0	
	10,000	30,000	0		10,000	30,000	0	
Penang Singapore	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	10,000	0		0	30,000	0	\$44,770,000
	10,000	0	0		10,000	0	0	

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e									
USA	0	20,000	0		0	0	0		
	10,000	30,000	0		10,000	30,000	0		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	0	10,000	0		0	40,000	0		\$42,300,000
Singapor	0	10,000	0		0	0	0		
e	0	20,000	0		0	0	0		
USA	0	40,000	0		0	40,000	0		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	10,000	0	0		3,333	0	6,667		\$38,210,000
Singapor	0	0	10,000		6,667	0	3,333		
e	20,000	0	0		20,000	0	0		
USA	30,000	0	10,000		30,000	0	10,000		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	0	0	10,000		3,333	0	6,667		\$38,210,000
Singapor	10,000	0	0		6,667	0	3,333		
e	20,000	0	0		20,000	0	0		
USA	30,000	0	10,000		30,000	0	10,000		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	0	0	10,000		0	10,000	0		\$36,710,000
Singapor	0	10,000	0		0	0	10,000		
e	20,000	0	0		20,000	0	0		
USA	20,000	10,000	10,000		20,000	10,000	10,000		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	0	10,000	0		0	10,000	0		\$36,710,000
Singapor	0	0	10,000		0	0	10,000		
e	20,000	0	0		20,000	0	0		
USA	20,000	10,000	10,000		20,000	10,000	10,000		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	0	0	10,000		0	20,000	0		\$34,260,000
Singapor	10,000	0	0		0	0	10,000		
e	0	20,000	0		10,000	0	0		
USA	10,000	20,000	10,000		10,000	20,000	10,000		
	Reuse	Repair	Scrap		Reuse	Repair	Scrap		
Penang	10,000	0	0		0	20,000	0		\$34,260,000
Singapor	0	0	10,000		0	0	10,000		
e	0	20,000	0		10,000	0	0		
USA	10,000	20,000	10,000		10,000	20,000	10,000		

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Penang Singapore USA	Reuse	Repair	Scrap		Reuse	Repair	Scrap	\$31,810,000
	0	0	10,000		0	30,000	0	
	0	10,000	0		0	0	10,000	
	0	20,000	0		0	0	0	
Penang Singapore USA	0	30,000	10,000		0	30,000	10,000	\$31,810,000
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	10,000	0		0	30,000	0	
	0	0	10,000		0	0	10,000	
Penang Singapore USA	0	20,000	0		0	0	0	\$29,250,000
	0	30,000	10,000		0	30,000	10,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	0	10,000		0	0	10,000	
Penang Singapore USA	0	0	10,000		0	0	10,000	\$25,250,000
	20,000	0	0		20,000	0	0	
	20,000	0	20,000		20,000	0	20,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore USA	10,000	0	0		0	0	10,000	\$24,614,000
	10,000	0	0		0	0	10,000	
	0	0	20,000		20,000	0	0	
	20,000	0	20,000		20,000	0	20,000	
Penang Singapore USA	Reuse	Repair	Scrap		Reuse	Repair	Scrap	\$23,250,000
	0	10,000	0		0	10,000	0	
	10,000	0	0		8,000	0	2,000	
	0	0	2,000		2,000	0	0	
Penang Singapore USA	10,000	10,000	2,000		10,000	10,000	2,000	\$20,350,000
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	10,000	0	0		0	10,000	0	
	0	10,000	0		0	0	10,000	
Penang Singapore USA	0	0	20,000		10,000	0	10,000	\$20,800,000
	10,000	10,000	20,000		10,000	10,000	20,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
	0	10,000	0		0	20,000	10,000	
Penang Singapore USA	0	10,000	0		0	0	10,000	\$20,800,000
	0	0	20,000		0	0	0	
	0	20,000	20,000		0	20,000	20,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore USA	0	0	10,000		0	20,000	0	\$20,800,000
	0	0	10,000		0	0	10,000	
	0	20,000	0		0	0	10,000	

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	0	20,000	20,000		0	20,000	20,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	0	0	10,000		0	0	10,000	\$11,790,000
	10,000	0	0		0	0	10,000	
USA	0	0	20,000		10,000	0	10,000	
	10,000	0	30,000		10,000	0	30,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	10,000	0	0		0	0	10,000	\$11,790,000
	0	0	10,000		0	0	10,000	
USA	0	0	20,000		10,000	0	10,000	
	10,000	0	30,000		10,000	0	30,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	0	10,000	0		0	10,000	0	\$9,790,000
	0	0	10,000		0	0	10,000	
USA	0	0	20,000		0	0	20,000	
	0	10,000	30,000		0	10,000	30,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	0	0	10,000		0	10,000	0	\$9,790,000
	0	10,000	0		0	0	10,000	
USA	0	0	20,000		0	0	20,000	
	0	10,000	30,000		0	10,000	30,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	0	0	10,000		0	0	10,000	(\$1,670,000)
	0	0	10,000		0	0	10,000	
USA	0	0	20,000		0	0	20,000	
	0	0	40,000		0	0	40,000	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	20,000	0	0		20,000	0	0	\$102,340,000
	20,000	0	0		20,000	0	0	
USA	40,000	0	0		40,000	0	0	
	80,000	0	0		80,000	0	0	
	Reuse	Repair	Scrap		Reuse	Repair	Scrap	
Penang Singapore	0	0	20,000		0	0	20,000	(\$3,340,000)
	0	0	20,000		0	0	20,000	
USA	0	0	40,000		0	0	40,000	
	0	0	80,000		0	0	80,000	

APPENDIX C

Equations for the Dynamic model to determine profitability of reverse logistics

- (01) Acquisition Cost= 0
Units: \$/pcs
Cost of acquisition per piece
- (02) Acquisition Rate=
ACTIVE INITIAL ((RANDOM NORMAL(0, Max acquisition, Mean acquisition,
STD Dev for acquisition , 0))/Collection time, Mean acquisition)
Units: pcs/week
Rate of acquiring returns taking into account the collection time
- (03) Air Freight cost per kg= GET XLS CONSTANTS('revlog.xls','input', 'B5')
Units: \$/kg
Cost of shipment per kg
- (04) Attractiveness of resales item= 0.75
Units: Dmnl [0,1]
Attractiveness to sell recondition items. 0.25 for low, 0.5 for moderate and 0.75 for high attractiveness
- (05) Average Cost to Repackage per pc= 200
Units: \$/pcs
Average cost to repackage a part
- (06) Average Cost to Repair per pc= 500
Units: \$/pcs
Average cost to repair a part
- (07) Average Cost to Scrap per pc= 30
Units: \$/pcs
Average cost to scrap a part

(08) Buy parts return ratio= GET XLS CONSTANTS('revlog.xls','input', 'B14')

Units: Dmnl [0,1]

Ratio of buy parts versus scrap parts

(09) Cannibalization Rate=

Ratio of Cannibalization to scrap disposal*Scrap Stocks/Cycle time for
Cannibalization

Units: pcs/week

Rate of extracting useful parts from assembly

(10) Collection time= 1

Units: week

Time taken to collect the returns for processing

(11) Custom Duty= Duty Percent*Item resales price

Units: \$/pcs

Custom duty chargeable based on item cost

(12) Cycle time for Cannibalization= 8

Units: week

Time taken to extract useful part

(13) Delay from supplier= 0.5

Units: week

Time delayed while corresponding with supplier

(14) Delay in repackaging= 0.5

Units: week

Time delayed before repackaging starts

(15) Delay in repair= 0.5

Units: week

Time delayed before repair starts

- (16) Delay in scrapping stock= 1
Units: week
Time delayed before scrapping starts
- (17) Delay in sorting= 0.5
Units: week
Time delayed before sorting the returns into suppliers return, scrap and manufacturing return.
- (18) Delay in stock sales= 2
Units: week
Time delayed before selling the parts
- (19) Delay in transportation= 0.2
Units: week
Time delayed before transporting the make part for repair or reuse
- (20) Delivery Rate for Repaired Stocks=
 $\text{Repaired Stocks} / \text{Delivery time} * (1 - \text{Fractional Repair failure})$
Units: pcs/week
Rate of transporting the repaired parts to central store
- (21) Delivery Rate for Reuse Stocks= $\text{Reuse Stocks} / \text{Delivery time}$
Units: pcs/week
Rate of transporting the repackaged parts to central store
- (22) Delivery time= 4
Units: week
Time taken to deliver the processed parts to central store
- (23) Despatch time to scrap= 4
Units: week
Rate of transporting the part for scrap

- (24) Disposal cycle time for single unit= 1
Units: week
Time taken to scrap a part
- (25) Disposal Rate for Scrap=
(1-Ratio of Cannibalization to scrap disposal)*Scrap Stocks/Disposal cycle time for single unit
Units: pcs/week
Rate of scrapping part
- (26) Duty Percent=
GET XLS CONSTANTS('revlog.xls','input', 'B6')
Units: Dmnl
Percentage of custom duty payable
- (27) Exchange time= 6
Units: week
Time taken to exchange faulty buy part with new one
- (28) FINAL TIME = 104
Units: week
The final time for the simulation.
- (29) Fixed Costs=
(Acquisition Cost+Custom Duty+Handling Cost+Transport Cost)
Units: \$/pcs
Fixed costs for reverse logistics
- (30) Fractional Repair failure= GET XLS CONSTANTS('revlog.xls','input', 'B13')
Units: Dmnl [0,1]
Ratio of repair part versus scrap part
- (31) Gross Profit from Exchange Stock=

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IF THEN ELSE(Total Unit Cost to Exchange>0,Sales Rate for Recovered Stocks
(Supplier Exchange Stocks/Total Return Stocks)(Item resales price-Total Unit
Cost to Exchange),0)

Units: \$/week [0,?]

Profit margin for selling parts exchanged with supplier per week

(32) Gross Profit from Repair Stock=

IF THEN ELSE(Total Unit Cost to Repair>0,Sales Rate for Recovered Stocks*
(Repaired Stocks/Total Return Stocks)*(Item resales price -Total Unit Cost to
Repair),0)

Units: \$/week

Profit margin for selling repaired parts per week

(33) Gross Profit from Reuse Stock=

IF THEN ELSE(Total Unit Cost to Reuse>0, Sales Rate for Recovered Stocks*
(Reuse Stocks/Total Return Stocks)*(Item resales price -Total Unit Cost to Reuse),0)

Units: \$/week

Profit margin for selling reused part per week

(34) Gross Profit from Scrap Stock=

Scrap Stocks*(1-Ratio of Cannibalization to scrap disposal)*(Item Weight*
Price of Scrap per kg-Total Unit Cost to Scrap)

Units: \$

Profit margin for selling a scrap part

(35) Handling Cost= Labor cost per hour*Number of hours per transaction

Units: \$/pcs

Cost of handling and administration based on the number of hours rendered.

(36) INITIAL TIME = 0

Units: week

The initial time for the simulation.

(37) Item resales price= Attractiveness of resales item*New Item Selling Price

- Units: \$/pcs
Sale value for recovered items
- (38) Item Weight= 5
Units: kg/pcs
Weight of an item
- (39) Labor cost per hour= 100
Units: \$/hr
Labor cost per hour of service rendered
- (40) Make parts return ratio= GET XLS CONSTANTS('revlog.xls','input', 'B11')
Units: Dmnl [0,1]
Ratio of make parts versus scrap parts
- (41) Manufactured return=
INTEG ((Return Rate for Manufactured Stocks-Return Rate for Repair Stocks-Return
Rate for Reuse Stocks),Return Rate for Manufactured Stocks*Delay in
transportation)
Units: pcs
Total quantity of make parts for processing
- (42) Max acquisition= GET XLS CONSTANTS('revlog.xls','input', 'B3')
Units: pcs
Average rate of acquiring returns for processing and scrap
- (43) Mean acquisition= GET XLS CONSTANTS('revlog.xls','input', 'B2')
Units: pcs
Average rate of acquiring returns for processing and scrap
- (44) New Item Selling Price= 2000
Units: \$/pcs
Original selling price

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- (45) Number of hours per transaction= 1
Units: hr/pcs
Number of processing hours
- (46) Number of items per pallet= 1000
Units: pcs/pallet
Volume of item
- (47) Price of Scrap per kg= 10
Units: \$/kg
Price of scrap per kg of scrap
- (48) Ratio of Cannibalization to scrap disposal=
GET XLS CONSTANTS('revlog.xls','input', 'B16')
Units: Dmnl
Ratio of cannibalizing parts to disposal of scrap
- (49) Recovered Stocks=
INTEG ((Delivery Rate for Repaired Stocks+Delivery Rate for Reuse Stocks+Stock
Exchange Rate to Supplier-Sales Rate for Recovered Stocks),(Delivery Rate for
Repaired Stocks+Delivery Rate for Reuse Stocks+Stock Exchange Rate to Supplier
Units: pcs
Total quantity of parts after processing and exchanging with suppliers
- (50) Repackaging Rate= Reuse Return Stocks/Reuse time
Units: pcs/week
Number of parts repackaged per week
- (51) Repair failure rate= (Repaired Stocks*Fractional Repair failure)/Despatch time to
scrap
Units: pcs/week
Rate of repair failure

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- (52) Repair Rate= Repair Returns Stocks/Repair time
Units: pcs/week
Number of parts repaired per week
- (53) Repair Returns Stocks=
INTEG ((Return Rate for Repair Stocks-Repair Rate), Return Rate for Repair
Stocks*Delay in repair)
Units: pcs
Stocks cumulated for repair
- (54) Repair time= 2
Units: week
Time taken to repair a part for use again
- (55) Repaired Stocks=
INTEG ((Repair Rate-Delivery Rate for Repaired Stocks-Repair failure rate),
Repair Rate*Delay in transportation)
Units: pcs
Total number of parts repaired for sales
- (56) Return Rate for Manufactured Stocks=
INTEGER((Returns*Make parts return ratio)/Sorting time)
Units: pcs/week
Rate of sorting manufacturing part
- (57) Return Rate for Repair Stocks=
(Manufactured return*(1-Reuse versus repair ratio))/Transport time
Units: pcs/week
Time taken for transporting parts for repair
- (58) Return Rate for Reuse Stocks=
(Manufactured return*Reuse versus repair ratio)/Transport time
Units: pcs/week
Rate of transporting parts for repackaging

- (59) Return Rate for Scrap Stocks= $\text{INTEGER}((\text{Returns} * \text{Scrap ratio}) / \text{Sorting time})$
Units: pcs/week
Rate of sorting scrap part
- (60) Return Rate for Supplier Stocks=
 $\text{INTEGER}((\text{Returns} * \text{Buy parts return ratio}) / \text{Sorting time})$
Units: pcs/week
Rate of sorting buy part
- (61) Returns=
 $\text{INTEG} ((\text{Acquisition Rate} - \text{Return Rate for Manufactured Stocks} - \text{Return Rate for Scrap Stocks} - \text{Return Rate for Supplier Stocks}), \text{Acquisition Rate} * \text{Delay in sorting})$
Units: pcs
Total quantity of returns collected
- (62) Reuse Return Stocks=
 $\text{INTEG} ((\text{Return Rate for Reuse Stocks} - \text{Repackaging Rate}), \text{Return Rate for Reuse Stocks} * \text{Delay in repackaging})$
Units: pcs
Stock cumulated for repackaging
- (63) Reuse Stocks=
 $\text{INTEG} ((\text{Repackaging Rate} - \text{Delivery Rate for Reuse Stocks}), \text{Repackaging Rate} * \text{Delay in transportation})$
Units: pcs
Total quantity of parts repackaged for sales
- (64) Reuse time= 1
Units: week
Time taken to repack a part for use again
- (65) Reuse versus repair ratio= $\text{GET XLS CONSTANTS}('revlog.xls', 'input', 'B12')$
Units: Dmnl [0,1]

Ratio of make parts that can be reused versus those that can be repaired

(66) Sales cycle time for Recovered Stocks= 4

Units: week

Time taken to sell a part

(67) Sales Rate for Recovered Stocks=

Recovered Stocks/Sales cycle time for Recovered Stocks

Units: pcs/week

Rate of sales of parts

(68) SAVEPER = TIME STEP

Units: week

The frequency with which output is stored.

(69) Scrap ratio=

IF THEN ELSE(Buy parts return ratio > 0, 1-Buy parts return ratio , 1-Make parts return ratio)

Units: Dmnl [0,1]

There is only one type of part attribute to consider for each item, either buy parts or make parts

(70) Scrap Stocks=

INTEG ((Return Rate for Scrap Stocks+Repair failure rate+Stock Credit Rate for Supplier -Disposal Rate for Scrap-Cannibalization Rate), Return Rate for Scrap Stocks*Delay in scrapping stock)

Units: pcs

Total quantity of scrap parts

(71) Sorting time= 1

Units: week

Time taken to sort the returns into make part, buy part and scrap part

(72) STD Dev for acquisition= GET XLS CONSTANTS('revlog.xls','input', 'B4')

Units: pcs

Average rate of acquiring returns for processing and scrap

(73) Stock Credit Rate for Supplier=

(Supplier Exchange Stocks*Supplier Credit versus exchange Ratio)/Despatch time to scrap

Units: pcs/week

Rate of scrapping buy parts that can be redeemed from supplier

(74) Stock Exchange Rate to Supplier=

(Supplier Exchange Stocks*Supplier Credit versus exchange Ratio)/Exchange time

Units: pcs/week

Rate to exchange faulty buy part with new part

(75) Storage Cost=

Storage cost per pallet/Number of items per pallet

Units: \$/(pcs*week)

Cost of storage based on item volume

(76) Storage cost per pallet= 100

Units: \$/(week*pallet)

Cost of storage based on volumetric measurement

(77) Supplier Credit versus exchange Ratio=

GET XLS CONSTANTS('revlog.xls','input', 'B15')

Units: Dmnl [0,1]

Ratio of buy parts for credit versus those for exchange

(78) Supplier Exchange Stocks=

INTEG ((Return Rate for Supplier Stocks-Stock Exchange Rate to Supplier-Stock Credit Rate for Supplier), Return Rate for Supplier Stocks*Delay from supplier)

Units: pcs

Total quantity of buy part for exchange or credit with suppliers

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- (79) TIME STEP = 1
Units: week
The time step for the simulation.
- (80) Total Exchange Cost=
 $\text{Supplier Exchange Stocks} * ((\text{Storage Cost} * \text{Delay from supplier}) + \text{Fixed Costs})$
Units: \$
Supplier pays for all costs incurred to exchange a faulty part with a new one
- (81) Total Gross Profit=
 $\text{Gross Profit from Exchange Stock} + \text{Gross Profit from Repair Stock} + \text{Gross Profit from Reuse Stock} + \text{Gross Profit from Scrap Stock}$
Units: \$
Total Expected Profit generated per week
- (82) Total Repair Cost=
 $\text{Repaired Stocks} * (\text{Average Cost to Repair per pc} + (\text{Storage Cost} * (\text{Delay in repair} + \text{Delay in transportation})) + \text{Fixed Costs})$
Units: \$
Total repair cost
- (83) Total Return Stocks= Reuse Stocks+Supplier Exchange Stocks+Repaired Stocks
Units: pcs
Total quantity of returns stocks
- (84) Total Reuse Cost=
 $\text{Reuse Stocks} * (\text{Average Cost to Repackage per pc} + (\text{Storage Cost} * (\text{Delay in transportation} + \text{Delay in repackaging})) + \text{Fixed Costs})$
Units: \$
Total cost for repackaging a part
- (85) Total Reverse logistics costs=
 $\text{Total Exchange Cost} + \text{Total Repair Cost} + \text{Total Reuse Cost} + \text{Total Scrap Cost}$
Units: \$

Total Cost for reverse logistics

- (86) Total Scrap Cost=
Scrap Stocks*(1-Ratio of Cannibalization to scrap disposal)*(Average Cost to Scrap
per pc +(Storage Cost*Delay in scrapping stock)+Fixed Costs)
Units: \$
Total scrap cost
- (87) Total Unit Cost to Exchange=
IF THEN ELSE(Supplier Exchange Stocks>0, Total Exchange Cost/Supplier
Exchange Stocks,0)
Units: \$/pcs
Cost to exchange a part with supplier
- (88) Total Unit Cost to Repair=
IF THEN ELSE(Repaired Stocks>0,Total Repair Cost/Repaired Stocks,0)
Units: \$/pcs
Cost to repair a part
- (89) Total Unit Cost to Reuse=
IF THEN ELSE(Reuse Stocks>0,Total Reuse Cost/Reuse Stocks,0)
Units: \$/pcs
Cost to reuse a part
- (90) Total Unit Cost to Scrap=
IF THEN ELSE(Scrap Stocks>0, Total Scrap Cost/Scrap Stocks, 0)
Units: \$/pcs
Cost to scrap a part
- (91) Transport Cost= Item Weight*Air Freight cost per kg
Units: \$/pcs
Cost of transport based on item weight
- (92) Transport time= 3

Units: week

Time taken to transport the make part for repair or reuse

Appendix D

APPENDIX D

Bill of material for A4318 with Costs and Price

Mat_Code	Description	Purchase Parts			Margin	Cum Margin
		Standard Cost	Purchase Cost	Ref Price		
A2263-40042	RUBBER FOOT-MISTY BLUE	0.11	0.11	1.00	0.89	0.89
A4125-84005	LBL, NAMEPLATE C200	0.31	0.31	1.55	1.24	2.13
A4200-00015	EISA BULKHEAD RETAINER	0.29	0.29	2.00	1.71	3.84
A4125-40002	I/O CARD GUIDE/FAN BRK	0.65	0.65	3.50	2.85	6.69
A4200-40062	POWER DIST BRKT	0.67	0.67	4.30	3.63	10.32
8120-1378	Pwr cord US 115v gr	8.50	8.50	13.00	4.50	14.82
A4200-40011	Fan Diffuser	1.45	1.45	6.00	4.55	19.37
A4200-62046	EISA BRACKET	0.93	0.93	6.00	5.07	24.44
A4200-61604	CABLE, FLOPPY	3.60	3.60	10.00	6.40	30.84
A4200-62054	FLOPPY BEZEL	1.71	1.71	9.00	7.29	38.13
A4200-00093	FLOPPY EMI PLATE	1.35	1.35	9.00	7.65	45.78
A4200-61607	CABLE, CD AUDIO	1.23	1.23	9.00	7.77	53.55
A4200-61606	CABLE, HUMAN INTERFACE	1.59	1.59	10.00	8.41	61.96
A4200-00092	CD ROM EMI PLATE	2.73	2.73	12.00	9.27	71.23
A4200-00094	DDS EMI PLATE	2.26	2.26	12.00	9.74	80.97
A4200-90041	SERV HANDBOOK C CLASS	4.04	4.04	16.00	11.96	92.93
8120-4753	Power cord Japan gry	2.46	2.46	16.00	13.54	106.47
A4200-90033	MDL C160/180/200/240/	6.17	6.17	22.00	15.83	122.30
8120-1351	Power cord UK grey	3.13	3.13	19.50	16.37	138.67
8120-1369	Power cord, Australia	5.38	5.38	22.50	17.12	155.79
A4200-90040	MNL,MDL C100/110 SRV HNDBK	7.35	7.35	26.00	18.65	174.44
SK5181-0779	CABLE-HPHIL 2.5M SPARE	7.45	7.45	29.00	21.55	195.99
A4200-90026	OWNERS GD FOR C160/180/	9.58	9.58	33.00	23.42	219.41
A1658-62147	PS2,3-BUTN MOUSE,PARCHMENT	7.43	7.43	31.00	23.57	242.98
A4200-40064	TOWER STAND-MISTY BLUE	6.38	6.38	30.00	23.62	266.60
1150-1980	MOUSE, PS2	7.25	7.25	34.00	26.75	293.35
A4200-62060	Disk Tray	6.76	6.76	35.00	28.24	321.59
A1658-62070	ULTRA W SE SCSI TERMNT	8.75	8.75	37.00	28.25	349.84
A4200-62021	I/O Tray	14.13	14.13	44.00	29.87	379.71
A4200-62030	Fan Assembly	5.63	5.63	37.00	31.37	411.08
C3757-60404	KEYBRD,Vectra PC Grey	15.57	15.57	50.00	34.43	445.51
C3757-60405	KEYBRD,Vectra PC Grey	15.57	15.57	50.00	34.43	479.94
C3757-60412	KEYBRD,Vectra PC Grey	15.57	15.57	50.00	34.43	514.37
C3757-60413	KEYBRD,Vectra PC Grey	15.57	15.57	50.00	34.43	548.80
C3757-60231	VERCOR, C3757A	17.90	17.90	55.00	37.10	585.90
C3757-60204	Keyboard, Vectra	15.57	15.57	56.00	40.43	626.33
C3757-60213	Keyboard, Vectra	15.57	15.57	56.00	40.43	666.76
A2840-60230	KEYBOARD, PS2	27.42	27.42	70.00	42.58	709.34
A2840-60231	KEYBOARD, PS2	27.42	27.42	77.00	49.58	758.92
46021-60414	KYBD,BELGIUM FLEMISH	58.89	58.89	110.00	51.11	810.03
46021-60417	KYBD,ITALY ITALIAN	58.89	58.89	110.00	51.11	861.14
46021-60411	KYBD,SWTZRLND GERMAN	58.52	58.52	110.00	51.48	912.62
A2840-60209	KEYBOARD, PS2	18.28	18.28	70.00	51.72	964.34

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A2840-60212	KEYBOARD, PS2	18.28	18.28	70.00	51.72	1016.06
A2840-60216	KEYBOARD, PS2	18.28	18.28	70.00	51.72	1067.78
A2840-60217	KEYBOARD, PS2	18.28	18.28	70.00	51.72	1119.50
46021-60406	KYBD,NETHERLANDS DUTCH	57.02	57.02	110.00	52.98	1172.48
A2840-60201	KEYBOARD, PS2	18.28	18.28	72.00	53.72	1226.20
C3757-60201	Keyboard, Vectra	14.93	14.93	70.00	55.07	1281.27
C3757-60401	KEYBRD,Vectra PC Grey	14.93	14.93	70.00	55.07	1336.34
1150-1922	MOUSE, HIL 3-BUTTON	18.65	18.65	75.00	56.35	1392.69
A2840-60203	KEYBOARD, PS2	18.28	18.28	77.00	58.72	1451.41
A2840-60205	KEYBOARD, PS2	18.28	18.28	77.00	58.72	1510.13
A2840-60211	KEYBOARD PS2	18.28	18.28	77.00	58.72	1568.85
46021-60409	KYBD,NORWAY NORWEGIAN	48.28	48.28	110.00	61.72	1630.57
46021-60410	KYBD,SWTZRLND FRENCH	48.28	48.28	110.00	61.72	1692.29
46021-60423	KYBD TAIWAN CHINESE	48.28	48.28	110.00	61.72	1754.01
46021-60501	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	1816.20
46021-60502	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	1878.39
46021-60504	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	1940.58
46021-60505	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2002.77
46021-60506	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2064.96
46021-60508	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2127.15
46021-60509	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2189.34
46021-60510	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2251.53
46021-60511	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2313.72
46021-60512	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2375.91
46021-60513	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2438.10
46021-60514	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2500.29
46021-60515	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2562.48
46021-60516	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2624.67
46021-60517	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2686.86
46021-60518	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2749.05
46021-60521	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2811.24
46021-60523	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2873.43
46021-60524	HP-HIL/HP-UX-KEYBOARD	37.81	37.81	100.00	62.19	2935.62
A4125-63001	ULTRA W SE INTNL CABLE	20.38	20.38	84.00	63.62	2999.24
46021-60402	KYBD,CANADIAN FRENCH	42.37	42.37	110.00	67.63	3066.87
46021-60503	HP-HIL/HP-UX-KEYBOARD	31.05	31.05	100.00	68.95	3135.82
46021-60421	KYBD KOREA KOREAN	40.37	40.37	110.00	69.63	3205.45
46020-60202	KYBD, (260 ONLY)	149.60	149.60	220.00	70.40	3275.85
46021-60415	KYBD FINLAND FINNISH	38.01	38.01	110.00	71.99	3347.84
46021-60416	KYBD DENMARK DANISH	38.01	38.01	110.00	71.99	3419.83
46021-60401	HP-HIL/HP-UX-KEYBOARD	32.19	32.19	105.00	72.81	3492.64
A2840-60204	KEYBOARD, PS2	18.28	18.28	92.00	73.72	3566.36
A2840-60213	KEYBOARD, PS2	18.28	18.28	92.00	73.72	3640.08
A1658-60014	4mb 3-MODE FLPY DRV MECH	29.03	29.03	105.00	75.97	3716.05
A4200-62023	Chassis	114.52	114.52	200.00	85.48	3801.53
46021-60412	KYBD,SWEDEN SWEDISH	32.19	32.19	120.00	87.81	3889.34
46021-60403	KYBD,GERMANY GERMAN	32.19	32.19	121.00	88.81	3978.15
46021-60404	KYBD,SPAIN SPANISH	32.19	32.19	121.00	88.81	4066.96
46021-60405	KYBD,FRANCE FRENCH	32.19	32.19	121.00	88.81	4155.77

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46021-60413	KYBD,UK ENGLISH	32.19	32.19	121.00	88.81	4244.58
46021-60418	KYBD,JAPAN JAPANESE	32.19	32.19	121.00	88.81	4333.39
46021-60424	KYBD,JAPAN JAPANESE KANJI	32.18	32.18	121.00	88.82	4422.21
46021-60408	KYBD,LTN AMER SPANISH	58.89	58.89	149.00	90.11	4512.32
A4200-66534	ASSY,PCA USER INTRFACE	35.04	35.04	134.00	98.96	4611.28
46021-60229	Keyboard, Taiwan	99.99	99.99	200.00	100.01	4711.29
46021-60529	HP-HIL/HP-UX KEYBOARD	45.00	45.00	150.00	105.00	4816.29
A4125-66505	ASSY BACKPLANE WO/EISA	412.68	412.68	525.00	112.32	4928.61
A1658-60019	12X CD-ROM DRIVE-FLINT	101.00	101.00	310.00	209.00	5137.61
A1658-60018	12X CD-ROM DRIVE-DOVE	101.00	101.00	323.00	222.00	5359.61
A4125-66531	ULTRA SE DISK TRAY PCA	55.90	55.90	286.00	230.10	5589.71
A4200-62059	CHASSIS-WHOLE	108.60	108.60	376.00	267.40	5857.11
A4125-66520	LEG BOARD-100/10BT	61.44	61.44	443.00	381.56	6238.67
A4125-66502	385W BACKPLANE W/EISA	583.32	583.32	1000.00	416.68	6655.35
A4125-66504	ASSY BACKPLANE W/EISA	550.27	550.27	1050.00	499.73	7155.08
5183-2400	KT,SPL PROV Nihon	151.02	151.02	713.00	561.98	7717.06
A3828-60001	32MB 50NS EDO MEMORY	180.94	180.94	900.00	719.06	8436.12
A4200-69501	PCI BKPLANE C160/180	314.42	447.93	1198.00	750.07	9186.19
A4125-60022	FW DIFF MAIN I/O PCA	419.32	419.32	1250.00	830.68	10016.87
A4125-60001	550W POWER SUPPLY ASSY	427.87	427.87	1313.00	885.13	10902.00
A4200-60022	I/O PCA ASSY	699.57	699.57	1650.00	950.43	11852.43
A4125-66501	550W BACKPLANE WO/EISA	320.05	320.05	1850.00	1529.95	13382.38
A4125-60021	SE WIDE MAIN I/O PCA	324.83	324.83	1881.00	1556.17	14938.55
A4125-66500	550W BACKPLANE W/EISA	412.07	412.07	2050.00	1637.93	16576.48
A3829-60001	64MB 50NS EDO MEMORY	344.45	344.45	2125.00	1780.55	18357.03
5183-3145	KT,SPL PROV Nihon	825.36	825.36	2707.00	1881.64	20238.67
A3830-60001	128MB 50NS EDO MEMORY	281.47	281.47	4875.00	4593.53	24832.20
A4553-66501	ASSY PCA WD48XL2	1380.44	1380.44	9000.00	7619.56	32451.76
A4125-60010	200MHZ PA8000 CPU ASSY	2269.50	2269.50	13000.00	10730.50	43182.26
5183-3169	KT,SPL PROV for OKI	4553.52	4553.52	23782.00	19228.48	62410.74
5183-2391	KT,SPL PROV Nihon	8402.99	8402.99	27899.69	19496.70	81907.44

Appendix D

Mat_Code	Description	Make parts			Margin	Cum Margin
		Standard Cost	Repair Cost	Ref Price		
C1537-69201	DDS-3 Drive for H.P.	303.05	176.40	315.00	138.60	138.60
C1539-69201	DDS-2 Drive for H.P.	244.90	92.06	241.00	148.94	287.54
A3828-69001	32MB 50NS EDO MEMORY	180.94	85.50	310.00	224.50	512.04
A4125-69101	550W POWER SUPPLY ASSY	427.87	100.00	420.00	320.00	832.04
A4125-69001	550W POWER SUPPLY ASSY	427.87	100.00	434.00	334.00	1166.04
A4125-69501	550W BACKPLANE WO/EISA	412.68	107.76	470.00	362.24	1528.28
A2874-69006	FAST/WIDE SCSI ADPTOR	192.60	33.95	401.00	367.05	1895.33
A4200-69511	PCI BKPLANE C160/180	314.42	50.41	430.00	379.59	2274.92
A1658-69020	2GB ULTRA WIDE SE DISK	296.00	250.00	675.00	425.00	2699.92
A4200-69005	SPARE,ASY P/S & DSTR BRD	346.62	127.00	571.00	444.00	3143.92
A4125-69201	550W POWER SUPPLY ASSY	427.87	100.00	550.00	450.00	3593.92
A1658-69021	4GB ULTRA WIDE SE DISK	306.00	265.00	725.00	460.00	4053.92
A4125-69021	SE WIDE MAIN I/O PCA	324.83	100.00	725.00	625.00	4678.92
A4125-69022	FW DIFF MAIN I/O PCA	419.32	100.00	725.00	625.00	5303.92
A4125-69500	550W BACKPLANE W/EISA	550.27	93.98	850.00	756.02	6059.94
A4200-69022	I/O PCA ASSY	699.57	92.03	865.00	772.97	6832.91
A1658-69022	9GM ULTRA WIDE SE DISK	616.00	400.00	1250.00	850.00	7682.91
A3829-69001	64MB 50NS EDO MEMORY	344.45	30.00	1099.00	1069.00	8751.91
A4125-69121	ULTRA SE I/O PCA	324.83	52.98	1554.00	1501.02	10252.93
A4553-69101	ASSY PCA WD48XL2	1380.44	75.00	2470.00	2395.00	12647.93
A3830-69001	128MB 50NS EDO MEMORY	281.47	50.00	2489.00	2439.00	15086.93
A4125-69010	200MHZ PA8000 CPU ASSY	2269.50	100.00	3066.00	2966.00	18052.93
A3398-69001	48XP BIG BOARD PCA	3550.46	91.59	3803.00	3711.41	21764.34

APPENDIX E

Serial Correlation Analysis

Estimated Autocorrelations for 1420_0314

Estimated Autocorrelations for A2335_69222_r

Estimated Autocorrelations for 1150_1922

Estimated Autocorrelations for C1536_69201_r

Estimated Autocorrelations for C2300_60005

Estimated Autocorrelations for A2084_69019_r

Estimated Autocorrelations for A2575_69001

Estimated Autocorrelations for 0957_0253

Estimated Autocorrelations for A2084_69511_r

Estimated Autocorrelations for A2084_69001_r

Estimated Autocorrelations for A2084_62004

Estimated Autocorrelations for C1429_60401

Estimated Autocorrelations for A2084_60010

Estimated Autocorrelations for 46021_60418

Estimated Autocorrelations for A4022_60006

Estimated Autocorrelations for 98236_69524_r

Estimated Autocorrelations for A1658_69023_r

Estimated Autocorrelations for 46020_60001

Estimated Autocorrelations for A2084_62014

Estimated Autocorrelations for 8120_1378

APPENDIX F

Trend Analysis

Trend-Cycle Component Plot for 0957_0253

Trend-Cycle Component Plot for 1150_1922

Trend-Cycle Component Plot for 1420_0314

Trend-Cycle Component Plot for 25567_69004_r

Trend-Cycle Component Plot for 46020_60001

Trend-Cycle Component Plot for 46021_60401

Trend-Cycle Component Plot for 46021_60418

Trend-Cycle Component Plot for 8120_1378

Trend-Cycle Component Plot for 98236_69524_r

Trend-Cycle Component Plot for A1658_69023_r

Trend-Cycle Component Plot for A2084_60010

Trend-Cycle Component Plot for A2084_60011

Trend-Cycle Component Plot for A2084_62004

Trend-Cycle Component Plot for A2084_62014

Trend-Cycle Component Plot for A2084_69001_r

Trend-Cycle Component Plot for A2084_69005_r

Trend-Cycle Component Plot for A2084_69012_r

Trend-Cycle Component Plot for A2084_69019_r

Trend-Cycle Component Plot for A2084_69510_r

Trend-Cycle Component Plot for A2084_69511_r

Trend-Cycle Component Plot for A4022_60006

Trend-Cycle Component Plot for C1536_69201_r

Trend-Cycle Component Plot for C2300_60005

GRAPHS GENERATED FROM THE DYNAMIC MODEL

Make part with average quality

Make part with poor quality

Buy part with superior quality

Buy part with average quality

Buy part with inferior quality

End of Thesis