A METHODOLOGY FOR EVALUATING THE PERFORMANCE OF REVERSE SUPPLY CHAINS IN CONSUMER ELECTRONICS INDUSTRY

by

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ABSTRACT

A METHODOLOGY FOR EVALUATING THE PERFORMANCE OF REVERSE SUPPLY CHAINS IN CONSUMER ELECTRONICS INDUSTRY

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Enterprises around the world are employing reverse supply chain practices to overcome the regulations and generate profit making opportunities. As a result of the rapid progress in technology the product lifecycles are shrinking faster than ever. In the face of global competition, heightened environmental regulations and a wealth of additional profits and improved corporate image opportunities, performing the reverse supply chain operations at a world class level is becoming quintessential. These factors in addition to the inherent complexity of reverse supply chains due to the uncertainties associated with the quantity, quality, and timing of returns make returns management all the more complicated. Existing literature on reverse supply chains focuses on how organizations are effectively using reverse logistics practices to sustain competition and how to optimize the overall reverse supply chain, but there is little investigation into how organizations are able to evaluate their reverse supply chain operations. This research spotlights on this particular problem from a consumer electronics industry perspective, as it poses the greatest challenges in handling returns due to the presence of high clock speed products and greater return volume and variability.

In this dissertation, a quantitative methodology called PEARL- Performance Evaluation Analytic for Reverse Logistics is developed to facilitate decision making from the perspective of an enterprise engaged in reverse logistics. It explores the various reverse logistics functions and product lifecycle stages. It also develops some key business strategies and performance metrics that can be employed to be successful in returns handling. The various relationships between these attributes are assessed using Analytical Network Process and Fuzzy Logic to generate an overall performance score called as the Reverse Logistics Overall Performance Index, indicating the organizations returns management process compared to best in class practices.

Deployment of the PEARL methodology in their organizations provides them with a real world assessment of what strategies, reverse logistics functions, product lifecycle stages, or key performance indicators impact the Reverse Logistics Overall Performance Index, thereby allowing them to continuously improve their returns management capabilities.

Key words: Reverse Supply Chains, Performance Measurement, Analytical Network Process, Fuzzy Theory, Performance Index

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CHAPTER 1

INTRODUCTION

1.1 Overview of Reverse Logistics

The logistics of products have always been from raw material to the end customer, but a rising number of products are returning back through the reverse supply chain. Reverse logistics (RL) has been spreading world wide, involving all the layers of the supply chain in various industry sectors, and has become a key source of competence in modern supply chains. Reverse Logistics is defined as "the process of planning, implementing, and controlling the efficient, cost effective flow of materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" (Rogers and Tibben-Lembke, 1998). Reverse logistics or reverse supply chains (used interchangeably) concentrate on those streams where there is some value to be recovered and deal with the management of products in the reverse way. It is the process of managing the flow of returned products and information from the point of consumption to the origin (Brito et. al, 2002).

The goods in the reverse flow can come from the end user or from another member of the distribution channel such as the retailer. The product can enter the reverse logistics flow from a customer due to inherent defects, a manufacturing recall, or if the product has reached its end of useful life. If a supply chain partner returns a product, it is because the firm has excess product due to an over-ordered marketing promotion, or because the product has failed to sell as well as desired, or damaged in transit. Fig 1.1 illustrates the why, what, how and who's of reverse logistics and product returns.

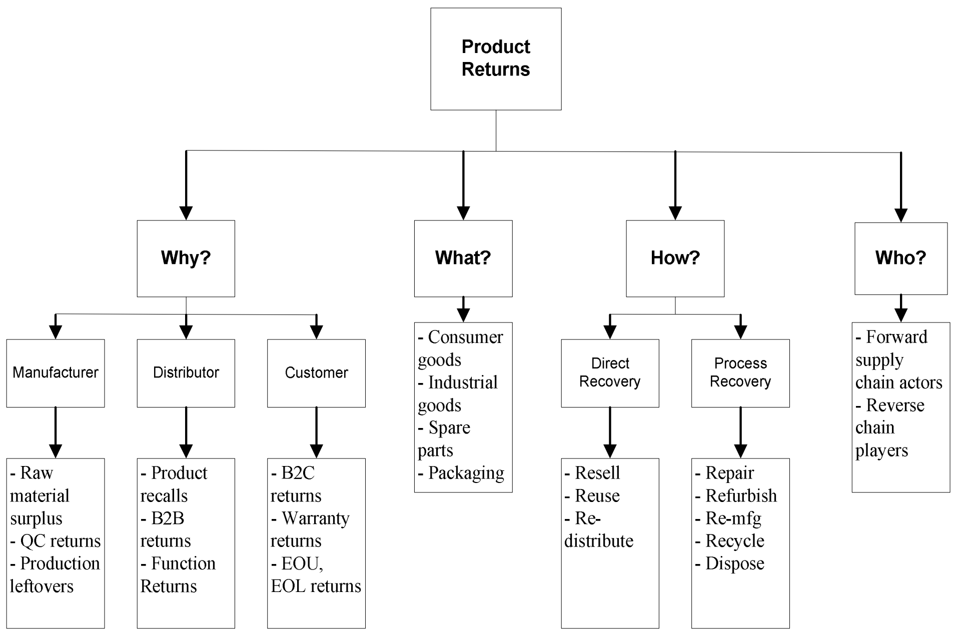


Fig 1.1 Classification of Product Returns
(Adapted from "A Framework for Reverse Logistics"; Brito and Dekker, 2003)

1.2 Problem Background

Returns can occur at any time during the product lifecycle (Ferguson et. al, 2005), and represent a growing financial concern for firms in the U.S and around the world. There are a number of reasons why products are returned from different players, within the supply chain. The importance of reverse logistics has increased in the recent years, as manufacturers and their distributors must now cope with an increased flow of returned products from their customers. Hewlett- Packard recently discovered that the total costs of consumer product returns for North America exceed 2% of the total outbound revenue (Reiss, 2003). In a survey conducted by Rogers and Tibben-Lembke in 1997, reverse logistics costs were as high as 4 per cent of total logistics costs, and amounted to approximately $35 billion. Stock et al. in 2002 estimated the total value of products returned by consumers in the U.S to be $100 billion annually. There are no world wide estimates of the economic scope of reuse activities, but the number of firms engaged in this sector is growing rapidly in response to the opportunities to create additional wealth, and in response to environmental legislations in several countries. The Reverse Logistics Executive Council (RLEC) estimates the cost of reverse logistics operations in the U.S to be between 0.5% and 1% of the total U.S GDP (RLEC, 2004).

The product returns are driven by the "consumer is king" attitude prevalent in U.S and supported by liberal product policies at most major retailers. The problems and costs of consumer product returns are projected to grow and many firms are just beginning to develop strategies and tactics to reduce the overall costs (Reiss, 2003). While in some cases companies are being forced to set up reverse supply chains because of environmental regulations or consumer pressures, in other cases companies are taking initiative, seeing opportunities to reduce their operating costs by reusing products (Guide and Wassenhove, 2003). Although the reverse supply chain of returned products represents a sizeable flow of potentially recoverable assets, only a relatively small fraction of the value is currently extracted by manufacturers; a large proportion of the product erodes away due to long and erroneous returns processing. There are significant opportunities to build competitive advantage from making the appropriate reverse supply chain design choices (Souza et. al, 2005).

Most returns processes in place today were developed for an earlier environment in which returns rates were low and the value of the asset stream was insignificant. While the cost efficient logistics processes designed earlier may be desirable for collection and disposal of products when return rates are low and profit margins are comfortable, this approach can actually limit a firm's profitability in today's business environment. This is typically the case of short life cycle, high return variability, and time sensitive products, where these losses can exceed 30% of the product value (Souza et. al, 2005). Consumer return rates range from 5-9% of sales for hard goods and up to 35 % for high fashion apparel (Toktay, 2003). Table 1.1 shows the return percentages for different industries. Return percentages vary widely by product category, by season and across global markets, and are typically much higher for internet and catalogue sales. Return rates are also rising in Europe rapidly due to new EU policies governing internet sales, and the entry of powerful U.S based resellers.

Table 1.1 Percentage of returns by industry
(Adapted from "Reverse Logistics"; Schatteman, 2003)

Industry	**Percentage**
Book Publishing	10-30%
Magazine publishing- special interest	50%
Computer manufacturers	10-20%
Apparel	35%
Mass merchandisers	4-15%
Auto Industry(parts)	4-6%
Internet retailers	20-80%
Direct to consumer computer manufacturers	2-5%
Consumer Electronics	4-5%
Household Chemicals	2-3%

Clearly, costs involved and the profit losses in the reverse logistics stream are a major concern on a global basis, but they are not the only problems. The “green logistics” aspect is gaining in importance with the growing environmental regulations being put in place. IAER research highlights that about 3 million consumer electronic units will be scrapped by 2010, and the total generation of consumer electronics waste in the U.S municipal waste stream is well over 2 million tones per year. Consumer electronics represents an average of 1.7% of the municipal waste stream currently (EPA, 2001). This is not good news if we look at the U.S sales trends. The consumer electronics association (CEA) reports that the total 2005 sales are due to increase 11% in 2005 to $126 billion (IAER, 2005), thereby increasing the volume of a product being returned. There is an enormous amount of e-waste to be generated in a few years: 4 billion pounds of plastic, 1 billion pounds of lead, 1.9 million pounds of cadmium, 1.2 million pounds of chromium, 400,000 lbs of mercury (Silicon Valley Toxics Coalition, 2002).

For many retailers that sell consumer electronics, the percentage of returns is high. These products being complex, the consumers do not understand how to operate them and are quick to return the product even if it’s not defective (Rogers and Tibben-Lembke, 1998). To tackle this mounting waste and returns problem, policy and business entrepreneurs are promoting product recovery as an environmentally and economically preferable alternative to disposal, and product recovery infrastructure and strategy has begun to develop in recent years (White, Rosen, & Beckman, 2003). Due to shortening of product life cycles for products like consumer electronics, the recovery of value from returns is becoming a necessity (Hillegersburg, Zuiwijk, van Nunen, & van Eijk, 2001). In an age of 60 day product life cycles and 90 day product warranties, and in a business where returns can lower profits by as much as 25%, reverse logistics is a serious business (Rogers and Tibben-Lembke, 1998).

In light of increasing profit making opportunities and larger cost cutting initiatives, coupled with changing customer attitudes and stricter legislation, return handling of electronic products has become a daunting challenge. Performance measurement and metrics have an important role to play in setting objectives, evaluating performance, and determining future courses of actions (Gunasekaran, et. al, 2004). Performance measurement and metrics pertaining to reverse supply chains have not received adequate attention from researchers or practitioners. Although a number of performance measures appropriate for traditional supply chains have been developed, these existing measures are inadequate for use in the closed loop environment. The existing measures are inadequate in capturing the dual extended supply chain objectives of economic efficiency and environmental protection (Beamon, 1999).

The scope of this research is delineated in Fig 1.2 which provides a schematic view of the activities involved in a typical forward and reverse supply chain in general. This research was limited to developing an integrated methodology for evaluation of reverse supply chain performance in consumer electronics industry. For developing the performance measurement methodology, it is assumed that the most profitable operation is selected, within the environmental considerations.

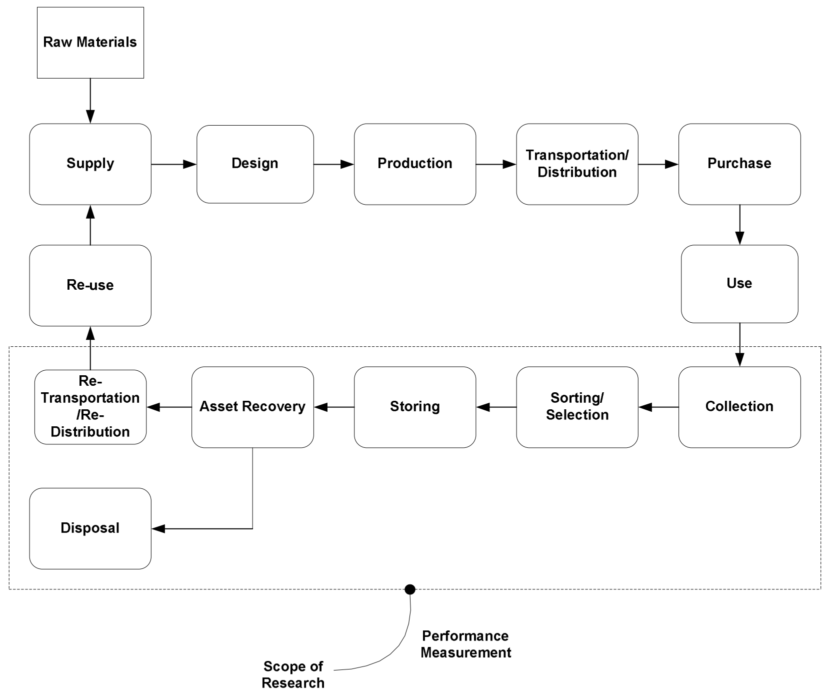


Fig 1.2 Research scope depicted in a closed loop supply chain

This research addresses the special reverse supply chain performance measurement problem faced by electronic companies. Typically supply chain performance is difficult to evaluate with multiple vendors, manufacturers, distributors and retailers. It is even more difficult in the consumer electronics industry with the changing variety of products and the high variability of returns. The methodology developed in this research takes all these factors into account and develops a composite reverse supply chain performance index to help organizations assess their returns management capability and thereby benchmark best practices, and improve their overall closed loop supply chain performance. The next section formally defines the problem that will be addressed in this dissertation.

1.3 Problem Definition

This section defines the problem that this research addresses. As discussed in the problem background, the complexities associated with handling reverse supply chain operations are multi-faceted due to uncertainties associated with the quality, quantity and the timing of returns. These coupled with the high environmental regulations are making companies struggle in handling their reverse logistics operations. However, there are a lot of profit making and corporate image development opportunities that cannot be neglected. With the increasing focus on environmentally sound products from the customers, the companies need to be adept at best practices in their operations. The legislations and the economic benefits of reverse logistics have forced organizations to take a new look at their operations. Due to intense competition and stringent environmental regulations, it is quite difficult to sustain successful business operations just by handling the forward supply chain effectively. Hence, it is imperative that companies begin to effectively manage their reverse supply chains also, thereby developing into a successful closed loop organization. No supply chain can be productive without a systematic process to manage material movement (Dowlatshahi, 2000).

Reverse supply chain is an integral component of supply chain management systems because of the cost and service dimensions associated with the process. Closely monitoring RL operations greatly enhance efficiencies within the entire company as well as the entire supply chain network (Stock, 1998). In any system, developing accurate and consistent performance measures is critical because it directly reflects on quality of the system and its effectiveness. The development of accurate and measurable performance metrics represents a major step in adopting a holistic approach to reverse supply chain management. Measures must be consistent with the specific needs of the firm and be capable of communicating to those within the organization what type of performance is desired (Griffis et al., 2004). There are innumerable methods and measures in the Forward Supply Chain (FSC) that helps design, plan, manage and control the various FSC activities. The returns management is a fairly new concept and very few measures have been developed thus far to evaluate the reverse supply chain performance. Griffis et al. (2004) have discussed about selecting performance measurement based upon goals and information reporting needs of an organization, but their work focused on the forward supply chain. Specifically, there is little research that deals exclusively with performance measures for an RL system.

This dissertation considers the specific problem from the perspective of a manufacturer of consumer electronic products that is required to handle product returns in today's changing environment. As the consumer electronics industry is more complex than other industries in terms of the uncertainty of product returns, this research will concentrate specifically on the consumer electronics industry namely the electronic products such as computers, printers, communication devices such as cell phones, etc (as depicted in fig 1.3).

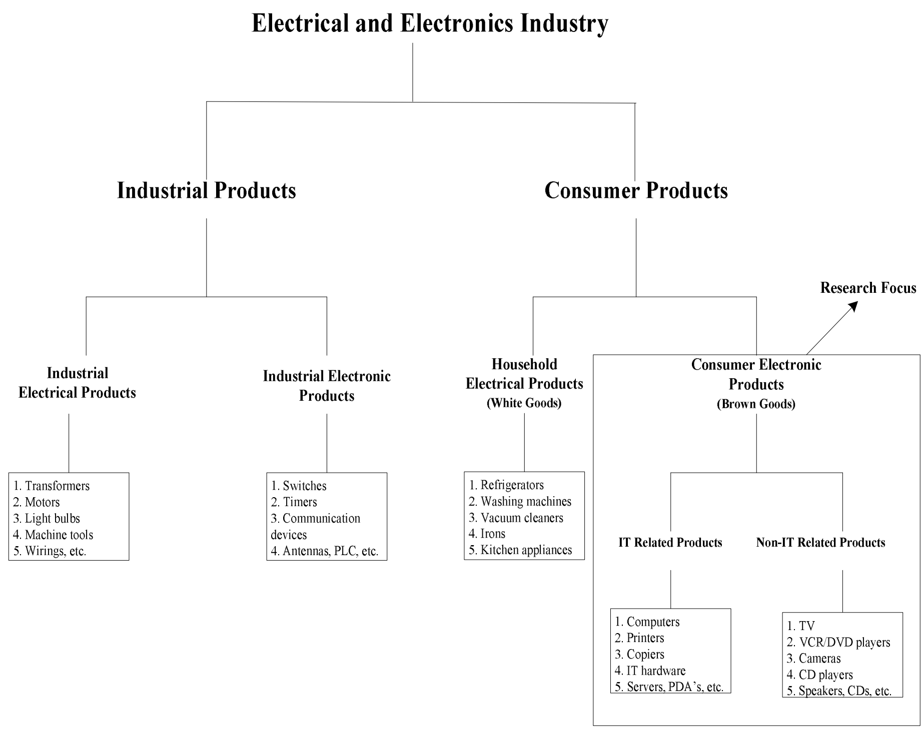


Fig 1.3 Electrical and Electronics Products Classification

Due to the rapid technological progress, these products have shorter life cycles and higher variability of returns than other consumer durable goods. The electronics reverse logistics systems may hold one of the most important promises due to the volume of product available to reuse, but at the same time, these types of reverse logistics networks represent some of the greatest challenges due to its complexity in time and variability in the rate of returns (Serrato, et. al, 2003). In addition to these difficulties, product acquisition is very difficult due to the global diffusion of products. Although, there has been extensive research in understanding the complexities of handling returns in the electronics industry, there seems to be a gap in developing effective performance measures for reverse supply chains. With the growing amount of electronic waste, the development of a reverse supply chain performance measurement methodology for the electronics industry is vital. This research investigates the performance measurement of the reverse supply chain and tries to address the "gap" in research, which renders the following questions unanswered:

1. For electronic products, what are the various strategies and performance measures for effectively conducting reverse supply chain activities?
2. How can the various attributes be quantified to indicate the overall capability of handling returns within the electronics industry?
3. How can a methodology be developed and implemented in the electronics industry to achieve the goals of maximizing revenue and environmental regulation conformance?

In summary the problem statement can be written as:

"***With growing market competition and increasing stringent environmental regulations, combined with the ever shortening product life cycles for electronic products, how can reverse supply chain performance be measured to improve returns handling capability and maximize profits?***"

1.4 Problem Justification

Electronics is the basic technology for many new products in the industry. Due to the increasing product variety and shorter life cycles, many electronic products end up in disposal sites. The development in the electronics sector is geared towards growing miniaturization, more complex and compact products, all of which stand in the way of economical and ecological recycling (Muller et. al, 1997). Electronics industries have started to realize that RSC can be used to gain competitive advantage (Marien, 1998). Effective performance management is an important aspect of the RSC initiative, and is the key to recognizing the benefits of efficient supply chain management systems. A performance evaluation framework for decision making provides a basis to evaluate alternatives and introduce measures. The electronics industry is now recognizing that management of RSC enhances the competitive edge of all players therein (Berry et. al, 1994).

The returns management process in the consumer electronics industry is an arduous task. It differs from other industries, as it is prone to the shortest lifecycle and highest return variability products as shown in figure 1.4. Moreover, unlike forward logistics, RL operations are inherently complex and prone to a high degree of uncertainty (Kokkinaki et al., 2001), affecting collection rates, the availability of recycled production inputs, and capacities in the reverse channel. Differences include the supply chain composition and structure, additional government constraints, rapid timing and uncertainty in the environment (Daugherty et al., 2002). Thus, U.S electronics manufacturers and other players in the reverse supply chain need to know what strategies to incorporate and how to structure their reverse logistics systems. One of the major bottlenecks in RL systems is the lack of accurate data, which complicates the management of RSC systems (Nagal & Meyer, 1999). Data on product returns is often non existent or of poor quality making it rather than the technology the limiting factors for coordinating RL supply chains (Brito et al., 2002). Efficient RL programs that take these factors into consideration can proactively minimize the threat of government regulation and can improve the corporate image of the companies (Carter & Ellram, 1998).

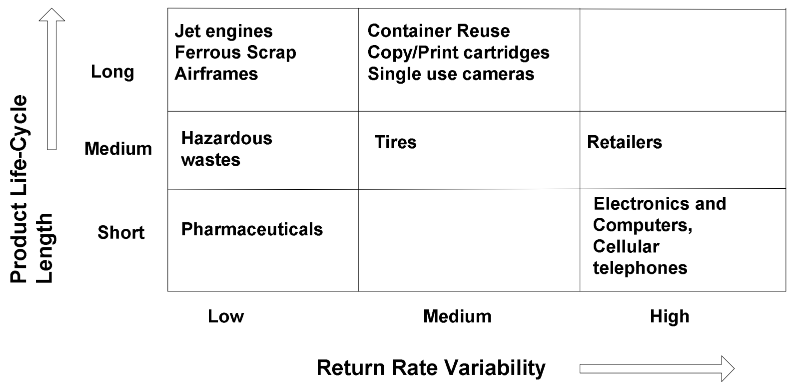


Fig 1.4 Lifecycle- Variability Matrix for different industries
(Adapted from "Characterization of RL networks for outsourcing decisions; Serrato et. al., 2003)

According to the consumer electronics industry survey by the RLEC, the average return rate is 8.46%. Returns have become endemic in electronics industry with rates as high as 20% in some sectors. As depicted in table 1.2, in 2004, the value of returned consumer electronics goods was $104 billion, with the cost of managing their return running about $8 billion. This high rate of return is only going to rise, with an increase in low cost, but low contact distribution channels like the web, customer uncertainty that emerges from a dramatic expansion if product choices; and shorter product life cycles. Therefore a significant impact on the corporate bottom line is inevitable (Thrikutam and Kumar, 2004).

Table 1.2 Value of returned goods in the electronics industry
(Adapted from "Turning returns management into a competitive advantage in hi-tech manufacturing"; Thrikutam and Kumar, 2004)

Product Category	**Indicative return rate**	**Sales- 2004 (US $ Billion)**	**Value of returned goods (US $ Billion)**
Computers	15 %	281.6	42.2
Office equipment	6 %	57.7	3.5
Household equipments	10 %	24.5	2.5
Semiconductor chips	15 %	216.9	32.5
CDs	20 %	30.7	6.1
Cameras	4 %	6.2	0.2
Software	20 %	85.1	17
Total		***702.7***	***104***

It is imperative that measures must be selected for situations where they are appropriate. This is particularly true in changing times as boundaries among the firm's various functional areas dissolve, and effective supply chain management requires evolving responsibilities and accountabilities. The legislation and the economic benefits of reverse logistics have forced organizations to take a new look at their RL operations. The reasons for this are multi-fold. First, the presence of good performance measures represents a major step in adopting a holistic approach to reverse supply chain management. Secondly, the organization cannot control its RL processes efficiently and effectively without having proper metrics. Thirdly, reverse logistics directly affects corporate image because it can be one of the significant competitive differentiators (Stock, 1998). If a company wants to be adept at reverse logistics, a performance evaluation methodology that guides them in improving its corporate image must be given high priority. Developing a comprehensive and cost effective approach to handling returns is a daunting challenge that reaches well beyond the operational level.

It is also a source of customer retention and competitive differentiation. Thus a well honed returns performance measurement methodology in place can be a vital strategic asset.

1.5 Dissertation Objective

The research objective of this dissertation was:

"To develop a quantitative methodology for evaluating the reverse supply chain performance in the consumer electronics industry, to maximize revenue within given technical and environmental constraints"

Given the complexity of reverse supply chains, it is imperative to develop a system of performance measures. This methodology uses a composite reverse logistics overall performance index (RLOPI) to benchmark organizational performance across industry. The methodology develops key performance metrics, a reverse logistics network highlighting the major functions, and reverse logistics enabling strategies based on the product lifecycle stages to achieve the desired reverse logistics capabilities. The methodology includes implementation techniques that can be used in industry. The development of performance measures and the performance index is based on prior research in the area of reverse logistics.

The methodology developed can be used in real world to aid organizations assess their reverse supply chain performance across best in class standards. This was accomplished by demonstrating the validation of the reverse logistics performance measurement methodology in case studies of consumer electronic companies. Knowledge and data gathered from these case studies was used to refine the methodology. This research resulted in the development of an integrated methodology for measuring the reverse supply chain and is expected to provide valuable insights to managers in revenue generation and environmental conformance in the electronics industry. The next section briefly discusses the organization of the dissertation.

1.6 Organization of the Dissertation

Chapter 1 of this dissertation identifies the need for this research. Reverse supply chain management is relatively new compared to its forward counterpart, and hence the lack of quantitative performance evaluation techniques in reverse supply chains is addressed. The problem is defined and the dissertation objective is stated.

Chapter 2 reviews the essential literature published so far to show that the problem gap this research intends to fill has not been addressed. It presents a literature review covering the various aspects of this problem. It summarizes current literature in topics such as reverse supply chains in consumer electronics, particularity of reverse logistics, Analytical Hierarchy Process, and Fuzzy Theory.

Chapter 3 restates the research objectives and outlines the research methodology and its associated dissertation work plan. Chapter 4 defines the steps of the proposed PEARL methodology and elaborates the development of various attributes that make up the Reverse Logistics Overall Performance Index (RLOPI), such as the business strategies, RL functions, product lifecycle stages, and key performance indicators. Finally the formulations to calculate the RLOPI are presented.

Chapter 5 discusses the demonstration and validation of the PEARL methodology on actual companies. Two companies were selected based on their successful returns management and handling capabilities. Some of the modifications and refinements to the proposed methodology are explained and the final revised PEARL methodology is presented. The RLOPI of the two companies is calculated based on the information obtained from the interview process to validate the methodology. The results of the case study demonstrations are discussed, and some benchmarking and process improvement techniques are proposed.

Chapter 6 summarizes and presents the conclusion and contributions of this dissertation. Significant directions for future research are also discussed.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the background of the literature reviewed in order to acquaint the reader with the areas related to the research

2.1 Literature on Reverse Logistics

The phenomenon of reverse logistics is ancient, and it will not wither away either in the future. In the last few years, accompanied with the intensification of logistics, more and more enterprises have started to realize the importance of reverse logistics management. The concept of reverse logistics is gaining significant attention from within the realms of academia and industry. Return flows, which consist of products at the end of their economic cycle, or that have become obsolete in the forward supply chain are gaining importance. The logistics of return flows, called reverse logistics, aims at executing product recovery efficiently. If no goods or materials are being sent backward, the activity probably is not a reverse logistics activity. There are a number of definitions of reverse logistics in literature and Table 2.1 shows a brief summary of the various elements considered in these definitions. Successful reverse logistics requires optimal take back and collection strategies, as well as recovery processes. If forward logistics is all about getting the right product in the right place, reverse logistics is all about making the right decision in the right place.

Table 2.1 Summary of reverse logistics definitions in literature

What is ?	Inputs	Activities	Outputs	From	To
- Process - Task - Skills and Activities	- Discarded products - Used products - Products or parts previously shipped - Information - Raw materials - In process inventory - Finished goods - Packages	- Collection - Transportation - Storage - Processing - Recovering - Packaging - Shipping - Reducing - Managing - Disposing	- Products again reusable - Re-cycling - Re-mfg - Disposal - Recapturing value	- Point of use	- Manufacturer - Central Collection Point - Point of origin

Reverse logistics stands for all the operations related to the reuse of used products, excess inventory of products and materials. The typical reverse logistics operations include the activities a firm, which uses returned merchandise due to product recalls, excess inventory, salvage, unwanted or outdated products, etc. In addition, it includes the recycling programs, hazardous material programs, and disposition of obsolete equipment and asset recovery. The various functions executed throughout the reverse logistics activities include gate-keeping, compacting disposition cycle times, remanufacturing and refurbishment, asset recovery, negotiation, outsourcing, finance management and customer service. Thus, the reverse logistics focuses on managing flows of material, information, and relationships for value addition as well as for the proper disposal of products. Competition and marketing motives, direct economic motives and concerns with the environment are some of the important factors for organizations to undertake reverse logistics. The implementation of reverse logistics practices may be a risky endeavor for the top management as it involves financial and operational aspects, which determine the performance of the company in the long run. A typical closed loop supply chain is depicted in Figure 2.1 below.

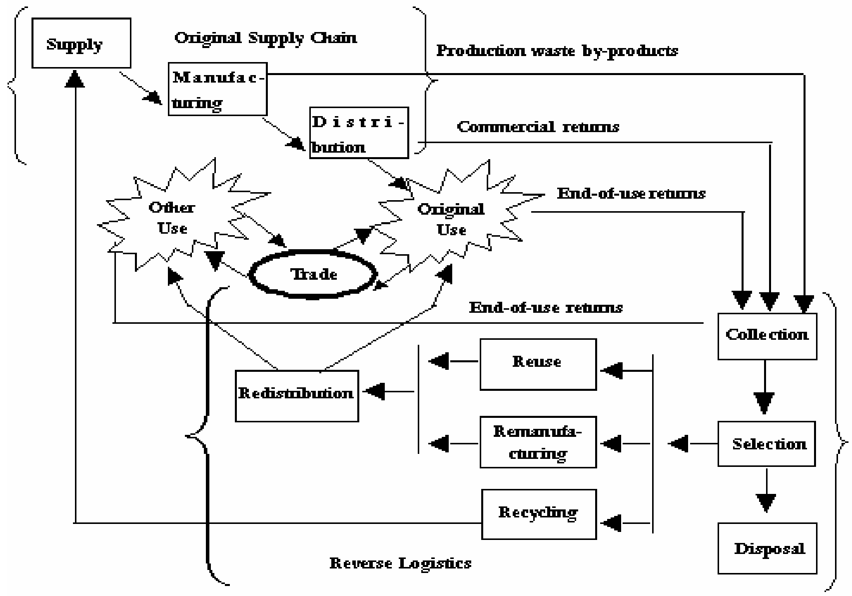


Fig 2.1 A Closed-Loop Supply Chain (forward and reverse)
(Adapted from E-trash to E-treasure; Kokkinaki et. al, 2001)

Once a product has been returned to a company, the firm has many options to choose such as 1) Return to Supplier 2) Resell 3) Sell via Outlet 4) Salvage 5) Recondition 6) Refurbish 7) Remanufacture 8) Reclaim Materials 9) Recycle 10) Landfill. There are several actors in reverse supply chain such as, supplier, manufacturer, and retailer (forward supply chain actors) and jobbers, recycling specialists (reverse chain players). There can be two types of recovery options: direct recovery and process recovery. In direct recovery, the products are in as good as new condition and so one can directly re-use, re-sale, and proceed to re-distribution. The second group is process recovery which involves elaborate reprocessing. On product characteristics, Brito and Dekker (2003) qualified the product characteristics that affect reverse logistics as 1) composition of the product 2) the deterioration process; and 3) the use-pattern. On product types Fleischmann et al (1997) classified the following types 1) civil objects 2) consumer goods 3) industrial goods 4) ores, oils and chemicals 5) packaging and distribution items 6) spare parts; and 7) other materials (like pulp, glass, and scraps).

Reverse logistics has been used in many industries like photocopiers (Krikke, van Harten, & Schuur, 1999; van der Laan, Dekker, & Van Wassenhove, 1999) single-use cameras (Toktay, Wein, & Stefanos, 2000), jet engine components (Guide & Srivastava, 1998), cellular telephones (Jayaraman, Guide, &Srivastava, 1999), and refillable containers (Kelle & Silver,1989). The computer hardware industry has already begun to embrace reverse logistics by taking steps to streamline the way they deploy old systems; and in the process make it easier for the customers to refurbish existing computers or buy new parts (Ferguson, 2000). Grenchus, Johnson, and McDonnell (2001) reported that the Global Asset Recovery Services (GARS) organization of IBM's Global Financing division has integrated some of the key components of its reverse logistics network to support and enhance environmental performance. Degher (2002) has done extensive research on Hewlett-Packard's recycling programs and implemented standard procedures for implementation of reverse supply chain practices. Gungor and Gupta (1999) have presented the development of research in environmentally conscious manufacturing and product recovery. Moyer and Gupta (1997) have conducted a comprehensive survey of previous works related to environmentally conscious manufacturing practices. Veerakamolmal and Gupta (1997) have discussed a technique for analyzing the design efficiency of electronic products, in order to study the effect of end-of-life (EOL) disassembly and disposal on environment. Boon et al. (2002) have investigated the critical factors influencing the profitability of end-of-life processing of PCs. They also suggested suitable policies for both PC manufacturers and legislators to ensure that there is a viable PC recycling infrastructure. Ferguson and Browne (2001) discussed the issues in end-of-life product recovery and reverse logistics. Ravi et al. (2005) developed an analytical network process model to address the problem of conducting RL operations to EOL computers. Knemeyer et al. (2002) utilized a qualitative methodology to examine the feasibility of designing a reverse logistics system to recycle or refurbish EOL computers that are deemed no longer useful by their owners. Environmental innovation is one of the key aspects of product and process development. Faced with the requirement to take back what they make, companies are redesigning process and rethinking products (Cairncross, 1992). In Taiwan, for example, proper disposition of computers and electronic equipment is mandatory because of the scarcity of the landfill space and the hazardous materials contained in these products (Shih, 2001). More companies are now taking Extended Producer Responsibility (EPR) or using third party de-manufacturing as the solution (Spicer & Johnson, 2004). Electronic equipment collection, remanufacturing and distribution were assessed by Jayaraman et al. (1999). Fleischmann et al. (2000) devised a framework of three typical RL networks structures and presented a continuous optimization model for RL network design.

The incorporation of return flows is easier said than done, as the behavior of consumers introduces uncertainties in the quality, quantity, and timing of product returns. Stock (1992) and Murphy (1986) both recognized the field of reverse logistics as being relevant for business and society in general. Dowlatshahi (2000) argues that from design through manufacture to consumer, firms should explore and integrate reverse logistics as a viable business option in the product life cycle. Computers seem to be the most disposed item of all the products. It has been estimated that over 12 million computers are disposed every year. Out of these only about 10% are remanufactured or recycled (Platt & Hyde, 1997). With the obsolescence rates and the sales on the rise (Blumberg, 1999) an important question that remains to be answered is how and what can be done to these EOL electronic products both from an economical and environmental point of view. Clearly from the above mentioned strategic issues, complying with rapidly changing regulations and fulfilling fast moving customer demands may require a fundamental change in doing business. Pro-active companies that incorporate RSC practices could use discarded products as a valuable source of components and materials, and develop an effective product recovery management policy (Thierry et. al, 1995).

Commercial returns represent a lost margin compared to End-Of-Life (EOL) returns which have already been sold for profit and now have the potential of generating additional benefits. Some of the most returns in commercial world are seen in catalog sales where an average rate of 12% is standard. Commercial returns impose high costs on retailers and manufacturers alike, and like EOL returns, an important lever in managing commercial returns is to accurately predict the return quantities for both tactical and operational level decisions (Brito M.P and Van der laan E.A., 2003). An important consideration in extracting value from returns is to actively manage their quantity and timing, and to increase the visibility and speed of the return process to maximize asset recovery. For items that depreciate rapidly, getting the used products back quickly for reprocessing is very valuable.

2.2 Particularity of Reverse Logistics

Reverse logistics has different traits compared to forward logistics. The origin and destination points are nearly opposite. Forward flows originate from one point (or a few) and is dispersed to many destinations; reverse flow originates from many points and is consolidated at just a few (or one) destination. Reverse logistics is not as routinized as forward logistics (Rogers, et. al., 2004). Another factor to consider when differentiating between forward and reverse logistics is the quantity, quality and timing of the product flow. Forward logistics can be planned and controlled by people, and products flow out basically according to a specific quantity, quality, and timing from one certain point to another. Reverse logistics, on the other hand is highly unpredictable, and organizations find it difficult to control and plan it. The management of reverse logistics is often ignored, and fails to get enough attention from organizations worldwide. The return units have different characteristics from those in forward logistics. They do not arrive in bulk on pallets and are often single units in non-standard packaging. The product handling in forward logistics is more standardized, while the processing methods and systems of reverse logistics are complicated. General information systems of logistics management are not capable of handling and managing reverse logistics. The costs of reverse logistics are dissimilar to that of forward logistics.

In the forward channel, costs are well defined, and accounting systems are designed to determine these costs. Products moving backwards are often measured inexactly and those costs are spread over several different budgets. Cost differences of reverse logistics from forward logistics are numerous. The most significant difference in costs tends to be related to transportation. No organization wants to ship a defective product a thousand miles before throwing it away, and care has to be taken while introducing a product in the returns stream (Rogers et. al., 2004). The handling costs, sorting and quality diagnosis costs, collection costs are also higher compared to forward logistics. Some of the other differences between forward and reverse logistics are shown in Table 2.2.

Table 2.2 Differences between forward and reverse logistics
(Adapted from Reverse Logistics Challenges" Rogers et. al., 2004)

Forward	**Reverse**
Forecasting relatively straightforward	Forecasting more difficult
One to many distribution points	Many to one distribution points
Product quality uniform	Product quality not uniform
Destination/routing clear	Destination/routing unclear
Disposition options clear	Disposition options unclear
Distribution costs easily visible	Reverse costs less directly visible
Inventory management consistent	Inventory management not consistent
Product lifecycle manageable	Product lifecycle issues more complex
Visibility of processes more transparent	Visibility of processes less transparent
Negotiation between parties straightforward	Negotiations complicated by additional considerations
Product packaging uniform	Product packaging often damaged

Reverse supply chains differ from forward supply chains in information flow, physical distribution flow and cash flow. To manage reverse supply chain, companies need sophisticated information systems. In the reverse supply chain, inbound logistics consists of defective units and other returns from customers. Inbound logistics follow sporadic or random routing. On the other hand, outbound logistics consists of repaired and remanufactured products; recycle items; or products meant for disposition. Outbound logistics follow both fixed and random routings. In forward supply chain, inbound logistics consists of flow of parts to a factory from the suppliers, which are consolidated, high-volume in nature and follows fixed routing. Outbound logistics in the forward supply chain consists of finished product from the factory to the customers, which is a single unit shipment and follows random routing. Cash flows in reverse supply chain are in terms of credits and discounts. With lack of good information systems, the randomness in reverse logistics leads to difficult situations in negotiations.

The differences in the activities and the costs involved with them between forward and reverse logistics are due to the inherent complexities that reverse logistics possesses. It is difficult to predict the quality, quantity, place, and timing of returns. These complexities result in increasing difficulties of managing the reverse logistics. Zheng et. al., (2005) suggest that if enterprise are driven by short term economic benefits, they will unavoidably restrict the development of reverse logistics to a certain extent. They argue that the management of RL should focus on the long run effect to guarantee effective operation of the reverse supply chain system.

2.3 Motivation for Reverse Logistics in Electronics Industry

Economic benefits, legislation, corporate citizenship (de Brito & Dekker, 2003) and customer service initiatives (Rogers & Tibben-Lembke, 1998) are the four main drivers or determinants of reverse logistics taken into account in this research. It is important to understand the determinants of a closed economy and reverse logistics before proactively addressing the returns management challenges. As shown in figure 2.2, legislation and customer service initiatives represent the conventional operational drivers, whereas business strategy and economic benefits have major bottom line benefits and can transform returns management to a strategic asset. These four perspectives are briefly described below.

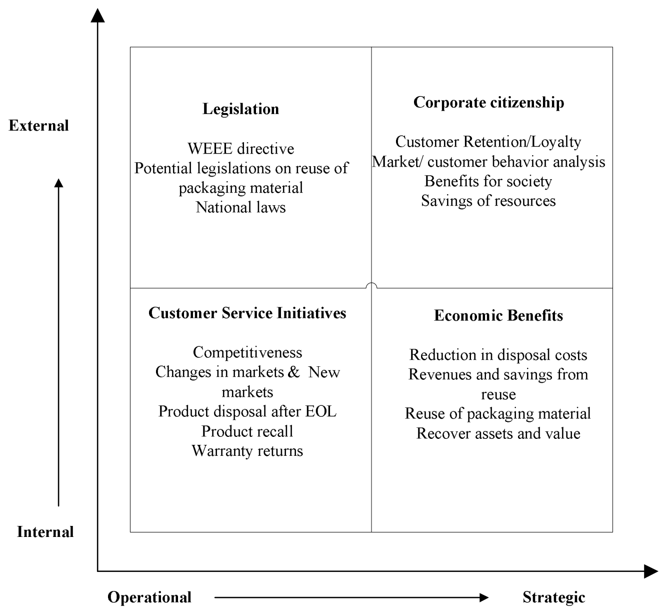


Fig 2.2 Drivers of Reverse Logistics in Electronics Industry

Economics is seen as the driving force to reverse logistics relating to all the recovery options, where the company receives both direct as well as indirect economic benefits. It is seen that companies continually strive for achieving cost savings in their production processes. If a firm does reverse logistics well, it will make money (Stock, 1998). The economic drivers of reverse logistics lead to direct gains in input materials, cost reduction, value added recovery and also in indirect gains by impeding legislation, market protection by companies, green image for companies and for improvement in customer/supplier relations. The recovery of the products for remanufacturing, repair, reconfiguration, and recycling can lead to profitable business opportunities (Andel, 1997). Reverse logistics is now perceived by the organizations as an 'investment recovery' as opposed to simply minimizing the cost of waste management (Saccomano, 1997). A reverse logistics program can bring cost benefits to the companies by emphasizing on resource reduction, adding value from the recovery of products or from reducing the disposal costs.

Another driver for the reverse logistics is the corporate citizenship, which concerns a set of values or principles that impels a company or an organization to become responsibly engaged with reverse logistics activities. Reverse logistics activities can lead to increase of corporate image (Carter & Ellram, 1998). Nike, the shoe manufacturer encourages consumers to bring their used shoes to the store where they had purchased them after their usage. They ship these back to Nike plant where these are shredded and made into basketball courts and running tracks. Nike also donates the material to the basketball courts and donates fund for building and maintaining these courts, thus enhancing the value of brand (Rogers & Tibben-Lembke, 1998).

Legislation refers to any jurisdiction that makes it mandatory for the companies to recover its products or accept these back after the end-of-life of the product. These may include collection and reuse of products at the end of the product life cycle, shift waste management costs to producers, reduce volume of waste generated, and the use of increased recycled materials (Ravi et. al, 2005). There has also been a restriction on the use of hazardous substances in the production processes, which facilitates the dismantling, and recycling of waste electronics. A reverse logistics decision for the EOL computers should ensure that the end-of-life products are retired in a way that is compliant with existing legislation. Good reverse logistics lead to benefits of environment (Byrne & Deeb, 1993).

Reverse logistics has led to competitive advantage to companies which proactively incorporate environmental goals into their business practices and strategic plans (Newman & Hanna, 1996). Managers are giving increasing importance to the environmental issues (McIntyre et. al., 1998). The environmental management has gained increasing interest in the field of supply chain management. Murphy et. al. (1995) have found that 60% in a group of 133 managers surveyed considered the issue of the environment to be a very important factor and 82% of them expected that the importance would increase in the years to come. A 'green' image of producing environmentally friendly products has become an important marketing element, which has stimulated a number of companies to explore options for take-back and recovery of their products (Thierry, 1997).

2.4 Reverse Supply Chain Performance Measurement

Reverse Logistics being a relatively new concept demands some kind of performance measurement tool. Logistics role in organizational strategy has been a topic of interest in the logistics literature since 1970s. During the 1980s this interest increased and became relevant to a broad spectrum of logistics issues (McGinnis & Kohn, 2002). Reverse logistics practices are fairly new in the academia and industry, and hence little work has been done in developing a tool to measure its performance.

There has been a lot of research into balance scorecard and the performance measurement of a forward supply chain, but there seems to be a gap in literature as to what are the strategies and performance measures that need to be developed for an effective reverse supply chains are and how to measure them. Specifically for electronics industry, where a number of factors lead to a complex reverse logistics scenario, the bridging of this gap is of utmost importance. The electronics industry is now slowly recognizing that management of reverse supply chains enhances the competitive edge of all players therein (Berry et. al, 1994). RL being a relatively new concept demands some kind of performance measurement methodology. In this section, the desirable structure of a performance measurement system, the use of strategic performance measurement tools such as balanced scorecard to reverse logistics, and the multi-criteria decision making process tools such as Analytical Network Process are discussed. This and the following sections make the reader understand how a performance measurement methodology needs to be developed. In addition, the process of developing measures linked to strategies and processes of reverse logistics, and the decision making process by quantifying the performance of the organizations to benchmark against industry best standards are also discussed.

2.4.1. Desirable structure of performance measurement systems

Effective performance management is an important aspect of reverse logistics initiative, and is the key to recognize the benefits and achieve efficient supply chain management systems. Performance measurement drives actions in two aspects. First monitored measures get high visibility with an organization, and people strive to achieve high performance with respect to these measures. Second, metrics drive organizational actions by identifying areas of improvement (Andersen, 2002). The essence of management is that one cannot manage that which one cannot measure (Sink and Tuttle, 1989). Some of the desirable attributes of performance management methodologies suggested by Adams (1999) that are relevant to this dissertation are:

1. Performance metrics should be linked to strategy
2. Performance metrics should be developed for activities and business processes
3. Performance metrics should be dynamic, keeping pace with changes in strategies, processes, and the competitive environment
4. Performance metrics should be developed in an inclusive, team based manner with the participation of those who perform the activities to be measured.

Measures provide a basis to evaluate alternatives and identify decision criteria. There is broad support in literature for the thought that the performance measurement should be viewed as a tool for deploying strategy through out the organization (Govindarajan and Shank, 1992; Hendricks, 1994). The performance metrics used for control and improvement of business processes should be derived from strategy (Kaplan and Norton, 1992). The degree to which the measures are aligned with strategy is a critical factor in determining the success of the business (Brown, 1991). Unfortunately, the development of strategically aligned metrics is a complex and difficult task (Eccles and Pyburn, 1992; Fisher, 1992). Actions taken by managers and operators to control and improve business processes and activities should be guided by performance metrics that are congruent with strategy (Dixon et al., 1991). The structure of formal or informal measurement systems drives decisions at the strategic, tactical and operational level (Gunasekaran et. al., 2001). Therefore performance management systems should not be cost and short term oriented (Kaplan and Norton, 1992). A balanced performance measurement methodology drives decisions that target optimizing the performance across multiple objectives. Moreover, a feedback control is an integral part of any performance measurement methodology. An effective performance measurement system allows proper monitoring of business process. The feedback is used to compare actual progress to planned values, facilitate benchmarking against industry best practices, and identify poor performance or improvement opportunities (Chan and Qi, 2003). A good performance measurement feedback loop should elicit actions that lead to strategic improvement.

Performance metrics should be developed for activities and business processes which define the organization. Metrics that are linked to strategy to activities promote operational improvements which can increased market share and profitability (Wisner and Fawcett, 1991). Effective performance measurement systems should be dynamic to ensure continued alignment of performance metrics with strategies and processes (Vokura and Fliedner, 1995). Businesses should discard old metrics as they lose relevance, and metrics should be continuously evaluated in response to changes in business processes, strategies, technologies, markets and the external environment (Vollmann, 1989). Development of metrics for business processes should involve people at all levels of the organization. The nominal group technique suggested by Wisner and Fawcett (1991) is a tool specifically designed for developing strategic performance metrics for business processes and activities. It does not include any specific methodology to ensure linkage of metrics to strategy for modeling the activities of the organization. There are a number of tools that address the issue of strategic performance measurement and one such tool is the balanced scorecard developed by Kaplan and Norton (1992).

2.4.2 Strategic performance measurement framework

An evaluation framework for decision making provides a basis to evaluate alternatives and introduce measures. One of the prime issues in this context is the assessment of various strategies for delivering objectives and developing measures, and how the organization should prioritize the determinants and the initiatives that impact them (Wheelwright, 1978). The balance scorecard has been recognized for some time now, as a leading tool for performance measurement in both research and industry. It was first described by Kaplan and Norton (1992), although around the same time, a number of other authors, for instance Maskell (1991), Eccles and Pyburn (1992), were expressing similar ideas. It helps align the measures with the strategies (Kaplan and Norton, 2000). The four perspectives in the balanced scorecard help managers the translate strategies into specific measures that can monitor the overall impact of the strategy on the enterprise (Ahmed and Abdalla, 2002). The BSC approach provides a comprehensive picture of the enterprise performance at a glance. It provides insight into whether an improvement is based on actual process improvement or by reducing the performance of other processes (Kaplan and Norton, 1992). The popular use of the BSC approach was extended to forward SCM by both researchers and practitioners (Kleijnen and Smits, 2003). Customizing the BSC to be applied to SCM includes one or more of the following activities: 1) Refining the four perspectives to fit within the SCM context (Brewer and Speh, 2000), (Bond, 1999) and 2) Introducing analytical tools to allow calculating a single measure or index that represents the overall supply chain performance (Chou and Liang, 2001), (Yurdakul, 2003) and 3) the implementation of the BSC framework form both an IT and business process prospective (Lohman et. al, 2003). Brewer and Speh (2000) mapped Kaplan's balanced scorecard dimensions into SCM specific measures. They replaced the Business Process perspective with SCM goals (e.g. waste reduction, flexible response), and the innovation and perspective with SCM process improvement (product/ process innovation, partnership management, information flows).

The balanced scorecard allows managers to look at the business from four divergent important perspectives: customer, internal business, innovation and learning, and finance (Kaplan & Norton, 1992). It is imperative that measures must be selected for situations where they are appropriate. This is particularly true in changing times as boundaries among the firm's various functional areas dissolve, and effective supply chain management requires evolving responsibilities and accountabilities. Measures must be consistent with the specific needs of the firm and be capable of communicating to those within the organization what type of performance is desired (Griffis, Cooper, Goldsby and Closs, 2004).There are innumerable methods and measures in the Forward

Supply Chain (FSC) that helps design, plan, manage and control the various FSC activities. But in the case of its' return counter-part, namely the Reverse Supply Chain (RSC) / RL, there aren't much. Unlike FSCs, design strategies for RSCs are relatively unexplored and underdeveloped (Blackburn et al., 2004).

The customer perspective asks what customers must believe about the company's reverse logistics operations in order for it to be successful. There has been an increased acceptance from the customers for recycled goods and packaging due to concerns with the environment. Thus, it is seen that the reverse logistics operations should offer services based on the customer perspective. The internal business perspective asks what the reverse logistics operations must achieve internally to meet and exceed the customer's needs. This perspective predominantly uses non financial measures focusing on quality, time, flexibility and cost (Brewer & Speh, 2000). The innovation and learning perspective asks how the reverse logistics operations can continuously perform and improve to create more value for the customers. The focus is on the future as opposed to current capabilities. Measures in this perspective relate to issues as cycle time and process improvement rates. Also, this is the segment of the scorecard in which organizations tend to incorporate human resource management. The finance perspective recognizes that ultimately companies must succeed financially in nature. It can be considered as a system of checks and balances. When financial success does not materialize despite glowing non-financial performance, it is a signal of flawed strategy. In this research, the balanced scorecard is used as a strategic tool to develop measures that are aligned with the strategies. These measures are then used in the multi-criteria decision making process to quantify the overall reverse logistics performance of the organization. There are numerous multi-criteria decision making tools, and probably the most commonly used is the Analytical Network Process, which is discussed in the next section.

2.5 Analytical Network Process

Since the AHP has been proposed by Saaty (1980), it has been widely used to deal with the dependence and the feedback involved in strategic decision making. One of the main advantages of this method is the relative ease with which it handles multiple criteria, both qualitative and quantitative. It involves the principle of decomposition, pair-wise comparisons, priority vector generation and synthesis. AHP has been extensively applied in many fields including performance evaluation in manufacturing (Wabalickis, 1987; Canada and Sullivan, 1989; Weber, 1993; Lee et al., 1995; Rangone, 1996). A general structure of AHP is depicted in Figure 2.3. ANP or system with feedback (Saaty and Takizawa, 1986), a generalization of AHP, can be used as an effective tool in those cases where the interactions among the elements of a system form a network structure (Saaty, 1996). ANP differs from AHP in a way that it does not impose strict hierarchical structure, and models the decision problem using a system with feedback approach.

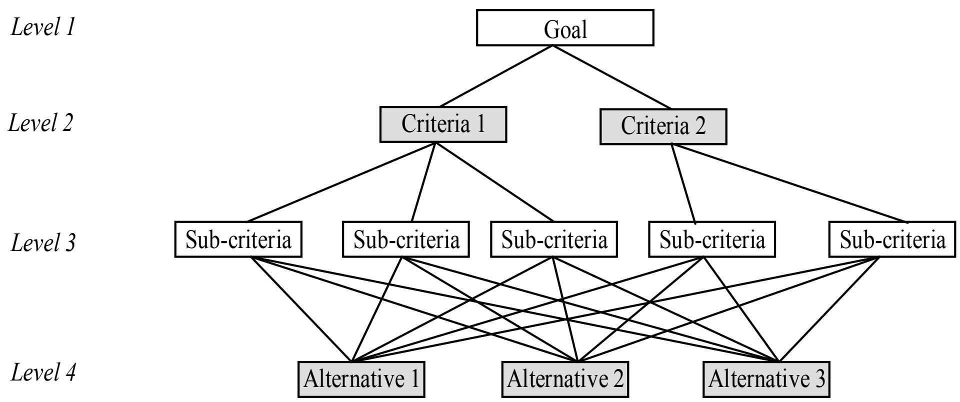


Fig 2.3 General Structure of Analytical Hierarchy Process

The ANP approach, though not so widely used as AHP, has also been used in performance evaluation and other applications (Hamalainen and Seppalainen, 1986; Azhar and Leung, 1993; Meade et al., 1997; Meade and Sarkis, 1999; Ravi et al., 2005). The ANP approach is capable of capturing feedback and interdependent relationships among and within the levels of components. Both the AHP and ANP approaches use Saaty's 1-9 scale similar to Likert scales to express the decision maker's subjective assessment of the relative contribution of components to their immediate higher level component in the hierarchy and structure pair-wise comparison matrices (Saaty and Alexander, 1981). The relative importance of component *i* compared to component *j* with regard to the parent component in the hierarchy is determined using Saaty's scale and assigned to the (i. j) th position of the pair-wise comparison matrix. The local weights are then calculated by solving for the eigen vector as described by Cheng and Li (2001). The process is repeated for each level of hierarchy to complete the decision making process. The super matrix is then constructed based on the eigen vectors and raised to limiting powers to achieve convergence (column stochastic or column sum equal to 1) and calculate overall priorities. The super matrix is a partitioned matrix, where each submatrix is composed of a set of relationships between two clusters in the graphical model (Meade and Sarkis, 2002). ANP has some other advantages over AHP such as (Saaty, 1999):

1. Allowance for interdependency and complex relationships
2. Looser and non linear network structure
3. Real world representation of the problem by making use of clusters
4. Allows consideration of tangible and intangible criteria in decision making

ANP relies on the process of eliciting managerial inputs, thus allowing for a structured communication among decision makers, thereby acting as a qualitative tool for strategic decision making problems (Sarkis and Sunderraj, 2002). This feature makes it superior from AHP which fails to capture interdependencies among different enablers, criteria, and sub-criteria (Agarwal and Shankar, 2003). Although ANP incorporates major relationships, it still has some disadvantages such as

1. Identifying attributes requires extensive brainstorming sessions
2. Data acquisition is a time intensive process
3. ANP requires a lot of calculations compared to the AHP process, and
4. Subjectivity of the comparisons is not considered

Though the purpose of AHP/ANP is to capture the expert's knowledge, the conventional version still cannot reflect the human thinking style and therefore, fuzzy AHP/ANP was developed. The decision maker can specify preferences in the form of natural language expressions about the importance of each attribute over another (Kahraman et al., 2004). There are many fuzzy AHP methods proposed by various authors. Decision makers are usually more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit about his/her preferences due to the fuzzy nature of the comparison process (Bozdag et al., 2003). Some of the early pioneers in applying fuzzy AHP for a number of applications were Laarhoven and Pedrycz, (1983); Buckley, (1985); Deng, (1999); Zhu et al., (1999); Cheng et al., 1999; and Leung and Cao, (2000). In fuzzy ANP, the weights are simpler to calculate than for conventional ANP. Several authors have applied the fuzzy ANP based approach recently to solve complex decision making scenarios (Lee and Kim, 2000; Emblemsvag and Tonning, 2003; Buyukozkan et al., 2004; Tran et al., 2004; Chung et al., 2005; and Lefley and Sarkis, 2005).

2.6 Fuzzy theory

To deal with vagueness and uncertainty of human thought, Zadeh (1965) first introduced the fuzzy set theory. Fuzzy theory enables decision makers to tackle the ambiguities involved in the process of the linguistic assessment of the data. The theory also allows mathematical operations and programming to be applied to the fuzzy domain (Dubois and Prade, 1979; Kauffmann and Gupta, 1988; Kahraman et al., 2004). A fuzzy set is a class of objects with a continuum of membership grades, where the membership grade can be taken as an intermediate value between 0 and 1. Fuzzy set theory is a perfect means for modeling uncertainty arising from mental phenomena which are neither random nor stochastic. Human beings are heavily involved in decision making and hence a rational approach should take into account human subjectivity, rather than employing only objective probability measures (Kahraman et al., 2006). In essence, fuzzy logic provides numerous methods to represent the qualitative assessment of the decision maker as quantitative data (Mohanty et al., 2005).

2.6.1 Triangular fuzzy numbers

A fuzzy subset M, of a universal set X, is defined by a membership function $\mu_M(x)$ which maps each element x in X to a real number in the [0, 1] interval (Karsak and Tolga, 2001). The function value $\mu_M(x)$ denotes the grade of membership of x in M; hence larger values imply higher degrees of set membership. In this research, triangular fuzzy numbers are used as membership functions to assess the preferences of decision makers. The reason for using a triangular fuzzy number (TFN) is that it is intuitively easy for the decision makers to use and calculate. A fuzzy number is a TFN if its membership function can be denoted as follows (Kauffmann and Gupta, 1991):

$$\mu_M(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \tag{2.1}$$

A triangular fuzzy number, M_i, is shown in Fig 2.4. It is simply represented as (l_i, m_i, u_i), where $l_i \le m_i \le u_i$. The parameters l, m, and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. When l=m=u, the TFN becomes just another non-fuzzy number by convention. Consider two triangular fuzzy numbers M_1 and M_2, $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, their operational laws are as follows (Chang, 1996):

$$(l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2.2)$$

$$(l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (2.3)$$

$$(\lambda, \lambda, \lambda) \otimes (l_1, m_1, u_1) = (\lambda l_1, \lambda m_1, \lambda u_1) \quad (2.4)$$

$$(l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1) \quad (2.5)$$

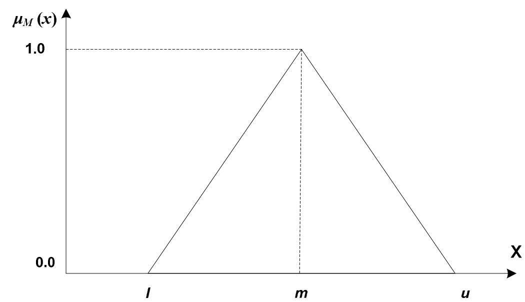


Fig 2.4 Membership function of a triangular fuzzy number

2.6.2 Linguistics assessment

A linguistic variable can be defined as a variable whose values are not numbers, but are words or sentences in natural or artificial language. The relative importance weights in the decision making process can be evaluated by linguistics terms such as very low, low, medium, high, and very high and so on. These linguistics terms can be quantified and expressed as TFNs using fuzzy set theory (Lin et al., 2006). The process of assigning membership functions to fuzzy variables is either intuitive or based on some algorithmic or logical operations. Intuition is simply derived from the capacity of experts to develop membership functions through their own intelligence and judgment (Ross, 1995). The successful use of a linguistics variable is highly dependent on the determination of a valid membership function. A number of different membership functions have been used in different applications such as robot selection (Liang and

Wang, 1993), and measuring manufacturing competence (Azzone and Rangone, 1996) to name a few. Similar to the scale of 1-9 suggested by Saaty (1980), a scale of M_1 to M_5 has been defined in this research to represent triangular fuzzy numbers. This scale is tabulated in table 2.3 and depicted in figure 2.5

Table 2.3 Linguistic terms for the importance weight of each criterion

Linguistic scale for importance	**Notation**	**Triangular fuzzy scale**	**Triangular fuzzy reciprocal scale**
Equally important	M_1	(1,1,1)	(1,1,1)
Weakly more important	M_2	(1, 3/2, 2)	(1/2,2/3,1)
Strongly more important	M_3	(3/2,2, 5/2)	(2/5,1/2,2/3)
Very strongly more important	M_4	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	M_5	(5/2,3,7/2)	(2/7,1/3,2/5)

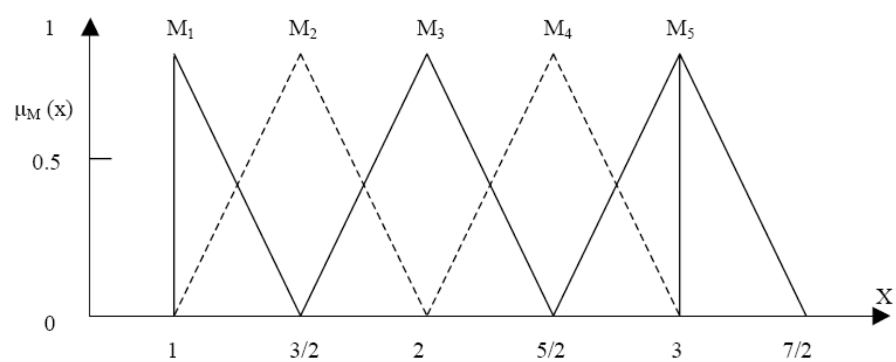


Fig 2.5 Membership functions of the linguistic values

2.6.3 Extent analysis

Chang's (1992, 1996) extent analysis: This analysis provides a general method of using crisp mathematical concepts to address fuzzy quantities. It determines the image of the object on the goal. Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $U=\{u_1, u_2, \ldots, u_n\}$is a goal set. According to Chang's method, each object is taken and extent analysis for each goal is performed, respectively. Now, if there are *m* objects for pair-wise comparison in a matrix, m extent analysis values for each object can be obtained as follows

$M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m$, *i*= 1,2,..,*n*, where all the M_{gi}^j (*j* = 1, 2… *m*) are triangular fuzzy numbers.

Step 1: In extent analysis, a synthetic evaluation of the hierarchy is made. The term 'synthetic' denotes the process of evaluation, where several individual elements and components of a matrix are synthesized into an aggregate form. The value of fuzzy synthetic extent with respect to the *i*th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}, \quad (2.6)$$

To perform $\sum_{j=1}^{m} M_{gi}^j$, perform the fuzzy addition operation of m extent analysis values for a particular matrix such that

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j \sum_{j=1}^{m} m_j \sum_{j=1}^{m} u_j \right) \quad (2.7)$$

and to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, perform the fuzzy addition operation of M_{gi}^j (j=1,2,…,m) values such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i \sum_{i=1}^{n} m_i \sum_{i=1}^{n} u_i \right) \quad (2.8)$$

and then compute the inverse of the vector such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M_{gi}^{j}\right]^{-1}=\left(1/\sum_{i=1}^{n}u_i,1/\sum_{i=1}^{n}m_{i,},1/\sum_{i=1}^{n}l_i\right) \qquad (2.9)$$

Step 2: The degree of possibility of $M_1 \geq M_2$ is defined as:

$$V\left(M_1 \geq M_2\right)=\sup_{x\geq y}\left\lfloor \min(\mu_{M_1}(x),\mu_{M_2}(y)\right\rfloor. \qquad (2.10)$$

When a pair (x, y) exists such that $x \geq y$ and $\mu_{M_1}(x)=\mu_{M_2}(y)$, the equality equation $V(M_1 \geq M_2)=1$ holds. Since M_1 and M_2 are convex fuzzy numbers (6) and (7) can be expressed as below:

$$V\left(M_1 \geq M_2\right)=1 \text{ if } m_1 \geq m_2, \qquad (2.11)$$

$$V\left(M_1 \geq M_2\right)=\text{hgt}\left(M_1 \cap M_2\right)=\mu_{M_1}(d), \qquad (2.12)$$

where *d* is the ordinate of the highest intersection point *D* between μ_{M_1} and μ_{M_2} (see figure 2.6). If $l_1 \geq u_2$, $V(M_1 \geq M_2)=0$.

When $M_1=(l_1,m_1,u_1)$ and $M_2=(l_2,m_2,u_2)$, the ordinate of *D* is given by the following equation:

$$V\left(M_2 \geq M_1\right)=\text{hgt}\left(M_1 \cap M_2\right)=\frac{l_1-u_2}{(m_2-u_2)-(m_1-l_1)} \qquad (2.13)$$

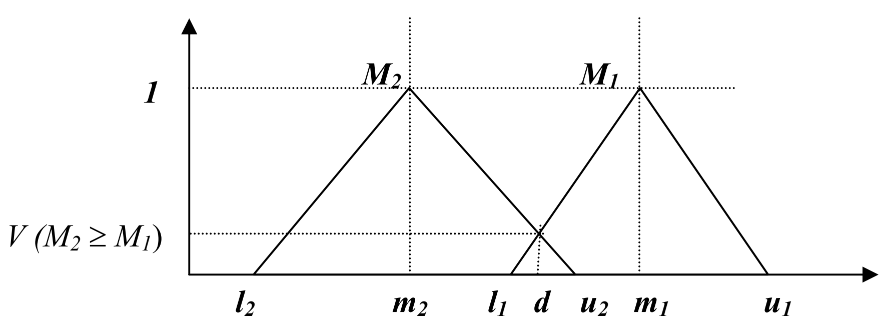


Fig 2.6 Intersection point “*d*” between two fuzzy numbers M_1 and M_2

To compare M_1 and M_2 we need both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 3: The degree possibility of a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i= 1,2,…,k) can be defined by

$$V(M \geq M_1, M_2, \ldots, M_k) = V\,[(M \geq M_1) \text{ and } (M \geq M_2 \text{ and} \ldots \text{and } (M \geq M_k)]$$

$$= \min V(M \geq M_i)\, i = 1, 2, 3, \ldots, k. \qquad (2.14)$$

Assume that: $d'(A_i) = \min V(S_i \geq S_k)$ (2.15)

For k=1,2,..,n; $k \neq i$. Then, the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T, \qquad (2.16)$$

where A_i (i=1,2,…,n) are n elements. Via normalization, the normalized weight vectors are: $W = ((d(A_1), d(A_2), \ldots, d(A_n))^T$, where W is a non-fuzzy number (2.17)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview

Ever since the Industrial Revolution, there has been a tremendous growth in the demand for consumer goods. Consumer awareness, constant demand for better products, and rapid development and improvement in technology has resulted in the shortening of product lifecycles. New products and product variants appear in the market with increasing regularity. An upshot of this phenomenon is the tendency of end consumers to return and discard products in lieu for better products with increased functionality long before the old products reach the end of its useful functional life (Parlikad et al., 2003). It has been realized in chapter 1 that there is a need to manage these returns in a more responsible manner. Reverse logistics activities are gaining importance all around the world and are being adopted not only to evade environmental legislations, but also to improve corporate image and generate profit making opportunities. The complexities associated with consumer electronics industry even more highlight the issue of improving the reverse logistics process. Much of the reverse supply chains literature available today describes how a reverse logistics network can be designed and operated, but it does not address how an organization can improve their processes and benchmark against industry. The relationship between various attributes of reverse logistics such as performance metrics, business strategies, and product lifecycle stages must be explored to fully understand how a dynamic and complex industry such as consumer electronics achieve successful reverse logistics. The organizations need to have a methodology to quantify the effect of the various attributes on its reverse logistics capabilities. They can use this knowledge to benchmark their performance across best in industry standards and decide on what processes to improve, what measures to implement, and what strategies to pursue to close the gap with the competitors.

3.2 Research Objective

The objective of this research was to develop a quantitative methodology for evaluating reverse supply chain performance in the consumer electronics industry, so as to maximize revenue within given technical and environmental constraints. The methodology developed in this research can be used by business managers in consumer electronics industry to evaluate their reverse logistics performance and design process performance metrics that are congruent with their strategies. The methodology can be used as a tool for deploying efficient processes, performance metrics, and product information in supportive of the strategies and goals of the organization. This alignment of the important attributes that are involved in the reverse logistics strategic decision making of an organization is a critical factor in determining the success of an organization. The methodology would help quantify the composite performance of the overall reverse supply chain process, and will be a function of the performance measures, strategies, processes and product lifecycle stages. Guidelines that would aid enterprises to implement the methodology are also included in this research. The development of performance measures and the methodology to develop the performance index is modeled on a system of processes obtained through an understanding of prior research in the area of the dynamics of reverse supply chains.

3.3 Dissertation Work Plan

In order to develop the methodology, a dissertation work plan was created. The dissertation work plan that makes sure the research is completed within the given time frame has five major tasks as depicted in figure 3.1 below. The detailed dissertation work plan and the deliverables are described in Table 3.1.

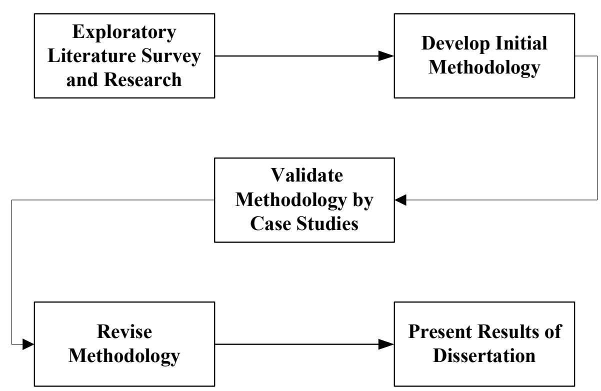


Fig 3.1 Dissertation Tasks

The exploratory literature survey phase aims at defining the scope of research, developing the vision for methodology, and to provide a foundation for the latter stages of research. In this phase, extensive literature reviews were conducted to understand the differences between forward and reverse logistics, and the selection of an industry. Literature survey with a focus to investigate the existing measures for forward supply chains and the need for a performance measurement system for reverse logistics was performed. The second phase involved the building of steps of the initial methodology through literature review and developing the formulations involved in quantifying the reverse supply chain performance of the organizations. The initial methodology called as "PEARL – Performance Evaluation Analytic for Reverse Logistics", was built from knowledge and data acquired through literature survey and analysis. The third major task in the work plan was to demonstrate the methodology. In order to have a detailed understanding of the reverse logistics processes in electronics industry, and to verify the validity of the methodology, case studies were conducted. The demonstration of methodology phase aimed at collecting data from case studies in the form a questionnaire for analyzing the validity of the proposed methodology. The main objectives of the proposed case studies, besides validation and verification of the methodology were to understand the following issues:

a. Current state of the art product recovery processes in the consumer electronics industry
b. Strategic decision making in reverse logistics
c. Metric requirements for measuring the reverse logistics processes
d. Product and market status of the various electronics products

As this research focuses on consumer electronic products, case studies were conducted at facilities that are involved in reverse logistics of the products under consideration. As stated before, this research assumed that the channel master is responsible for reverse logistics, either directly or indirectly with in each reverse supply chain. Observations and data from these case studies were used to further refine the methodology developed in the second phase. This took place in the fourth phase, namely, the revise methodology phase. Based on the recommendations from demonstrations, modifications to the initial methodology were introduced in order to integrate the requirements of real systems into the methodology. In the final phase of present results of dissertation, the methodology developed and refined was presented. The case study results, the performance scores of organizations across the electronics industry were analyzed. This phase also suggested some benchmarking and process improvement techniques, and identified strength and weakness areas of the organizations. Generalizations were drawn towards the applicability of the results to other industries, and managerial implications of the methodology were also discussed. Finally, future research directions are suggested. This research will provide significant insight into the strategic decision making involved within the dynamic consumer electronics industry. It will also have far reaching impact on the general understanding of the significance of strategic reverse supply chains process performance measurement.

Table 3.1 Dissertation Work Plan

	Dissertation Tasks	Deliverable
I. Exploratory Literature Survey and Research		
1.	Define the scope of the research a. Literature review on reverse logistics & reverse supply chains b. Identify the scope of research c. Conduct studies to determine the requirements of performance measurement in reverse logistics d. Select the industry and classify the products based on characteristics that would affect product recovery e. Define the gap in literature the research intends to address f. Define the aims and objectives of the research	➢ Differences between forward and reverse logistics ➢ Scope of research diagram ➢ Description of reverse logistics in consumer electronics industry ➢ Product classification diagram ➢ Problem statement ➢ Text summary of problem justification ➢ Dissertation objective statement
2.	Design the research methodology a. Develop an outline for the work plan b. Identify the phases of the research methodology	➢ Steps of research methodology ➢ Text description of the various phases of the methodology
3.	Develop a vision for methodology a. Determine the steps of the initial methodology from literature research, industry practices, and personal experiences	➢ Vision for methodology steps and flowchart
II. Development of Initial Methodology		
1.	Identify the common goals and objectives of undertaking reverse logistics in consumer electronics industry a. Literature review b. Current consumer electronics market conditions survey	➢ Description of some common goals and objectives of the consumer electronics industry ➢ Summary of the dynamic consumer electronics market
2.	Analyze the product and market characteristics a. Identify different product and market information necessary for product recovery b. Categorize the main drivers of RL in electronics industry c. Literature review on product returns and sales relationships	➢ Description of various internal and external product information required for product recovery ➢ List of the major drivers of returns management ➢ Sales vs. Returns graph, Sales, volume and variability matrix ➢ Text summary of lifecycle assessment in RL

Table 3.1 – Continued

3.	Design the reverse supply chain network consisting of the various players and their roles depicting the various functions	➢ Reverse supply chain network and assumptions ➢ Text summary of RL functions
4.	Analyze the dimensions of a balanced scorecard (BSC) from a reverse logistics perspective a. Literature review b. Research the applicability of balanced scorecard in a reverse supply chain performance measurement	➢ Summary of the application of balanced scorecard in reverse logistics ➢ Explanation of the four perspectives in developing measures for reverse supply chains
5.	Develop reverse logistics enabling strategies a. Literature review b. Develop key RL competitive strategies	➢ Text Summary of RL enabling strategies
6.	Develop performance measures for each process within the reverse supply chain a. Research literature on applicability of FSC measures b. Identify authors and metrics c. Identify the various dimensions of performance measurement d. Identify best practices from academic research and industry e. Develop key performance indicators for reverse logistics	➢ List of performance metrics to measure reverse supply chain performance ➢ Description of the metric development using industry wide best practices ➢ Formulations to calculate the performance measures ➢ Summary of importance of each metric
7.	Develop a decision making hierarchy of the various attributes that aid performance evaluation a. Identify the relationships between the various attributes required to develop the performance index b. Literature review on various quantitative strategic performance measurement tools c. Illustrate the use of ANP in RL performance evaluation d. Illustrate the use of fuzzy logic for quantifying human assessment in real world e. Develop pairwise comparison matrices for the various attributes in the hierarchy f. Develop the super matrix	➢ Analytical Network Process (ANP) hierarchical decision structure ➢ Cluster relationships diagram ➢ Summary of ANP usage in academia and industry ➢ Summary of fuzzy logic usage in data collection ➢ Linguistic scales to de-fuzzify human judgment ➢ Pairwise comparison matrices ➢ Super matrix

Table 3.1 – Continued

8.	Develop reverse logistics overall performance index (RLOPI) a. Formulate calculations to develop and synthesize reverse logistics overall performance index b. Develop scales to rate scores of the firm at the measures as per industry standards	➢ RLOPI weights diagram ➢ RLOPI input output diagram ➢ RLOPI calculation table ➢ Formulations to calculate RLOPI
9.	Develop process improvement techniques a. Identify sensitivity analysis methods b. Develop methods to benchmark with competitors and demonstrate the benefits of RLOPI usage	➢ Sensitivity analysis description ➢ Description of the applicability of RLOPI in benchmarking against industry competitors
III. Validation of Methodology		
1.	Identify target companies for case studies a. Select organizations engaged in reverse logistics operations b. Mail letters for approval of acceptance to interview	➢ Organization list ➢ List of topics to cover in interviews ➢ Recruitment letters
3.	Interview experts a. Select experts to interview b. Validate the methodology c. Gather data and calculate the RLOPI of the organization	➢ Individual title list ➢ RLOPI of the organization ➢ Text summary ➢ Identify strength and weakness areas of the firm
IV. Revise Methodology		
1.	Modify the methodology if necessary a. Analyze results of validation in case studies b. Refine methodology steps based on recommendations	➢ Refined PEARL methodology as needed ➢ Modified formulations
2.	Develop Implementation guidelines (See Appendix B) a. Develop user friendly presentations to implement the methodology b. Develop easy to use calculations involving the RLOPI c. Develop analysis and benchmarking suggestions	➢ Implementation guidelines ➢ Pairwise comparison matrices ➢ User friendly formulations ➢ Benchmarking and Sensitivity analysis tools ➢ Cost-Benefit analysis tools
V. Present Results of Dissertation		
1.	Demonstrate case study results a. Identify strength and weakness areas of the companies b. Perform sensitivity analysis on the results of the case studies	➢ RLOPI of the organizations ➢ SWOT analysis of each company ➢ Sensitivity analysis for each company

Table 3.1 – Continued

	c. Benchmark the performance across the electronics industry	➢ Text summary of organizational performances
2.	Defend final dissertation a. Draw generalizations towards the applicability of the results in other industries b. Discuss managerial implications of RLOPI c. Suggest future research directions	➢ Summary of flexibility of the methodology to incorporate other attributes ➢ Summary of extension to other industries ➢ Managerial implications summary ➢ Description of future research directions

CHAPTER 4

PERFORMANCE EVALUATION ANALYTIC FOR REVERSE LOGISTICS (PEARL) METHODOLOGY

4.1 Overview

The Performance Evaluation Analytic for Reverse Logistics (PEARL) Methodology is a tool for developing the Reverse Logistics Overall Performance Index (RLOPI) that helps an organization to assess its returns management capabilities and benchmark against best in class standards. The attributes that make up the performance index can vary across enterprises based on the nature of the business and type of product. This research identifies product lifecycle, reverse logistics enabling strategies, reverse logistic processes and key process performance indicators as the attributes in developing RLOPI. In the following sections, the basic network design and the processes under consideration assumed for this research is explained. It is followed by the description of the importance of product lifecycle as a key attribute for consumer electronics, development of right strategies and the key process performance indicators. The actual steps of the PEARL methodology are discussed illustrating the hierarchical ANP decision making structure and the interrelationships associated in between the attributes. Finally, the formulations needed to calculate the RLOPI are developed and discussed.

4.2 Reverse Supply Chain Network Design

The reverse supply chain network design structure illustrated in figure 4.1 is assumed throughout the context of this research. The network structure takes into account the maximum number of nodes that are physically possible in a RSC. The structure has the capability to account for the longest path of product and information flow. In other words, this "maximum node" network structure would take into account the worst case scenario where the product and the information have to flow through the maximum number of nodes. For example, products may actually reach the "Asset Recovery" center after "gate-keeping" without even passing through the regional distribution centers and the centralized return centers (CRC). But the "maximum node" assumption was designed to account for any product and information flow involving the regional distribution centers and the CRCs that may happen anytime in the future. The network is developed on the assumption that the Original Equipment Manufacturer (OEM) is responsible for reverse logistics, whether directly or indirectly. Finally, this network is built to handle end consumer returns only.

A typical RSC starts from the "gate keeping" operation where the incoming products are checked for their eligibility to enter the RSC. This step ensures that only truly deserving products traverse the RSC. It is ensued by a series of operations like "transportation", "sorting", "storing" and "asset recovery". The transportation is typically from the gate-keeping center to a "Centralized Return Center (CRC)" through a "Regional Distribution Center". From the CRC, the product can be transported to a variety of locations like the recycling center, secondary market etc. Since we assume the longest node network, we say that it passes through the "Asset Recovery" site that makes the disposition decision. In reality, this center may itself host a variety of reverse logistics disposition options like remanufacturing, refurbishing and repair. After the "Asset Recovery" site, the product is again transported to the appropriate location. This marks the last reverse logistics operation done on the product.

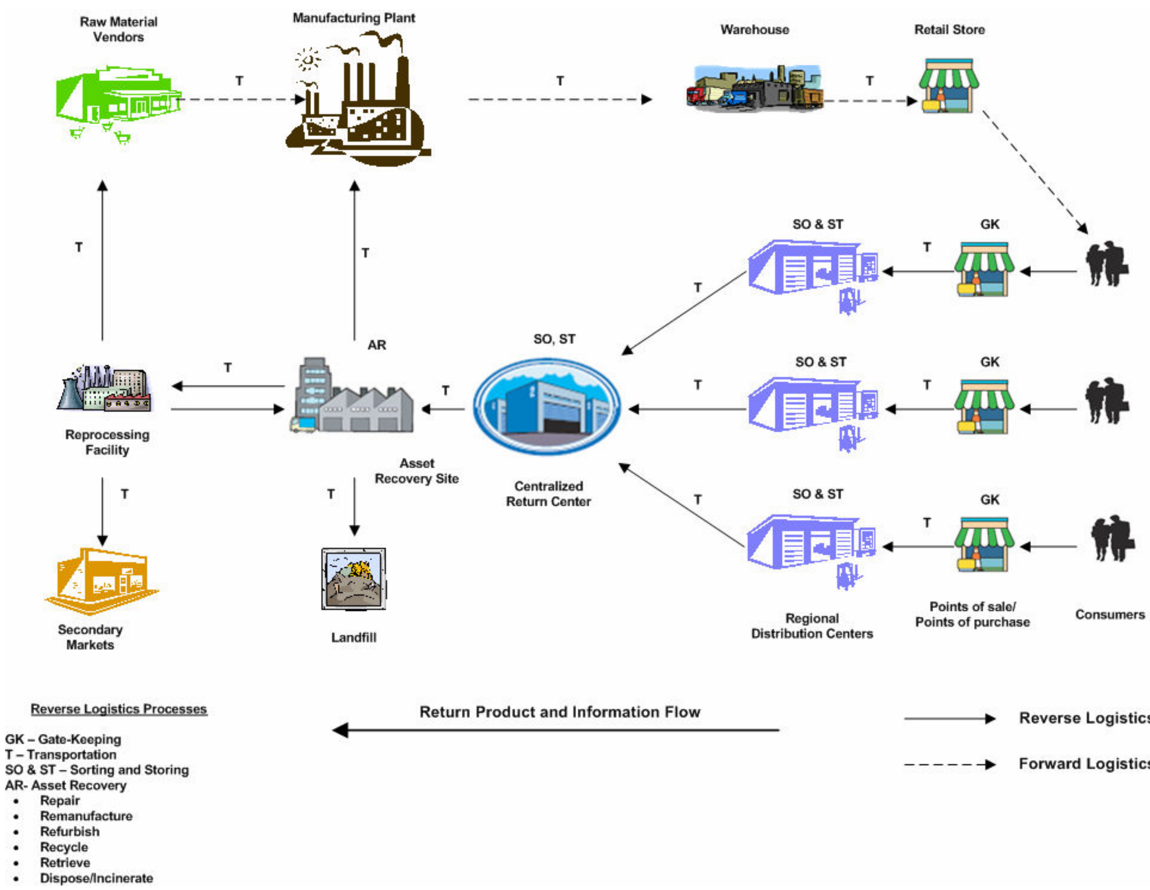


Fig 4.1 Reverse Supply Chain Network Design

Gate keeping has been defined as "the screening of defective and unwarranted returned merchandise at the entry point into the reverse logistics process". It is determining which products to allow in the reverse logistics system. Gate-keeping is done at the point of collection which is typically the point of sale or purchase. Often products enter the supply chain that should not enter in the first place and cause unnecessary transportation, administration and handling costs. In an ideal reverse supply chain, products are screened at the point of collection and disposition decisions are taken based on customer agreement on a product-by-product basis (Schatteman, 2003). The number of products allowed can be decreased by employee training and verification as well as simplification of the product (Caldwell, 1999). Gate-keeping is making decisions to limit the number of items that are allowed into the reverse flow. Successful gate-keeping allows firms to control and reduce the rate of returns without damaging customer service. Gate-keeping eliminates the cost associated with returning products that should have not been returned or the cost of products that have been returned to the inappropriate destination. The point of entry into the reverse flow is the best point to evade unnecessary cost and management of materials by screening unwarranted returned merchandise.

Sorting and Storing refers to deciding what to do with each product by segregating into categories that will be processed, sold, or disposed. Sorting and storing is a crucial step in the reverse logistics process because employees make decisions on what ultimately happens to the returned product. Determining the best channel for disposition of the product is of critical importance in maximizing revenue from the products in the reverse logistics pipeline. Complex business rules underlying these decisions need to be updated continuously and designed so that employees can implement the rules easily (Schatteman, 2003). Many companies have dedicated returns handling centers called as centralized return centers (CRCs). Some of the key benefits of CRCs are: efficiency can increase as employees occupy positions full time and can focus on handling returns only, quicker disposition decisions, lower cycle times resulting in better asset recovery and higher customer satisfaction. It is always a complex undertaking to have decentralized return centers or consolidated forward and reverse handling centers because of limited docking space and priorities.

Asset recovery is the “classification and disposition of returned goods as surplus, obsolete, scrap, waste and excess material products, and other assets, in a way that maximizes returns to the owner, while minimizing costs and liabilities associated with the dispositions” (Rogers and Tibben-Lembke, 1998). Asset recovery process involves decisions and actions associated with the fate of the product once a customer demonstrates product dissatisfaction and can happen on-site or off-site. The various actions that an organization can take in asset recovery are repair, remanufacture, refurbish (these three involve making the product reusable for its intended purpose), recycle, retrieve (these two for reusing the parts of a product for different purpose) and dispose (landfill as waste).

- Recycle: The process recovery of a product by reducing it to its basic elements (material level) for reuse
- Refurbish: The process recovery of a product similar to recycling, with more work involved in reconditioning the product at the module level
- Repair: The process recovery of a product similar to refurbishing, with more work involved in reconditioning the product at the product level

- Remanufacture: The process recovery of a product similar to refurbishing, but requiring more extensive work, often requiring completely disassembly.
- Retrieve: The process recovery of selective parts from the returned product for reuse
- Dispose/Incinerate: The process recovery of the product at the energy level in a controlled environment

The objective of asset recovery is to recover as much of the economic and ecological value as reasonably possible, thereby reducing the ultimate quantities of waste. This is a good cash generating opportunity for companies who can sell these goods that would otherwise end up in landfills. Recovered assets from product returns are sold in secondary markets where companies buy otherwise un-sellable products from manufacturers at a tremendous discount, then resell them as defective or lesser quality products. When resold, products are sometimes stripped of identity to spare the manufacturing company of cheap quality image (Rogers & Tibben-Lembke, 2001).

Transportation stage of the reverse logistics process is considered to be the actual movement of goods from one node to another within the reverse supply chain. The transportation stage is extensively involved in all aspects of reverse logistics. Transportation is usually the largest reverse logistics cost, often 25 per cent or more of the total reverse logistics costs (Stock, 1998). The transportation responsibilities can be on the manufacturer; any other actor with in the supply chain; a third party reverse logistics provider; or any combination of the above scenarios. The transportation function in reverse logistics can be extremely complex and hence most companies outsource this aspect of their business to third party service providers.

4.3 Product Lifecycle Analysis of Consumer Electronics

The consumer electronics industry is one of the most dynamic sectors of the world economy. In the U.S, this industry has grown at a rate three times that of the overall economy in the last ten years (Solomon et al., 2000). The rapid growth of the electronics industry has spurred dramatic changes in the products and systems that the public buys. Increases in speed, reductions in size and supply voltage, and changes in the technologies are becoming events that occur nearly monthly. Consequently, electronic products and their parts have significantly shorter lifecycles than other industry products. A product becomes obsolete when it is no longer manufactured either because demand has dropped to low enough levels that is not practical for manufacturers to continue to make it, or because the materials or technologies necessary to produce it are no longer available. The public's demand for products with increased warranties only makes the obsolescence problem worse. At our rate of technological development, the complexity of an integrated circuit, with respect to minimum component cost will double in about 24 months (Moore, 1965).

The product lifecycle also has a distinct affect on the reverse supply chain thereby complicating the strategic decision making process. Not all products are fortunate enough to have periods of significant growth and stability. The length of the product lifecycle affects the variability of expected returns over time. Once products have reached the end of their useful life, they may be able to be remanufactured, refurbished or repaired; thus extending their useful life. These options can provide significant benefits in consumer electronic products due their modular product design. Tibben-Lembke (2002) extends the study of reverse logistics and product lifecycle by looking at how the reverse logistics needs of a company may be expected to change over three different forms of the product lifecycle namely; product class, product form and product model. The relationship between product sales and returns varies significantly between products, depending on many things, including the price of the product, pace of technological change, and many other factors. In general (figure 4.2), as product sales increase, returns are likely to increase rapidly, and then remain fairly constant as long as sales remain constant, then decline as sales decline. In order to understand the reverse logistics flow behavior, it is relevant to look at the product's lifecycle. This research identifies five phases that are defined during the lifecycle of an electronic product: introduction, growth, maturity, decline, and obsolete.

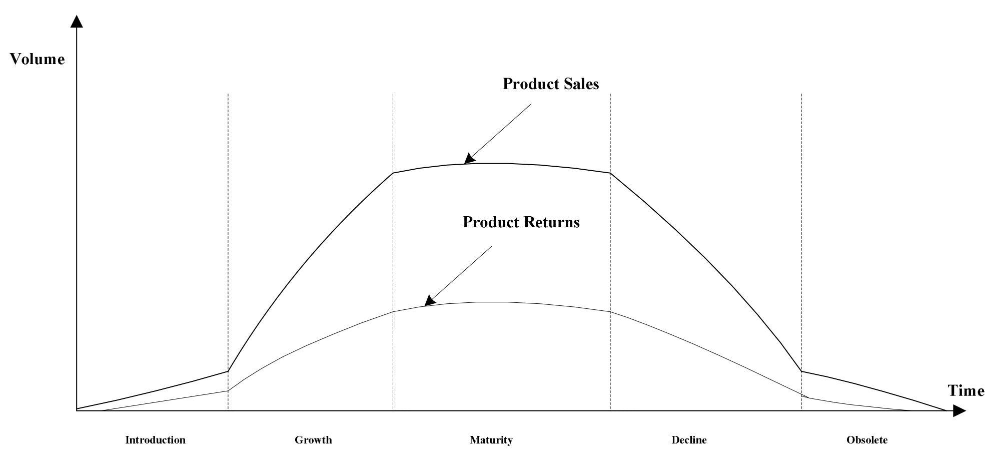


Fig 4.2 Typical Product Lifecycle for Consumer Electronic Products

Most of the research in understanding the lifecycle affects on the returns has been limited. The characteristic of every RL system is based on the product lifecycle length, and it varies across industries and products. To determine the lifecycle of a product, the organization must look for demand turning points and past sales history. However, analyzing the lifecycle of a product is difficult in industries such as the consumer electronics due to their short lifecycles (Guide and Wassenhove, 2003). In the electronics sector, the introduction of new products accelerates the demise of the models previously introduced. The stage where a product is located in its lifecycle is significantly related to the amount of units returned through its RL network. The management of the product returns process in a timely and effective manner in the case of short lifecycle products such as consumer electronics presents enormous difficulties compared to products whose lifecycle length is longer (Serrato et al., 2003). Table 4.1 summarizes the typical lifecycle characteristics of returns management process.

Table 4.1 Sales vs. Return Volumes and Variability of Returns Matrix

Characteristics	**Introduction**	**Growth**	**Maturity**	**Decline**	**Obsolete**
Sales	Slow but increasing	Increasing rapidly	High and stable	Decreasing	Sales only from aftermarket sources, if at all
Return Volumes	Low	High	High and Stable	Low	Low
Variability of returns	Low	Very High	High	Low	Low

As seen from table 4.1, the product lifecycle stage and length strongly determines the expected amount and the variability of returns for a particular product over time. The reverse logistics networks for electronics represent some of the greatest challenges due to its complexity in time and variability in the rate of return. The consumer electronics have the shortest lifecycles and the highest return variability compared to any other industry. These when coupled with the inherent characteristics such as difficult product acquisition; volatile supply and demand rates and prices; and dynamic market conditions, strategic decision making is extremely complicated.

4.4 Reverse Logistics Enabling Strategies

The selection of business strategies shapes the characteristics of an organization. Every organization must decide how it plans to operate its business and what strategies to pursue in order to be successful. Resources, in terms of time and money are spent on strategies. A strategy provides guiding principles for operations. To lay the foundations of a successful reverse logistics strategy, companies must recognize that it is not solely a supply chain issue. Developing the right strategies assists organizations in recognizing that their product returns processes can be altered from poorly handled return streams that are increasingly expensive into time-sensitive approaches producing significant profits. With the proper strategies in place, reverse logistics can serve as a foundation for establishing customer loyalties and increasing market share. While many companies have begun to recognize the need to address reverse logistics, few have strategically examined the opportunity or established explicit contribution objectives and formal processes/metrics (Moore, 2005).

Companies are becoming increasingly aware that the choices made concerning how they handle return products and processes can directly impact their bottom line. With the development and advancement of reverse logistics concepts and practice, there are several different business strategies an organization can pursue. Unfortunately, there is no one reverse logistics strategy that is ideally suited to all industries. This is largely because the frequency, number, and character of items returned will differ drastically from company to company. Many companies struggle to design, plan, and control the reverse supply chains that process returned products from the customer. When addressing strategic issues the decision maker is overwhelmed with a plethora of stakeholder views such as environmental agencies and a social conscious towards workers, consumers and communities, as well as ensuring a reasonable return on investment and long term enterprise viability.

Economic factors, legislation, corporate citizenship (de Brito and Dekker, 2003), and environmental and green issues (Rogers and Tibben-Lembke, 1998) are considered as the four main drivers of reverse logistics. Based on the importance of these drivers to an organization and their goals and objectives, the company must adopt a number of strategies to be successful in RL operations. This is easier said than done, and this aspect of developing the right strategy has been dealt by a number of authors in recent years. This research is to measure the performance once the strategies are developed and implemented. This methodology focuses on six core business strategies that enable reverse logistics. These strategies have been identified by various authors as supporting reverse logistics operations. The selected strategies are; Customer Satisfaction, New Technology Implementation, Eco-compatibility, Strategic Alliance Formation, Knowledge Management, and Value Recovery. These strategies are a common set of techniques that organizations can utilize to be successful in reverse logistics. An argument could be made for various other strategies that can be adopted, and the ANP model is flexible enough to incorporate other strategies.

Customer Satisfaction vis-à-vis the voice of the customer is the most important aspect of reverse logistics management. The success of a prospective reverse supply chain depends heavily upon the participation of three important groups, viz. customers, local government officials, and supply chain executives who have multiple, conflicting, and in-commensurate goals and thus the potentials must be evaluated based on the maximized consensus among these three groups. For the customers, the principal concern is convenience (Pochampally and Gupta, 2004). The present day customers demand that manufacturers reduce the quantities of waste generated by their products. They demand clean and energy saving production processes from their suppliers, and want the potentially dangerous materials used in the production process be replaced by those that minimize harm to users (Ravi et al., 2005). The customers are ready to pay more for a green product and drive the corporation green (Vandermerwe and Oliff, 1990). Reverse logistics also influences the customer service and satisfaction; as for example, the ability of companies to quickly and efficiently handle the return of product for necessary repair is critical for its survival (Blumberg, 1999). Customers do respond to companies' behaviors, and the goodwill developed through reverse logistics and proper disposal of products can create substantial customer loyalty. A customer focused strategy requires streamlined, no hassle policies and fast crediting to the customer’s account. Efficient reverse supply chains can mean happier customers and higher profits.

New Technology Implementation and technology support has been recognized as a competitive weapon capable of enhancing firm performance (Porter, 1985). More specifically, technology/performance relationship is well documented and recognized within logistics operations (Closs et al., 1997; Mentzer and Firman, 1994). A very serious problem faced by the firms engaging in reverse logistics is the dearth of good technologies (Rogers and Tibben-Lembke, 1998). An efficient information and technological system is very necessary for supporting the reverse logistics during various stages of the product life cycle. Information technology support is one of the ways to develop linkages to achieve efficient reverse logistics operations (Daugherty et al., 2002).New returns technologies help to address the increasing demand for better solutions in returns management (Daga, 2005). For efficient reverse logistics organizations need IT systems that generate location, route and time for returns; RFID and bar code real time tracking systems and tightly integrated automatic data capture. Most organizations live with labor intensive, manual, inefficient, and often undisciplined returns management process. The reason- bulk of their supply chain related technology investments is in the forward supply chain. An effective IT infrastructure to support returns needs to be implemented to handle data analysis, gate-keeping, tracking, and accounting system capabilities. The various application systems supporting the operations in an organization need to be modified or enhanced in order to support the environmental compliance requirements. New applications and tools may be required for compliance reporting, track and monitor customer returns and manage returns data. With the emphasis being given on reverse logistics today, the technology development to handle reverse logistics should be flexible enough for inevitable future expansion, as well as to have the ability to handle the many exceptions involved in reverse logistics.

Eco-compatibility and environmental performance continues to be a focus item for many companies. Regulations, laws, corporate and consumer awareness, as well as competitiveness, have companies initiating actions to reduce hazardous material, to take back their products, and to minimize product energy usage to name a few (Grenchus et al., 2001). Reverse logistics has led to competitive advantage to companies which proactively incorporate environmental goals into their business practices and strategic plans (Newman and Hanna, 1996). Managers are giving increasing importance to the environmental issues (McIntyre et al., 1998). Reverse logistics lead to benefits of environment and environmental management has gained increasing interest in the field of supply chain management (Carter and Ellram, 1998). In order to be competitive and successful in reverse logistics, organizations need to be actively engaged in making use of recycled and less energy intensive renewable materials and design their products for disposability and sustainability. Environmentally conscious manufacturing is an obligation not only to the environment but to the society also. Every organization, thus, needs to integrate environmental thinking into product development to overcome the escalating deterioration of the environment.

Increasing competition, higher customer expectations, and rising legislations have forced electronics companies to seek radically new ways to succeed in the marketplace. *Strategic alliances* are often used to rationalize business operations and improve the overall competitive position of a company. The process of forming a strategic alliance is important because of the sheer speed and dynamism of technological changes that have opened up a wide range of new activities. A strategic alliance allows a company to take advantage of what it does well and enables it to seek partners who have strengths in other areas. The strategic alliance formation strategy is very necessary to create competitive advantage as the customers become more environment conscious (Marien, 1998). OEMs and their supply chain partners can reengineer their business processes to better serve the ultimate customers, rather than being regulated into positions that may not be of most advantageous to the channel members. Strategic alliances are made with various members of supply chain as the companies are realizing that the individual attempts at product reclamation make little sense both economically or environmentally (Cairncross, 1992). The strategic alliance formation benefits every member of the supply chain to focus on their core competencies making it a win-win situation for both the supply chain members and the end customer.

Knowledge management is a multi-disciplined approach to achieve organizational objectives by making best use of knowledge. It involves the design, review and implementation of both social and technological processes to improve the application of knowledge, in the collective interest of stakeholders. A significant barrier to reverse logistics is lack of good personnel resources (Rogers and Tibben-Lembke, 1998). Lack of training and education is a major challenge to commercial cycling. Education and training are prime requirements for achieving success in any organization. The need for training on reverse logistics extends throughout the company and reaches up and downstream. New or revamped technology necessitates change and the personnel should be given adequate training in the new technology and processes that will be implemented. The training should be provided in critical business functions like product development, customer account management, etc., which gives rise to new development opportunities to improve integration of environmental issues (Ravi and Shankar, 2005). The environmental sustainability and ecological performance of a company depends on the whole reverse supply chain (Godfrey, 1998). Organizations need to partner and mentor their suppliers such as providing guidance to set up an environmental management system to improve the operational efficiency (Hines and Johns, 2001). Constant innovation and learning processes are necessary for the successful conduct of reverse logistics operations.

Value Recovery from returns is a key to successful reverse logistics in any organization. It is probably the greatest area of financial opportunity in the whole of reverse supply chain. To most companies, product returns have been viewed as a nuisance; consequently, their reverse supply chains were designed to be cost efficient. Very few companies have realized the benefits of faster responsive reverse supply chains (Blackburn et. al., 2004). Some of the returned products cannot be resold as new, including damaged and out-of-date or obsolete items. For items that can be resold, the goal is to get them back in the sales channel at the highest selling price as soon as possible. The longer the delay, the more value of the item is lost due to obsolescence. This is absolutely critical in consumer electronics industry, where product lifecycles are very short. The revenue gained by getting returned product quickly back into the selling cycle to control obsolescence is significant. If a firm does reverse logistics well, it will make money (Stock, 1998). The recovery of the products can lead to profitable business opportunities (Andel, 1997). An efficient value recovery process in place can bring significant cost benefits to the companies by emphasizing on resource reduction, adding value from the recovery of products, or from reducing the disposal costs. The goal of an organization in terms of value recovery is to get returned product available for resale at the highest possible price. Recapturing value from recovered products through reverse logistics activities of waste reduction and cost savings, organizations can contribute to bottom-line improvement (Bacallan, 2000; Hans & Byrne, 1993).

4.5 Reverse Logistics Performance Metrics

Lack of performance metrics is a major barrier to the development of successful reverse logistics programs. Performance metrics form the basis of integrated work measurement systems. Simply stated, "Work not measured cannot be managed" (Fawcett & Magnan, 2001). The performance measurement of any system is a key element in enabling the process of performance management, performance improvement, performance documentation, etc. If the firms take action linking their performance measurement system to their reverse logistics practices, they will be in a better position to succeed in their endeavors. Successful reverse logistics programs will effectively coordinate all the processes, focus on recapturing value or proper disposal of products, create environmental friendly products, and create performance measurement systems that provide data as to whether the designed reverse logistics is performing up to the expectations (Ravi & Shankar, 2004).

Traditional supply chain metrics are focused on minimizing the time between cash from sales and cash paid to suppliers; ensuring that work in process idle time across the supply chain is as low as possible; and finally, freeing up cash from fixed assets to expand the business. On the other hand, no standard reverse supply chain metrics are available to guide system design and implementation and to measure performance (Reddy, 2003). For the most part, traditional supply chain measures aren't meant to deal with finished products. The lack of standard measures for reverse supply chain performance can lead to disappointing results. Reverse supply chain implementation initiatives that promise great salvage value don't take into account the costs of handling unsold inventory as it flows back upstream into the forward-oriented supply chain. Developing reverse supply chain performance metrics that look at the process performance of recycling or salvaging products from retail outlets is the first step to success.

The two measures that have been developed for gate-keeping process are *Value of returns entering RSC/ unit time (RV)* and *Gate-keeping Effectiveness (GE)*. The value of returns entering the reverse supply chain is a key analytic in performing a health check of the overall reverse logistics. It will help the decision maker of an organization in answering questions such as:

a. What is the current volume and value of return inventory in the supply chain?

b. What are the trends in return rejections?

c. What are the trends in return processing times at the gate-keeping sites?

d. What is the efficiency of gate-keeping?

As discussed before, gate-keeping is the most important operation of the reverse supply chain. The goal of the organization is to minimize the number of returns that should not have entered the reverse loop in the first place. The value of returns can be calculated as follows:

$$RV = \sum_{i=1}^{n}\left[\sum_{D=1}^{D_{max}}\left(\sum_{OD=1}^{OD_{max}}(N_i * C_i) + \sum_{TD=1}^{TD_{max}}(N_i * C_i)\right) + \sum_{I=1}^{I_{max}}\left(\sum_{OI=1}^{OI_{max}}(N_i * C_i) + \sum_{TI=1}^{TI_{max}}(N_i * C_i)\right)\right] \quad (4.1)$$

where,

$i = 1,2,..,n$ is the number of product categories in the company

N_i is the number of returned products in a product category

C_i is the cost of returned products in a product category

(Assumption: The maximum value of a return is equal to the manufacturing cost of the product)

D is the number of domestic locations; D_{max} is the max. # of domestic locations

I is the number of international locations

I_{max} is the maximum number of international locations

OD is the number of online domestic locations

OD_{max} is the maximum number of online domestic locations

OI is the number of online international locations

OI_{max} is the maximum number of online international locations

TD is the number of traditional domestic locations

TD_{max} is the maximum number of traditional domestic locations

TI is the number of traditional international locations

TI_{max} is the maximum number of traditional international locations

Gate-keeping effectiveness is a qualitative aggregate measure that helps an organization compare its practices to some of the best practices obtained from academic research and industry. It is used to reflect the importance of gate-keeping to the organization's successful reverse logistics strategies. The analytic developed here is a combined qualitative assessment to make it easy and simple to use in industry and help companies benchmark easily with industry standards. The "best practices" that constitute the gate-keeping effectiveness are:

- Clear and visible return policies to reduce the number of defective products into reverse supply chain
- Use of dedicated skilled labor for return product inspection and testing at gate-keeping site
- Use of latest test equipment for checking the reliability of the product
- Use of IT and information software for generating a return good authorization
- Devote necessary utilities, supervision and maintenance requirements for the proper administration
- Use of multiple channels such as phone and internet to provide support and troubleshooting
- Employ programs to reduce idle time of trucks and products at gate-keeping
- Presence of economic benchmarks for acceptance / rejection of returned items

- Develop EDI linkages for the return goods management
- Established business rules to assist customer representatives for faster customer credit

The two measures developed in this research for Sorting and Storing processes are *Warehousing effectiveness (WE)* and *Carrying cost percentage of returned goods in a CRC per unit time (RC)*. Warehousing Effectiveness is an aggregate measure of warehousing performance of an organization in handling returns. Effective warehousing is a critical part of successful reverse logistics. Return handling is more costly than product handling in the forward supply chain. The Reverse logistics Executive Council states that U.S. firms bear losses of the order of billions of dollars on account of return handling (Rogers and Tibben-Lembke, 1998). Many managers have disregarded warehousing returns or they handle returns extemporarily (Meyer, 1999). The handling of returns is not as the usual handling of forward flows coming into the warehouse, and involves complex decision making process. Many quantitative models have been developed to handle returns, but in order to implement them successfully, more qualitative or empirical approaches are necessary. This research develops a list of some "best practices" (Dowlatshahi, 2002) that may help decision makers to come up with solutions for sorting, storing and other warehousing functions, and combines them into an aggregate performance measure. The following is the list of "best practices" that make up the warehousing effectiveness:

- Real time updating of inventory in warehouses
- Application of RFID technologies for tracking stored return products

- Availability of detailed shipping and receiving data for the proper handling and management of returned items
- Use of existing warehousing functions and resources
- Use of current warehousing methods and equipment
- Improvements in warehousing layout design for the physical separation of virgin and returned items
- Use of separate CRCs to handle returns
- Compliance with OSHA and ISO 14000
- Provision of special handling requirements
- Use of full time employees dedicated to handling returns

The cost to carry return products, measures the overhead that an organization carries to support its inventory. The longer the return inventory spends in the reverse supply chain, the more the product value gets eroded, thereby losing significant opportunities to build competitive advantage. Carrying cost is usually expressed as a percentage that represents the cents per dollar that will be spent on inventory overhead per year. The total carrying cost is usually a sum of fixed (space, equipment, and personnel) and variable (cost of money, taxes, insurance, obsolescence, pilferage, etc.). Each of the costs can be calculated as a percentage of the actual product manufacturing cost. A low carrying cost of inventory sends a message to people within the organization that holding return inventory is cheap which makes it an easy solution for other problems. The average value of return inventory is the amount of return goods in dollars tied up within the reverse supply chain over the span of a year. The carrying cost percentage is then calculated by dividing the sum of these expenses by the average inventory value. It is the amount of money it takes to maintain one dollar's worth of inventory for an entire year.

$$\text{Carrying Cost Percentage (RC)} = \frac{\text{Fixed costs} + \text{Variable costs}}{\text{Average value of return inventory}}$$

$$= \frac{[(S+E+P)+(M+T+I+O+P)]}{Q}$$

$$= \frac{\left\langle \sum_{i=1}^{n} [(S+E+P)+(M+T+I+O+P)] * R_i \right\rangle}{\sum_{i=1}^{n} (R_i * C_i)} \quad (4.2)$$

where, i = 1,2,..,n is the number of product categories in the company

R_i is the number of returned products in a product category located in the warehouse

C_i is the cost of returned products in a product category

S is the cost of space per unit return

E is the cost of equipment needed to handle a unit return

P is the cost of personnel to handle a unit return

M is the cost of money tied up in a unit return

T is the cost of taxes on a unit return

I is the insurance cost per unit return

O is the obsolescence and shrinkage cost per unit return

P is the pilferage cost involved in a unit return

Q is the average value of inventory in the warehouse

Using an approximate return carrying cost does not help to identify areas for potential improvement in the warehouse operations. By closely examining the specific components of the return inventory carrying cost and comparing the numbers to other firms in industry, organizations can identify areas that are candidates for improvement.

Three metrics were developed in this research to measure Asset Recovery. They are *Recovery Efficiency (RE), Recovery Rate (RR_j),* and *Environmental conformance effectiveness (EE)*. Every organization that engages in reverse logistics needs to add the most value with the least use of resources, during their asset recovery process. Recovery efficiency measures the ability of an organization to simultaneously meet cost, quality, and performance goals, reduce environmental impacts, and conserve valuable resources (Schmidheiny, 1992). It is defined as:

$$RE = \frac{\text{Value recovered}}{\text{Resources used} + \text{Environmental impact}} \tag{4.3}$$

The value recovered can be considered to be equivalent to the sales generated from the returned products. The resources used are the costs incurred in product recovery that can again be divided into fixed (space, labor, and equipment) and variable (taxes, insurance, etc.). The environmental impact is the charges incurred due to pollution of environment due to the discharge of gases such as CO_X, NO_X, SO_X, etc. Ideally, every organization must strive to keep this figure as high as possible.

Recovery Rate for a product j is defined as

$$RR_j = 1 - \left(\sum_{i=1}^{n} S_{ij} / N_j\right), \qquad \text{(Guide et. al., 1997)} \tag{4.4}$$

where,

S_{ij} is the number of units of item j scrapped in time period i, and

N_j is the total number of item j inducted into the asset recovery process

Returns are time sensitive and firms frequently lose much of the value remaining in their returned products by not making quick disposition decisions (Souza et al., 2005). This is especially true in high clock-speed industries such as consumer electronics. Studies of time based competition (Blackburn, 1991) have demonstrated that faster response in business processes can be a source of competitive advantage. Recovery rate essentially captures the time taken to perform the asset recovery operation for different products, and help managers to identify the bottlenecks and improve the process.

Asset recovery operation should ensure that the environmental and green issues are taken into account. While some of the global leaders have begun adopting the environment compliance regulations, most of the organizations haven't yet realized the impact of non-compliance of these directives. The impact could be in terms of loss of revenues, low brand equity, reduced customer base and a risk of potential penalties (Pathania and Andrews). To minimize this impact, companies need to have a well defined metric to measure their environmental conformance. Environmental conformance effectiveness is an easy to use and implement qualitative measure that combines the best practices in environmental compliance, and ensures that the investments made in compliance initiatives are best leveraged.

- Presence of educational and training programs to employees
- Use of employee incentive programs related to environmental goals
- Use of supplier environmental audits and assessments
- Compliance with regulations such as WEEE, EPA, ISO 14001 and RoHS
- Use of eco-friendly product and packaging materials
- Use of recycle materials to manufacture virgin products
- Promotion of industry wide cooperative efforts on environmental issues
- Develop tools that assist in designing products for environment
- Support end-of-life processing by tracking product data from design through end-of-life(significant for products with long lifecycles)
- Use of compliance reporting and material declaration sheets for all products manufactured

The metrics that were developed for return transportation function are *Overall Vehicle Effectiveness (VE)* and *Average return transit time (RT).* Products that enter the reverse supply chain require transportation to their respective processing facilities. The transportation services, loads, routes, networks,, and resources (including the use of third party providers) for inbound and outbound operations should be considered and used for effective and efficient utilization of transportation facilities (Dowlatshahi, 2005). The returned products in the reverse logistics system compel the organizations to re-define and restructure traditional transportation functions. Transportation forms the major part of any reverse logistics cost and every organization should strive to keep it low. The overall vehicle effectiveness is an aggregate qualitative measure that helps the company to compare its transportation with some of the best practices in the industry. The practices considered for this research are:

- Use of existing transportation routes and schedules
- Use of inter-modal transportation on a timely basis
- Use of shipping in bulk and cube utilization
- Use of computer network technology to track return products from gate-keeping to disposal
- Availability of detailed shipping and receiving data for the proper handling and management of returned items
- Use of special bins for distinction between virgin and returned items
- Use of automated systems for generating return good authorization (RGA) and other shipping documentation
- Provision of online web capability to schedule returns pickups
- Use of rate engines that allow selection of the lowest shipping cost option across multiple carriers
- Coordinate returns shipments to get lower transportation costs and improve vehicle and mileage utilization

It is measured by the number of days (or hours) from the time a returned product spends in transit, after it enters the reverse supply chain at the gate-keeping site, to the point it leaves the reverse supply chain. Transit times can vary substantially, based on freight mode and carrier systems. As discussed before, time is an important factor in high clock-speed industries such as consumer electronics. The more the product spends in transit the more it loses its value over time. Every organization or its third party freight carrier should optimize their travel routes and schedules to reduce the overall return transit time. The average return transit time can be expressed as

$$RT = \frac{\sum_{i=1}^{N} T_i}{N} \qquad (4.5)$$

where,

i=1,2,…,N is the number of products entering the reverse supply chain

T_i is the total time spent by a product return in transit

Table 4.2 Summary of Key Process Performance Indicators

Performance Measure Classification	**Performance Measure**
Gate-keeping	Value of returns entering RSC per unit time (RV) Gate-keeping Effectiveness (GE)
Sorting and Storing	Warehousing Effectiveness (WE) Carrying cost percentage of returns in a CRC per unit time (RC)
Asset Recovery	Recovery Efficiency (RE) Recovery Rate (RR) Environmental Conformance Effectiveness (EE)
Transportation	Overall vehicle effectiveness (VE) Return good total transit time (RT)

A summary of the metrics developed in this research is provided in table 4.2. To monitor RL performance each metric must take a reverse supply chain perspective; each process in the reverse supply chain should be measured and improved with common goals, and additional and creative efforts are needed to design new measures. Scrutiny of reverse supply chains literature and operating characteristics of successful reverse logistics operations illustrates what measures represent an accurate measurement of reverse logistics processes. The relative importance of the measures may be weighted differently by different industries, among different companies, or for different individuals. The key performance metrics were classified based on the reverse supply chain activity, and are the characteristics that can be used to describe a reverse logistics offering. The measures developed in this research are not exhaustive, and an argument can be made to incorporate more measures depending upon the organizational requirements.

4.6 Structure and Treatment of Initial "PEARL" Methodology

This section provides a detailed treatment of the development of the initial methodology, depicted in figure 4.3 that comprises of 16 steps. As suggested earlier, the methodology is a tool that can assist organizations in developing world class reverse supply chain operations. However, no methodology is a fit for all, and has to be tailored to the particular industries or products. Some of the steps in the methodology need to be iterative to continuously improve the returns management processes with in the reverse supply chain and thereby close the gap with the best in class standards. The discussion of the steps will be supported with diagrams wherever necessary.

1. Construct a decision makers committee
2. Determine the goals and objectives of the organization pertaining to the RL
3. Identify the various actors and functions that compose the organization's RSC
4. Design a reverse logistics network of the organization
5. Identify the lifecycle stages and market status of the product mix of the organization (Conduct market survey)

6. Identify the main drivers of returns in the consumer electronics industry, and analyze the current returns to evaluate your returns policy (Conduct Delphi study)
7. Develop the reverse logistics enabling strategies based on steps 2 – 6
8. Develop the reverse supply chain balanced scorecard to aid strategic decision making and performance measurement
9. Develop the appropriate process performance measures supporting the overall goals and strategies
10. Determine the inter-relationships between the various clusters of attributes
11. Establish the hierarchical Analytic Network Process decision framework of different attributes depicting the various clusters and their interdependencies
12. Develop super matrix using fuzzy AHP and ANP decision making approach
    a) Choose the appropriate linguistics terms to express the opinion of the decision makers in linguistic form
    b) Convert the linguistic information into triangular fuzzy numbers (TFN)
    c) Form pair-wise matrices with respect to the inter and intra dependencies between the clusters
    d) Evaluate the weights of each attribute based on their relationships in the hierarchy
    e) Calculate the aggregate weights for each criterion
    f) De-fuzzify the aggregate weights into crisp values
    g) Form the super matrix and converge it to a high power to make it column stochastic
13. Calculate the organization's Reverse Logistics Overall Performance Index (RLOPI)
    a) Determine the performance values at the measures for each RL function within the organization
    b) Collect performance values at the measures for other firms within the industry (commercial sources or trade associations)

c) Categorize the performance within the electronics industry in the form of scales to assign performance ratings at the measures
d) Calculate the performance rating of the firm at the measures reflecting it's relative position within the electronics industry
e) Calculate the performance score at the measure
f) Determine reverse logistics overall performance index (RLOPI)

14. Perform sensitivity analysis (Go to step 12 and repeat steps 12 - 14)
15. Perform SWOT analysis (Identify strength and weakness areas)
16. Benchmark with industry competitors and feedback the performance and process improvement decisions (Go to step 7 and repeat steps 7 – 16)

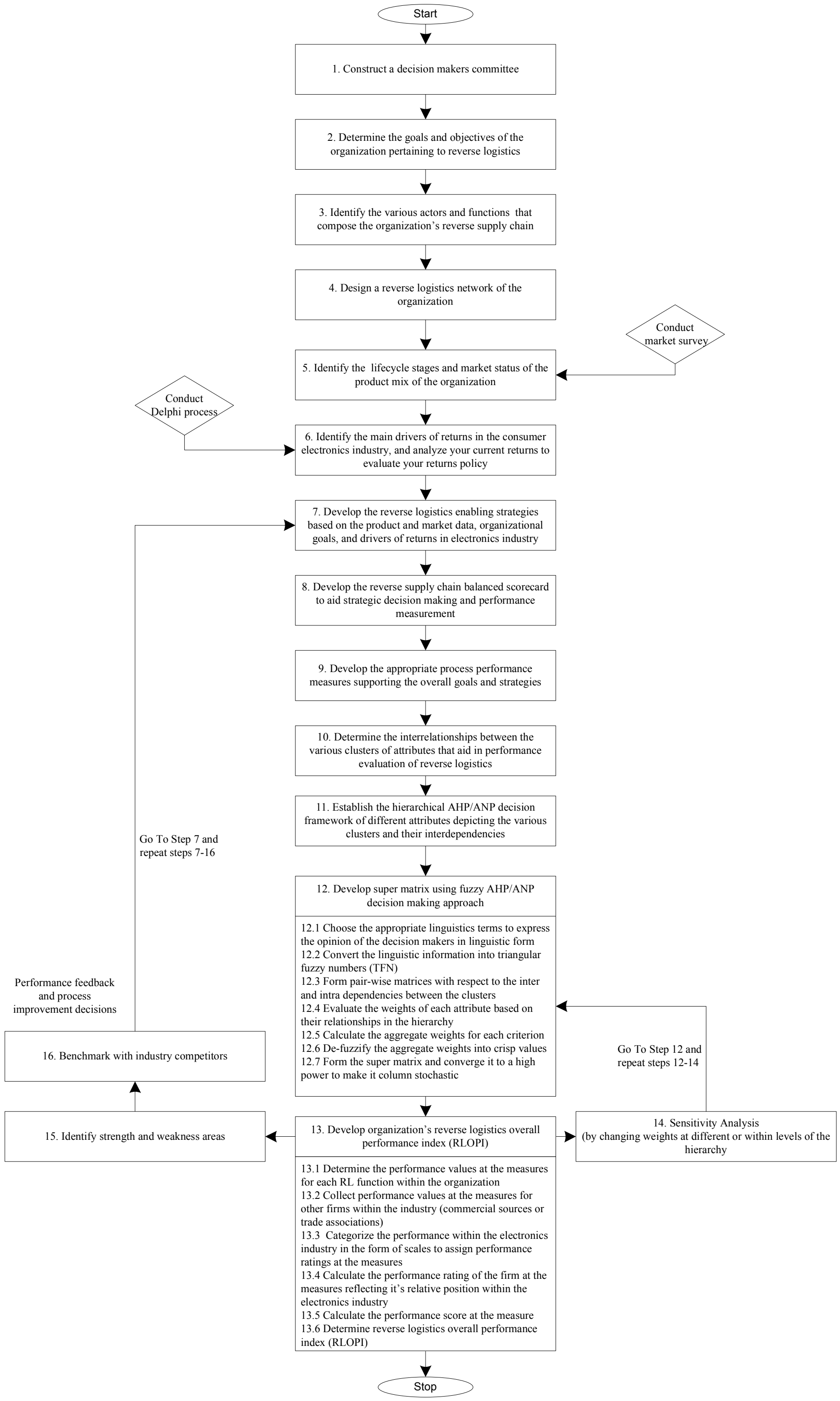


Fig 4.3 Structure of the "PEARL" Methodology

Steps 1 through 7 have been discussed in the earlier sections of chapter 4 and predominantly suggest the organization to develop the right goals and the right attributes that are necessary to reach the goals. Before doing so, first and foremost a decision makers committee needs to be formed. The team need to comprise members of inter functional and inter departmental responsible for handling reverse supply chain activities within the organization either directly or indirectly. The committee brainstorms on what the organizational goals and objectives are and what are the right attributes that are necessary in assessing the organizational reverse supply chain performance. They develop the reverse logistics network, identify the lifecycle stages of the product mix, identify the major drivers of returns and build appropriate business strategies.

Step 8 serves the purpose of linking the balanced scorecard with the drivers of returns to measure the organizations reverse supply chain performance. Identifying the drivers of reverse logistics and linking them to the four perspectives of the balanced scorecard is a key step in the methodology. The decision making team can modify the traditional balance scorecard, if necessary, to develop a comprehensive strategic framework for measuring RSC performance. A BSC helps us to organize the objectives, measures, targets and initiatives from all the four perspectives and link them with the drivers of RL management systems. A detailed discussion of the balanced scorecard is available in chapter 2 of this dissertation. The bond between RL and the four perspectives of the BSC is depicted below in figure 4.4. The key issue to note is that both business strategy and legislation seem to be the drivers and can be assessed via measures that equate with the internal business and innovation and learning perspectives. An example of a reverse supply chain balanced scorecard is depicted in figure 4.5.

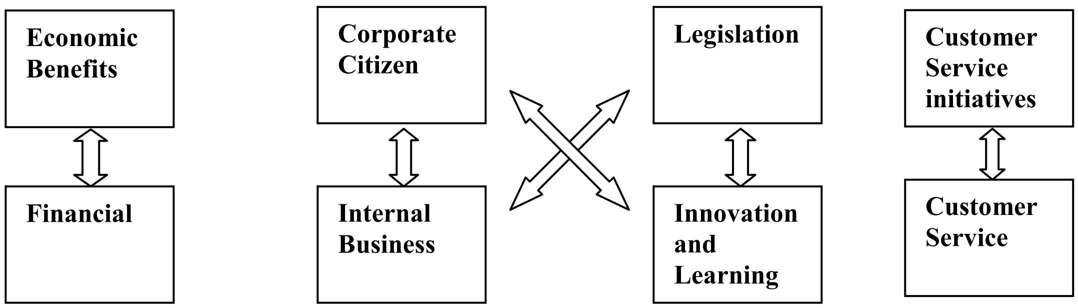


Fig 4.4 Link between RL drivers and Balanced Scorecard perspectives

Step 9 involves a crucial step of developing the right key performance indicators to measure the organizations reverse supply chain performance. This research developed performance measures holistically from a focus (strategic or operational), type (qualitative and quantitative), basis (responsive or efficient), source (internal or external), and frequency (diagnostic or monitoring) perspectives of the balanced scorecard. This kind of approach assists an organization to develop an unbiased performance index that is not skewed with respect to a particular dimension of performance measurement. A similar approach can be consummated by organizations in order to perform a health check and make sure that their performance measures are not skewed. The key performance indicators developed in this research and discussed in earlier section are quite comprehensive in evaluating the reverse supply chain performance of a consumer electronics organization. However, no measure is universally true and needs to be tailored to the situation on hand.

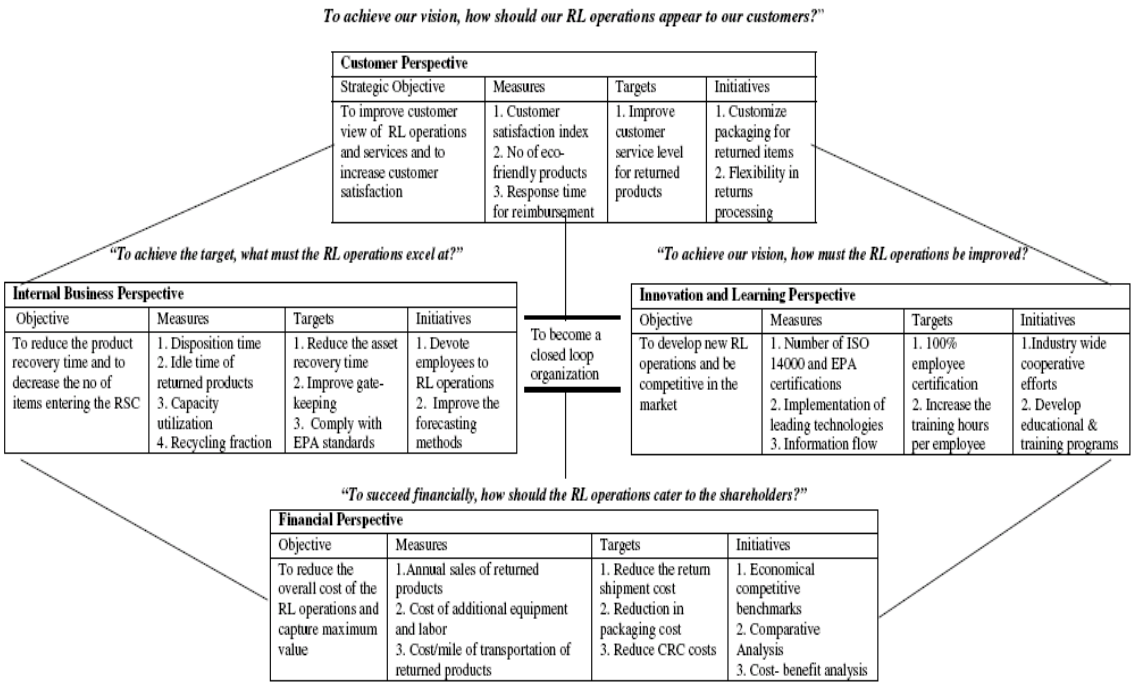


Fig 4.5 Illustration of balanced scorecard framework for successful RL operations in consumer electronics industry
(Yellepeddi and Rajagopalan, 2005)

Step 10 suggests identifying the inter-relationships between the various attributes that are necessary to evaluate the organizational reverse supply chain performance. The attributes identified in this research are the product lifecycle stages, reverse logistics functions, reverse logistics enabling strategies, and the performance measures. The process of analyzing the relationships is an extensive and painstaking process, but very critical with respect to implementing the PEARL and developing the RLOPI. Figure 4.6 below depicts the various inter and intra relationships between the various attributes developed in this research.

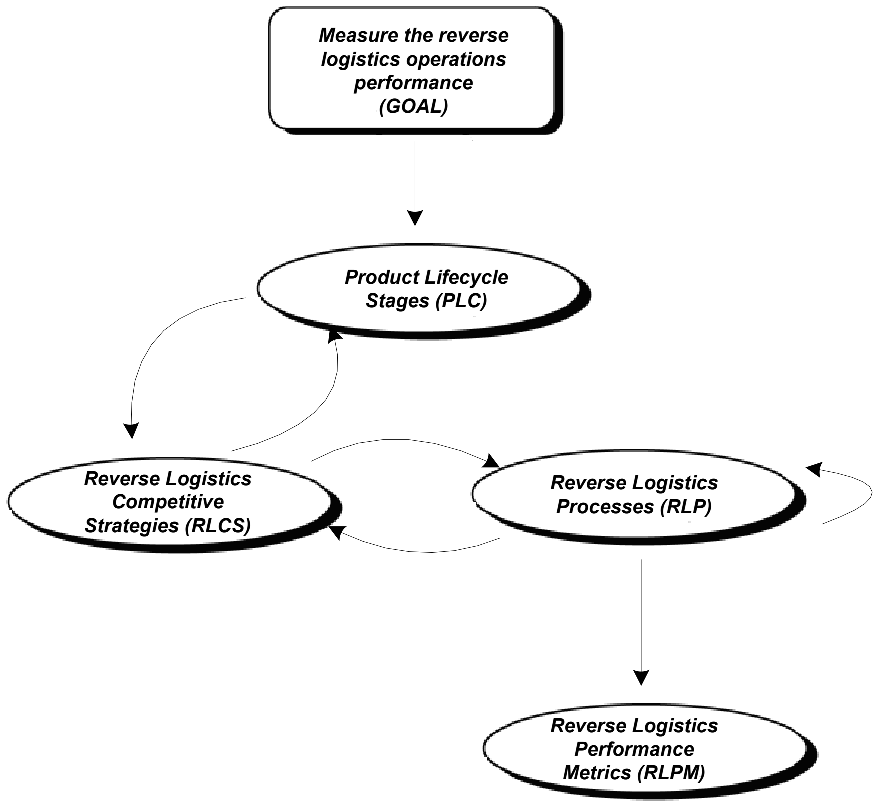


Fig 4.6 Graphical representation of clusters and influence relationships of decision making framework
(Yellepeddi, Liles, and Rajagopalan, 2006)

Step 11 recommends developing the Analytical Network Process hierarchy of the various decision making attributes. Of the complex and dynamic circumstances surrounding a consumer electronic firm, market and product characteristics provide the starting basis. Depending on the lifecycle stage of the product, the company must adopt competitive RL strategies to guide their priorities in their decisions, which are often complicated by the uncertainty of the product returns. Determining the lifecycle stage of a product and the variability of the returns are difficult. However, if this challenge is faced adequately, it becomes a critical piece for an adequate RL performance measurement system management (Serrato et al., 2003). The stage where a product is located in its lifecycle is significantly related to the product return rates. Competitive environments in consumer electronics have caused product lifecycle to continuously shrink, and hence it's imperative that these companies consider the length of the product lifecycle and the variability of the returns to adopt appropriate strategies (Guide and Wassenhove, 2003).

Economic factors, legislation, corporate citizenship and environmental and green issues were considered as the four main drivers of reverse logistics. Based on the importance of these drivers to an organization and their goals and objectives, the company must adopt a number of strategies to be successful in RL operations. This is easier said than done, and this aspect of developing the right strategy has been dealt by a number of authors in recent years. This research is to measure the performance once the strategies are developed and implemented. For this study, some of the strategies identified, to be competitive in RL as Customer Satisfaction, New technology Implementation; Eco-compatibility; Strategic alliance formation; Knowledge management; and Value recovery. An argument could be made for various other strategies that can be adopted and the ANP model is flexible to incorporate other strategies. The lifecycle stage and the strategy are inter-dependent. The lifecycle stage determines what strategies to adopt and their relative importance. Similarly, the strategy adopted will determine which lifecycle stage needs more consideration. The ANP model is illustrated in figure 5. The RL process functions include Gate-keeping, Sorting and Storing, Asset Recovery, and Transportation. The strategies and RL functions are also interdependent. The importance of strategies differs for each RL function and vice versa. Moreover, there is an inter cluster relationship within the RL process, as for each strategy the relative importance of the functions varies.

The performance measures form the last level of the ANP model and these directly tie into their respective RL process. It should be born in mind that metrics should be dynamic, as they need to be updated and changed when needed. Once processes are improved, the frequency and type of metric measurement might change; possibly the metric will become unnecessary as improvements are institutionalized. The presence of good performance measures represents a major step in adopting a holistic approach to RL management. The organization cannot control its RL processes efficiently and effectively without having proper metrics. The relationship between the functions and their respective performance indicators can be represented in a two-level unidirectional hierarchical structure. Development of these measures varies as per the organizational goals and strategies. The hierarchical structure for decision making and in further developing the Reverse Logistics Overall performance Index (RLOPI) is presented below. It is to be noted here that this structure has been formed from the attributes identified and developed in this research as critical to evaluating the performance of a consumer electronics organization.

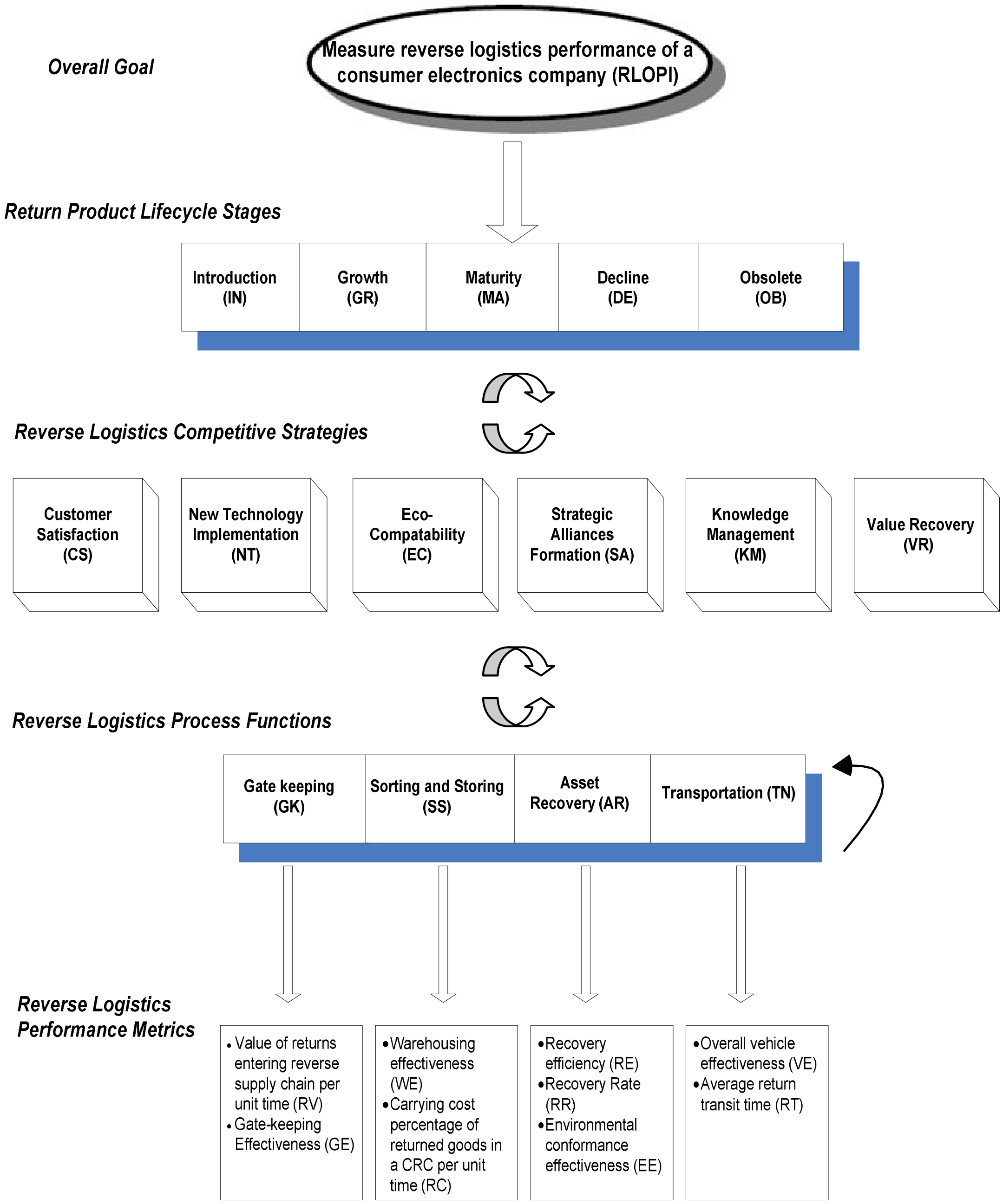


Fig 4.7 Graphical representation of AHP/ANP reverse logistics performance analytical engine
(Yellepeddi, Liles, and Rajagopalan, 2006)

Step 12 is the stage in the methodology where the organizations start to synthesize all the valuable information collected and analyzed for formulating the RLOPI. In this step, a super matrix is formed using a number of sub-steps. A set of linguistic terms are framed to evaluate the relative importance weights of the attributes involved in the decision making process. These linguistic terms are later converted into triangular fuzzy numbers to capture the preferences of the decision makers. The process of assigning membership functions to fuzzy variables is either intuitive or based on some algorithmic or logical operations. The scale used in this research has been developed earlier in section 2.4, where a detailed understanding of the fuzzy theory, linguistic variables and Chang's extent analysis to de-fuzzify the aggregate weights into crisp values is provided. Table 2.3 in chapter 2 clearly depicts the linguistics terms and their corresponding TFNs developed for this research.

Once the linguistics scale has been developed, the next step is to form the pairwise matrices based on the inter-relationships identified. Based on the relationships and hierarchy developed in this research and depicted in figure 4.7, the following pairwise matrices (Tables 4.3 to 4.31) were developed. As discussed in section 2.5 of this dissertation, comparisons are made in the form a matrix. The cells representing the intersection between a row and a column contain the relative importance of the row attribute compared to the column attribute. The diagonal of a fuzzy pairwise comparison matrix will always contain (1,1,1) because this is the evaluation of an attribute relative to itself.

Table 4.3 Pair-wise comparison matrix and importance of measures for Gate-keeping function

Gate-keeping (GK)	RV	GE	Weight
RV	(1,1,1)		
GE		(1,1,1)	

Table 4.4 Pair-wise comparison matrix and importance of measures for Sorting and Storing function

Sorting and Storing (SS)	WE	RC	Weight
WE	(1,1,1)		
RC		(1,1,1)	

Table 4.5 Pair-wise comparison matrix and importance of measures for Asset Recovery function

Asset Recovery (AR)	RE	RR	EE	Weight
RE	(1,1,1)			
RR		(1,1,1)		
EE			(1,1,1)	

Table 4.6 Pair-wise comparison matrix and importance of measures for Transportation function

Transportation (TN)	VE	RT	Weight
VE	(1,1,1)		
RT		(1,1,1)	

Table 4.7 Pair-wise comparison matrix of relative importance of functions with respect to Gate-keeping function

Gate-Keeping (GK)	SS	AR	TN	Weight
SS	(1,1,1)			
AR		(1,1,1)		
TN			(1,1,1)	

Table 4.8 Pair-wise comparison matrix of relative importance of functions with respect to Sorting to Storing function

Sorting and Storing (SS)	GK	AR	TN	Weight
GK	(1,1,1)			
AR		(1,1,1)		
TN			(1,1,1)	

Table 4.9 Pair-wise comparison matrix of importance of functions with respect to Asset recovery function

Asset Recovery (AR)	GK	SS	TN	Weight
GK	(1,1,1)			
SS		(1,1,1)		
TN			(1,1,1)	

Table 4.10 Pair-wise comparison matrix of importance of functions with respect to Transportation function

Transportation (TN)	GK	SS	AR	Weight
GK	(1,1,1)			
SS		(1,1,1)		
AR			(1,1,1)	

Table 4.11 Pair-wise comparison matrix to determine the effect of RL functions on each other under Customer Satisfaction strategy

Customer Satisfaction (CS)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.12 Pair-wise comparison matrix to determine the effect of RL functions on each other under New Technology Implementation strategy

New Technology Implementation (NT)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.13 Pair-wise comparison matrix to determine the effect of RL functions on each other under Eco-Compatibility strategy

Eco-Compatibility (EC)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.14 Pair-wise comparison matrix to determine the effect of RL functions on each other under Strategic Alliance Formation strategy

Strategic Alliance Formation (SA)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.15 Pair-wise comparison matrix to determine the effect of RL functions on each other under Knowledge Management strategy

Knowledge Management (KM)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.16 Pair-wise comparison matrix to determine the effect of RL functions on each other under Value Recovery strategy

Value Recovery (VR)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Table 4.17 Pair-wise comparison matrix to determine the relative importance of strategies under Gate-keeping function

Gate-Keeping (GK)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.18 Pair-wise comparison matrix to determine the relative importance of strategies under Sorting and Storing function

Sorting and Storing (SS)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.19 Pair-wise comparison matrix to determine the relative importance of strategies under Asset Recovery function

Asset Recovery (AR)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.20 Pair-wise comparison matrix to determine the relative importance of strategies under Transportation function

Transportation (TN)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.21 Pair-wise comparison matrix to determine the relative importance of strategies under Introduction lifecycle stage

Introduction (IN)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.22 Pair-wise comparison matrix to determine the relative importance of strategies under Growth lifecycle stage

Growth (GR)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.23 Pair-wise comparison matrix to determine the relative importance of strategies under Maturity lifecycle stage

Maturity (MA)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.24 Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage

Decline (DE)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.25 Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage

Obsolete (OB)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Table 4.26 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Customer Satisfaction strategy

CS	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Table 4.27 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under New Technology Implementation strategy

NT	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Table 4.28 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Eco-Compatibility strategy

EC	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Table 4.29 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Strategic Alliance Formation strategy

SA	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Table 4.30 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Knowledge Management strategy

KM	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Table 4.31 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Value Recovery strategy

VR	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

The next sub-step in step 12 is to evaluate the weights of each attribute and fill the pair-wise matrices. This can be achieved through well structured questions that have been developed and demonstrated in section H of the questionnaire (Appendix A). The attributes developed in this dissertation were identified to characterize an organization engaging in reverse logistics. Although these do not differ much for most companies, the importance of these attributes changes from firm to firm. Once the weights are determined and the pairwise matrices are filled, the next 2 sub steps is to calculate the aggregate weights for each matrix provided in the last column of every matrix, and to de-fuzzify the weights into crisp values. Both these steps can be achieved using the Chang's extent analysis provided in section 2.4.3 of this dissertation. A more detailed analysis of how to use it will be undertaken while discussing the case studies and in the Implementation Workbook in Appendix B.

The last sub step in step 12 is to form the super matrix itself. The two dimensional supermatrix is formed from the relative importance weight vectors to allow for the resolution of the effects of the inter-dependence that exists between clusters within the decision network hierarchy. The supermatrix is a partitioned matrix where each submatrix is composed of a set of relationships between two clusters. After the formation of the supermatrix, the final step is to determine the final relative importance weights that are used in the calculation of RLOPI. To complete this step and guarantee convergence, the columns of the supermatrix must be column stochastic. That is the weights of each column for the supermatrix need to sum to 1. This is achieved by raising the supermatrix to a large power until stabilization of weights occurs (i.e. when values in the supermatrix do not change when it is multiplied by itself again) as illustrated in tables 4.32 and 4.33 respectively.

Step 13 is the stage of the PEARL methodology where RLOPI is calculated based on the data and knowledge collected from the previous steps. The first sub-step in this stage is to measure the performance of the organization using the key performance indicators developed in section 4.5 of this chapter. Then, the values of the performance measures for other industry competitors and best in class firms are collected from benchmarking publishing companies and trade associations.

Table 4.32 Super Matrix (M)

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC						0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0							0	0	0	0
SS	0	0	0	0	0							0	0	0	0
AR	0	0	0	0	0							0	0	0	0
TN	0	0	0	0	0							0	0	0	0

Table 4.33 Converged Super Matrix (M^{2k+1})

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC						0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0							0	0	0	0
SS	0	0	0	0	0							0	0	0	0
AR	0	0	0	0	0							0	0	0	0
TN	0	0	0	0	0							0	0	0	0

The performances of the various organizations collected from various sources and the organization itself are categorized in the form of scales to assign performance ratings at the measures. In the development of the scales, the average of the performance values of the firms is assigned the performance rating of 0.5. The best and lowest performance values at each measure are respectively assigned 1.0 and 0.0. The performances of the organizations at the nine different performance measures developed in this research based on the two case studies conducted are shown below in tables 4.34 to 4.37. For qualitative measures, a simpler method similar to a Likert scale was used to calculate the performance score at the measure as depicted in the tables. Ideally, these scales would need to be constructed on more than two company sources to draw any relevant conclusions applicable throughout the consumer electronics industry.

Table 4.34 Performance scale developed to rate the Gate-keeping performance of an organization in the consumer electronics industry

Gate-Keeping (GK)			
RV ($/unit time)		GE	
Value	Rating	Range	Rating
0	1.00	GE=10	1.00
72	0.50	GE=9	0.90
144	0.00	GE=8	0.80
		GE=7	0.70
		GE=6	0.60
		GE=5	0.50
		GE=4	0.40
		GE=3	0.30
		GE=2	0.20
		GE=1	0.10

Table 4.35 Performance scale developed to rate the Sorting and Storing performance of an organization in the consumer electronics industry

Sorting and Storing (SS)			
WE		RC (%)	
Range	Rating	Value	Rating
WE=10	1.00	0	1.00
WE=9	0.90	2.5	0.50
WE=8	0.80	5	0.00
WE=7	0.70		
WE=6	0.60		
WE=5	0.50		
WE=4	0.40		
WE=3	0.30		
WE=2	0.20		
WE=1	0.10		

Table 4.36 Performance scale developed to rate the Asset Recovery performance of an organization in the consumer electronics industry

Asset Recovery (AR)					
RE (%)		RR (days)		EE	
Value	Rating	Value	Rating	Range	Rating
25	1.00	0	1.00	EE=10	1.00
12.5	0.50	13	0.50	EE=9	0.90
0	0.00	26	0.00	EE=8	0.80
				EE=7	0.70
				EE=6	0.60
				EE=5	0.50
				EE=4	0.40
				EE=3	0.30
				EE=2	0.20
				EE=1	0.10

Table 4.37 Performance scale developed to rate the Transportation performance of an organization in the consumer electronics industry

Transportation (TN)			
VE		RT (days)	
Range	Rating	Value	Rating
VE=10	1.00	0	1.00
VE=9	0.90	8.5	0.50
VE=8	0.80	17	0.00
VE=7	0.70		
VE=6	0.60		
VE=5	0.50		
VE=4	0.40		
VE=3	0.30		
VE=2	0.20		
VE=1	0.10		

The reverse logistics overall performance index has three primary components as shown in figure 4.8. These are the

1. Performance rating of the firm across the consumer electronics industry,

2. Function weights, and

3. Performance measure weights

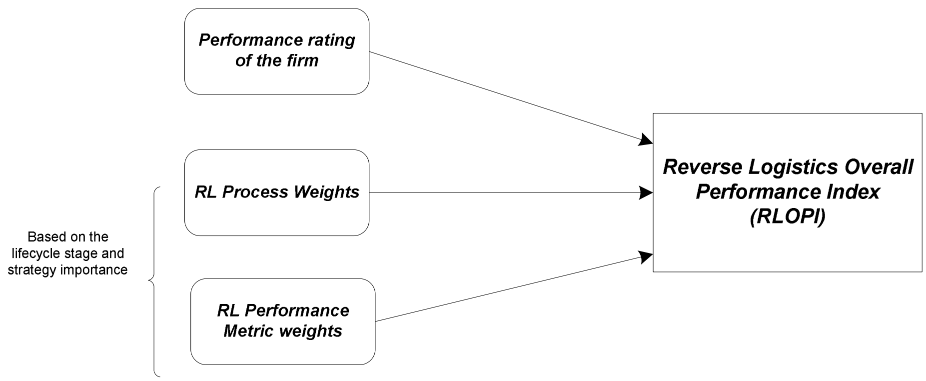


Fig 4.8 Reverse Logistics Overall Performance Index components

The RLOPI for the firm can be calculated using equations 4.6 and 4.7. The relative importance weights of the RL functions (from the supermatrix) and the relative importance weights of the measures from the pairwise comparison matrices are placed in the columns entitled RL function weight (W_{FX}) and Measure weight (W_{mX}) respectively (see Table 4.38). The performance of the firm at a measure can be calculated by multiplying the performance rating at the measure (PR_X), the measure weight and the RL function weight. The calculated performance scores of the firm at the measures are placed in the column titled Performance score at the measure. The final RLOPI of a firm is calculated by summing the performance scores of the firm at the measures (a column sum).

Performance Score at the RL measure: $S_{mX} = PR_X * W_{mX} * W_{FX}$ (4.6)

Reverse Logistics Overall Performance Index:

$$RLOPI = \sum S_{mX} \qquad (4.7)$$

Table 4.38 Calculation of the Reverse Logistics Overall Performance Index

	Companies		**Performance Rating across electronics industry (PR_X)**		**Measure Weight (W_{mX})**		**RL Function Weight (W_{FX})**		**Performance score at the measure (S_{mX})**	
	C-1	C-2	PR-1	PR-2	W_{mX1}	W_{mX2}	W_{FX1}	W_{FX2}	S_{mX1}	S_{mX2}
GK										
RV										
GE										
SS										
WE										
RC										
AR										
RE										
RR										
EE										
TN										
VE										
RT										
									RLOPI $= \sum S_{mX1}$	RLOPI $=\sum S_{mX2}$

The overall process of calculating the RLOPI can be represented using a simple input/output (I/O) diagram as shown in figure 4.9 below. It highlights the various inputs and outputs at each stage and the process undertaken to calculate the various weights.

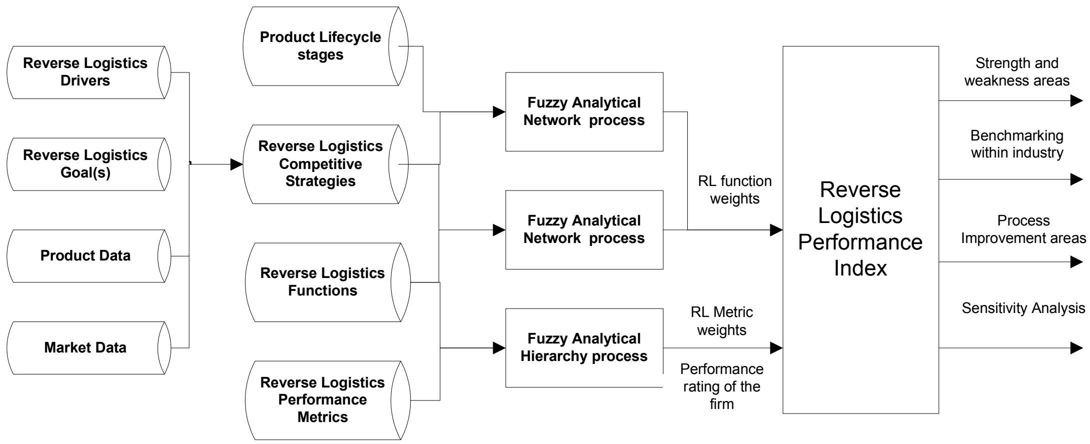


Fig 4.9 Reverse Logistics Overall Performance Index I/O diagram

Steps 14 to 16 recommend the organization to conduct a post RLOPI calculation analysis. Based on the RLOPI that reflects the returns management performance in the consumer electronics industry, an organization can determine the areas that need more attention in terms of capital investments, process improvement initiatives, and improving corporate image. From table 4.34, the organization can assess the performance scores across each RL function and each measure as compared to the best in class standards. A valuable step is to perform a sensitivity analysis to determine how the changes in measure weights and function weights are affecting the overall performance of the firm. In order to do so, steps 12 to 16 need to be iterated until the areas that have the greatest influence on the RLOPI are marked for immediate attention. This step highlights the strengths and weaknesses of the organization with respect to the industry and helps it prioritize improvement projects. Step 15 is the process of gathering the knowledge accumulated from the sensitivity analysis and performing a SWOT –

Strength, Weakness, Opportunity, Threat analysis. This is a critical step before taking any process improvement decision as it helps the organization to underscore the various strength and weak areas, discover new opportunities for process improvement and identify the threats as to what the obstacles are and what the competition is doing. Strengths and weaknesses are internal to your organization**.** Opportunities and threats relate to external factors. For this reason the SWOT Analysis is sometimes called Internal-External Analysis and the SWOT Matrix is sometimes called an IE Matrix Analysis Tool. This analysis aids in answering other questions such as:

- What advantages does your company have?
- What do you do better than anyone else?
- What unique or lowest-cost resources do you have access to?
- What should you avoid?
- Where are the good opportunities facing you?
- What is your competition doing?
- Could any of your weaknesses seriously threaten your business?

Since the results from this kind of analysis are quantitative, the decision makers can evaluate and benchmark with their competitor's performance and feedback their improvement decisions and repeat steps 7 to 16 of the PEARL methodology. No process is 100% accurate and needs continuous improvement and so is returns management. In order to facilitate the implementation of PEARL and developing RLOPI an implementation workbook was developed (Appendix B). The workbook demonstrates a step by step procedure of implementing the methodology and developing the RLOPI with all the formulations. This allows an organization to work through the development of Reverse Logistics Overall Performance Index with little background knowledge of the various topics such as AHP and fuzzy theory. The results from the case studies and the revised methodology with correlation to the implementation workbook will be discussed in the next chapter.

CHAPTER 5

METHODOLOGY DEMONSTRATIONS IN CASE STUDIES

5.1 Case Study Approach

The case study approach was selected because it is an ideal method when a holistic, in-depth investigation is needed (Feagin, Orum, and Sjoberg, 1991). This case study approach helps to gather the facts from the real world and explain the linkages between causes and effects. There are a variety of benefits to conducting a case study approach to research, especially in comparison with other methodologies. One such benefit is that the information provided is usually more concrete and contextual, specifically due to the in depth analysis it offers of the case being studied. One of the biggest advantages is the ability to use the results of the case study as a springboard for framing quantitative questions, which can then be analyzed in greater depth in future analysis (Bell, 1999). This research involves understanding the complex relationships between the various decision making attributes that make up the performance index. The nature of this research required an approach that could be flexible to allow open questions to collect information from organizations under study that have many different settings. Therefore, the case study approach is suitable for this research as it accommodates for collection of real world information to validate the proposed methodology through in-depth interviews.

The initial methodology developed in chapter 4 was demonstrated at two companies in the consumer electronics industry. These companies were selected based on their expertise in returns management processes and their proximity within the Dallas-FortWorth Metroplex. First, an invitation to participate in this study was made to the organizations. The invitational letter sent to these companies was followed up by telephone calls regarding inquiring about their willingness to participate in this project. Finally, an on site presentation of the type of data to be collected and the methodology demonstration process was conducted to get their final approval. The data was collected mainly through face to face interviews and questionnaires. The questionnaire (Appendix A) developed for this investigation was administered to logistics managers in the studied organizations. The questionnaire addressed the following issues:

- Electronic product classification structure
- Reverse logistics network and processes, Reverse logistics drivers
- PEARL (Performance Evaluation Analytic for Reverse Logistics) methodology
- Return product lifecycle analysis
- Reverse logistics strategies
- Reverse logistics performance metrics and calculations
- Inter-relationships and hierarchy between the various attributes involved in the decision making process
- Pairwise comparison of various attributes
- Reverse logistics overall performance index formulations

The interviews were accomplished by visiting the logistics managers of both the companies and completing the questionnaires. This approach helped to conduct in-depth interviews and was useful in answering a number of questions regarding the validity of the methodology. Further, it provided an opportunity to explore issues of interest in greater detail and identify certain pros and cons of implementing the methodology in a real world reverse supply chain system. An overview of the companies and a detailed discussion of the validity of the PEARL methodology and the case study recommendations and results are discussed in the following sections. Finally, a revised and validated methodology will be presented.

5.2 Overview of Company A and Company B

Founded in 1974, **Company A**, is a leading distributor of IT products, with more than 90,000 customers in over 100 countries. The company's business model enables technology solution providers, manufacturers and publishers to cost-effectively sell to and support end users ranging from small-to-midsize businesses (SMB) to large enterprises. Ranked 107th on the FORTUNE 500®, the company generated $20.5 billion in sales for its fiscal year ended January 31, 2006. Its core business is worldwide logistics management of technology products. The company and its subsidiaries operate 26 fulfillment centers in the U.S., Canada, Latin America, Europe and the Middle East. The company's original charter was to market data processing supplies directly to end users of mini and mainframe computers. In 1983, the company expanded its targeted markets and redirected its efforts toward servicing microcomputer resellers as a wholesale distributor. It initially employed about a dozen people during its formative years and handled all customer orders from a small office/warehouse building in Clearwater, Fla., not far from the company's current headquarters campus. From 10 employees in 1983 to about 8,200 employees today, it has emerged as a leading global provider of IT products, logistics management and other value-added services.

The company has evolved its business from a "pick, pack and ship" operation into an "integrated supply chain specialist.” Through initiatives such as its Specialized Business Units (SBUs), Company A tailors its product and service offerings, logistics management and technical support to individual market segments. These specialized offerings combined with the infrastructure and economies of scale that only a broad line market leader can deliver enable resellers, manufacturers and publishers to capitalize on incremental business opportunities. It has successfully extended its operations into markets throughout the world. Solid performance in the United States supported the corporation's foray into international markets. The company’s geographic expansion has been matched by an equally successful movement into new market segments. In 1992, for example, the customer base of 25,000 was comprised largely of value-added resellers (VARs), corporate resellers and franchisees. Today, it serves more than 90,000 customers including ASPs, ISPs, web integrators, VARs, corporate resellers, systems integrators, system builders, government resellers, exporters, retailers, direct marketers, catalogers and Internet resellers. Company A has developed many specialized programs and business units to help ensure its continued success in both new and traditional business channels.

Since its formation in 1974, **Company B** has grown faster than the semiconductor industry as a whole and it has been one of the world's Top Ten semiconductor suppliers since 1999. It has close to 50,000 employees, 16 advanced research and development units, 39 design and application centers, 16 main manufacturing sites and 78 sales offices in 36 countries. The company's U.S. Headquarters are in Carrollton, Texas.

Today, an unrivalled combination of silicon and system expertise, manufacturing strength, Intellectual Property (IP) portfolio, industrial and academic partnerships, and one of the industry's broadest product ranges makes Company B a world leader in developing and delivering semiconductor solutions across the spectrum of microelectronics applications. It is one of the world's largest semiconductor companies, with net revenues of US$8.88 billion in 2005 and market leadership that is spread across many fields.

According to the latest industry data, Company B is the world's fifth largest semiconductor company and has leading positions in sales of Analog Products, Analog Application Specific Integrated Circuits and Analog Application Specific Standard Products. Furthermore, it was the 3rd biggest semiconductor supplier in China in 2005. Today, the company offers one of the world's broadest product ranges, with over 3,000 main types of products. The carefully balanced portfolio includes both application-specific products containing a large proprietary IP content and multi-segment products that range from discrete devices to high-performance microcontrollers. The Company's sales are well balanced between the industry's five major high-growth sectors:

Communications (38%), Consumer (16%), Computer (17%), Automotive (15%) and Industrial (14%). The balanced portfolio approach allows the company to address the needs of all microelectronics users, from global strategic customers to local enterprises that need fully-supported general-purpose devices.

It has leading-edge manufacturing facilities on four continents. The wafer fabs are complemented by highly efficient assembly and test facilities located in China, Malaysia, Malta, and Morocco. Since its creation, Company A has exhibited an unwavering commitment to R&D. In 2005, it spent US$1.63 billion in R&D, which was some 18.3% of its 2005 revenues. The company's technical, marketing, and manufacturing strengths are matched and further enhanced by an unswerving commitment to Total Quality and Corporate Responsibility (TQCR) that has earned prestigious awards around the world. Since 1991, the company's sites have received more than 70 awards for excellence in all areas of Corporate Responsibility, from quality to corporate governance, social issues and environmental protection. Its commitment to environmental responsibility has resulted in substantial reductions over the years in the consumption of energy, water, paper, and hazardous chemicals, increased recycling of waste products and a significant cut in greenhouse-gas emissions.

5.3 Discussion of Demonstration Results

Several conclusions about the methodology resulted from the case study demonstrations. The feedback from both the participants was mostly favorable, and the overall consensus was that the PEARL methodology is a practical and valuable tool in evaluating the performance of reverse supply chains. Both the companies agreed that the Reverse Logistics Overall Performance Index provided organizations around the world engaging in reverse logistics activities a quantitative measure to demonstrate and evaluate their returns management capabilities and benchmark against best in class standards. To facilitate company demonstrations, an interview questionnaire was developed and provided in Appendix A of this dissertation. Analysis of the methodology demonstrations in case studies resulted in the general conclusions presented in table 5.1 and it was established that the methodology required no modifications. However, there were some good recommendations offered by the companies that were considered in the refinement of the methodology discussed in the next section of this chapter.

Table 5.1 Generic comparison of methodology demonstration across cases

Methodology Criteria	**Company A**	**Company B**
Product Classification	✓	✓
Reverse Supply Chain Network Design	✓	✓
Identification of RL functions and major players	✓	✓
Major drivers of Reverse Logistics	✓	✓
Product lifecycle analysis of returns	✓	✓
Business Strategies for Reverse Supply Chains	✓	✓
Key Process Performance Metrics	✓	✓
Inter-relationship between the four attributes	✓	✓
Development of the RLOPI	✓	✓
Use of ANP and Fuzzy Logic in weight calculations	✓	✓
Overall structure of the PEARL methodology	✓	✓

In addition to validating the methodology through case studies, the demonstrations also benefited in calculating the Reverse Logistics Overall Performance Indexes of the organizations thereby providing the participants a rough estimate on their returns management performances across industry best standards. The first step in calculating the RLOPI after developing the right attributes and identifying their inter-relationships is to determine the weights of each attribute on RLOPI. This can be done using ANP and fuzzy theory and forming pairwise matrices based on the inter-dependencies between the clusters of attributes. The participants were asked to answer questions in terms of how their customers would rate the importance of one attribute over another. The Fuzzy Analytical Network Process was used to facilitate this process (Refer section H of the interview questionnaire in Appendix A). In both these cases, the decision maker was assumed to be just one person, but in reality there could be more than one decision maker. In such a scenario, the average value is considered as the importance of one attribute over another. Once the importance of one attribute over another is established using the questions and the tables are populated, the next step is to calculate the weights. This can be achieved using Chang's Extent Analysis discussed in section 2.6.3 of this dissertation. It is depicted for one pairwise matrix below for illustration.

Table 5.2 Pair-wise comparison matrix and importance of measures for Gate-keeping function – Company A

Gate-keeping GK)	RV	GE	Weight
RV	(1,1,1)	(1/3,2/5,1/2)	0
GE	(2,5/2,3)	(1,1,1)	1

Performing Step 1 of the analysis and using equations 2.6, 2.7, 2.8 and 2.9 we have

S_1= (1.33, 1.4, 1.5) * (1/5.5, 1/4.9, 1/4.33) = (0.24, 0.28, 0.35)

S_2= (3, 3.5, 4) * (1/5.5, 1/4.9, 1/4.33) = (0.54, 0.71, 0.92)

Performing Step 2 of the analysis and using equations from 2.10 to 2.13 we have

$V\ (S_1 \geq S_2) = 0$

$V(S_2 \geq S_1) = 1$

Performing Step 3 of the analysis and using equations from 2.14 to 2.17 we have

$d'(A_1) = \min V(S_1 \geq S_2) = \min(0) = 0$

$d'(A_2) = \min V(S_2 \geq S_1) = \min(1) = 1$

Therefore, $W' = (0, 1)^T$

$W = (0, 1)^T$

Table 5.3 Pair-wise comparison matrix and importance of measures for Sorting and Storing function – Company A

Sorting and Storing (SS)	WE	RC	Weight
WE	(1,1,1)	(2,5/2,3)	1
RC	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.4 Pair-wise comparison matrix and importance of measures for Asset Recovery function – Company A

Asset Recovery (AR)	RE	RR	EE	Weight
RE	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	0.23
RR	(2,5/2,3)	(1,1,1)	(2,5/2,3)	0.77
EE	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.5 Pair-wise comparison matrix and importance of measures for Transportation function – Company A

Transportation (TN)	VE	RT	Weight
VE	(1,1,1)	(1/3,2/5,1/2)	0
RT	(2,5/2,3)	(1,1,1)	1

Table 5.6 Pair-wise comparison matrix of relative importance of functions with respect to Gate-keeping function – Company A

Gate-Keeping (GK)	SS	AR	TN	Weight
SS	(1,1,1)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.29
AR	(2/5,1/2,2/3)	(1,1,1)	(2,5/2,3)	0.36
TN	(2,5/2,3)	(1/3,2/5,1/2)	(1,1,1)	0.35

Table 5.7 Pair-wise comparison matrix of relative importance of functions with respect to Sorting and Storing function – Company A

Sorting and Storing (SS)	GK	AR	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.53
AR	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.38
TN	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0.09

Table 5.8 Pair-wise comparison matrix of relative importance of functions with respect to Asset Recovery function – Company A

Asset Recovery (AR)	GK	SS	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(1,1,1)	0.57
SS	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.43
TN	(1,1,1)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.9 Pair-wise comparison matrix of relative importance of functions with respect to Transportation function – Company A

Transportation (TN)	GK	SS	AR	Weight
GK	(1,1,1)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.29
SS	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.32
AR	(2,5/2,3)	(2/5,1/2,2/3)	(1,1,1)	0.39

Table 5.10 Pair-wise comparison matrix to determine the effect of RL functions on each other under Customer Satisfaction strategy – Company A

Customer Satisfaction (CS)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	0.73
SS	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0
AR	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	0.17
TN	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	0.10

Table 5.11 Pair-wise comparison matrix to determine the effect of RL functions on each other under New Technology Implementation strategy – Company A

New Technology Implementation (NT)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(3/2,2,5/2)	0.63
SS	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(3/2,2,5/2)	0.37
AR	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	0
TN	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.12 Pair-wise comparison matrix to determine the effect of RL functions on each other under Eco-Compatibility strategy – Company A

Eco-Compatibility (EC)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.48
SS	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	(3/2,2,5/2)	0.13
AR	(2/5,1/2,2/3)	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	0.39
TN	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.13 Pair-wise comparison matrix to determine the effect of RL functions on each other under Strategic Alliance Formation strategy – Company A

Strategic Alliance Formation (SA)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(1/2,2/3,1)	(3/2,2,5/2)	0.43
SS	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(1,3/2,2)	0
AR	(1,3/2,2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	0.57
TN	(2/5,1/2,2/3)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.14 Pair-wise comparison matrix to determine the effect of RL functions on each other under Knowledge Management strategy – Company A

Knowledge Management (KM)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.49
SS	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.35
AR	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.16
TN	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.15 Pair-wise comparison matrix to determine the effect of RL functions on each other under Value Recovery strategy – Company A

Value Recovery (VR)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.49
SS	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
AR	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	0.36
TN	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	0.15

Table 5.16 Pair-wise comparison matrix to determine the relative importance of strategies under Gate-keeping function – Company A

GK	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	0.23
NT	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	0.25
EC	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
SA	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.05
KM	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	0.29
VR	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.18

Table 5.17 Pair-wise comparison matrix to determine the relative importance of strategies under Sorting and Storing function – Company A

SS	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2/5,1/2,2/3)	(2,5/2,3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.03
NT	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	0.32
EC	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.25
SA	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	0
KM	(1,1,1)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,3/2,2)	(1,1,1)	(1,1,1)	0.19
VR	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.21

Table 5.18 Pair-wise comparison matrix to determine the relative importance of strategies under Asset Recovery function – Company A

AR	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	0.02
NT	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	0.22
EC	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0.02
SA	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0.05
KM	(3/2,2,5/2)	(1,3/2,2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.33
VR	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.36

Table 5.19 Pair-wise comparison matrix to determine the relative importance of strategies under Transportation function – Company A

TN	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1,1,1)	(2,5/2,3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	0.3
NT	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	0.23
EC	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
SA	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0.05
KM	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	0.16
VR	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.26

Table 5.20 Pair-wise comparison matrix to determine the relative importance of strategies under Introduction lifecycle stage – Company A

IN	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	0.39
NT	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	0.15
EC	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0
SA	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	0.14
KM	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	0.32
VR	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.21 Pair-wise comparison matrix to determine the relative importance of strategies under Growth lifecycle stage – Company A

GR	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(3/2,2,5/2)	(2,5/2,3)	(3/2,2,5/2)	(1,1,1)	(1,3/2,2)	0.39
NT	(2/5,1/2,2/3)	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	0
EC	(1/3,2/5,1/2)	(1,3/2,2)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0.03
SA	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.1
KM	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	0.16
VR	(1/2,2/3,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.32

Table 5.22 Pair-wise comparison matrix to determine the relative importance of strategies under Maturity lifecycle stage – Company A

MA	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	0.27
NT	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
EC	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.08
SA	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	0.07
KM	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(1,3/2,2)	(1,1,1)	(1,1,1)	0.22
VR	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	0.36

Table 5.23 Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage – Company A

DE	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
NT	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	0
EC	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(2/5,1/2,2/3)	0.27
SA	(3/2,2,5/2)	(2,5/2,3)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.16
KM	(3/2,2,5/2)	(2,5/2,3)	(1/2,2/3,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.18
VR	(3/2,2,5/2)	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.39

Table 5.24 Pair-wise comparison matrix to determine the relative importance of strategies under Obsolete lifecycle stage – Company A

OB	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)	(2/5,1/2,2/3)	0
NT	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/2,2/3,1)	(1/3,2/5,1/2)	0
EC	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.4
SA	(1,1,1)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0.03
KM	(1/2,2/3,1)	(1,3/2,2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	0
VR	(3/2,2,5/2)	(2,5/2,3)	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.57

Table 5.25 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Customer Satisfaction strategy – Company A

CS	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	0.23
GR	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.42
MA	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.33
DE	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.02
OB	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.26 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under New Technology Implementation strategy – Company A

NT	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.42
GR	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.33
MA	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.22
DE	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.03
OB	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.27 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Eco-Compatibility strategy – Company A

EC	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
GR	(3/2,2,5/2)	(1,1,1)	(1,3/2,2)	(1/2,2/3,1)	(3/2,2,5/2)	0.33
MA	(3/2,2,5/2)	(1/2,2/3,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.35
DE	(3/2,2,5/2)	(1,3/2,2)	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)	0.30
OB	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/2,2/3,1)	(1,1,1)	0.02

Table 5.28 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Strategic Alliance Formation strategy – Company A

SA	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.30
GR	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.36
MA	(1,1,1)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.25
DE	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.09
OB	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.29 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Knowledge Management strategy – Company A

KM	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.73
GR	(1/2,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.27
MA	(1/2,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1,1,1)	0
DE	(1/2,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1,1,1)	0
OB	(1/2,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1,1,1)	0

Table 5.30 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Value Recovery strategy – Company A

VR	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.70
GR	(1/2,2/5,1/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.15
MA	(1/2,2/5,1/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.15
DE	(1/2,2/5,1/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0
OB	(1/2,2/5,1/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.31 Pair-wise comparison matrix and importance of measures for Gate-keeping function – Company B

Gate-keeping GK)	RV	GE	Weight
RV	(1,1,1)	(5/2,3,7/2)	1
GE	(2/7,1/3,2/5)	(1,1,1)	0

Table 5.32 Pair-wise comparison matrix and importance of measures for Sorting and Storing function – Company B

Sorting and Storing (SS)	WE	RC	Weight
WE	(1,1,1)	(2,5/2,3)	1
RC	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.33 Pair-wise comparison matrix and importance of measures for Asset Recovery function – Company B

Asset Recovery (AR)	RE	RR	EE	Weight
RE	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.82
RR	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.18
EE	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.34 Pair-wise comparison matrix and importance of measures for Transportation function – Company B

Transportation (TN)	VE	RT	Weight
VE	(1,1,1)	(3/2,2,5/2)	1
RT	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.35 Pair-wise comparison matrix of relative importance of functions with respect to Gate-keeping function – Company B

Gate-Keeping (GK)	SS	AR	TN	Weight
SS	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.66
AR	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.34
TN	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.36 Pair-wise comparison matrix of relative importance of functions with respect to Sorting to Storing function – Company B

Sorting and Storing (SS)	GK	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.77
AR	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.23
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.37 Pair-wise comparison matrix of relative importance of functions with respect to Asset recovery function – Company B

Asset Recovery (AR)	GK	SS	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.77
SS	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.23
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.38 Pair-wise comparison matrix of relative importance of functions with respect to Transportation function – Company B

Transportation (TN)	GK	SS	AR	Weight
GK	(1,1,1)	(2,5/2,3)	(2/5,1/2,2/3)	0.40
SS	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	0
AR	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.60

Table 5.39 Pair-wise comparison matrix to determine the effect of RL functions on each other under Customer Satisfaction strategy – Company B

Customer Satisfaction (CS)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(1/3,2/5,1/2)	(2,5/2,3)	0.32
SS	(1/3,2/5,1/2)	(1,1,1)	(5/2,3,7/2)	(2,5/2,3)	0.36
AR	(2,5/2,3)	(2/7,1/3,2/5)	(1,1,1)	(2,5/2,3)	0.32
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.40 Pair-wise comparison matrix to determine the effect of RL functions on each other under New Technology Implementation strategy – Company B

New Technology Implementation (NT)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(1,1,1)	(2,5/2,3)	(1/3,2/5,1/2)	0.14
SS	(1,1,1)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.43
AR	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2/7,1/3,2/5)	0
TN	(2,5/2,3)	(1/3,2/5,1/2)	(5/2,3,7/2)	(1,1,1)	0.43

Table 5.41 Pair-wise comparison matrix to determine the effect of RL functions on each other under Eco-Compatibility strategy – Company B

Eco-Compatibility (EC)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	0
SS	(2,5/2,3)	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	0.32
AR	(2,5/2,3)	(2,5/2,3)	(1,1,1)	(5/2,3,7/2)	0.68
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(1,1,1)	0

Table 5.42 Pair-wise comparison matrix to determine the effect of RL functions on each other under Strategic Alliance Formation strategy – Company B

Strategic Alliance Formation (SA)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.64
SS	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.36
AR	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	0
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(1,1,1)	0

Table 5.43 Pair-wise comparison matrix to determine the effect of RL functions on each other under Knowledge Management strategy – Company B

Knowledge Management (KM)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(5/2,3,7/2)	0.09
SS	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.62
AR	(3/2,2,5/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.29
TN	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.44 Pair-wise comparison matrix to determine the effect of RL functions on each other under Value Recovery strategy – Company B

Value Recovery (VR)	GK	SS	AR	TN	Weight
GK	(1,1,1)	(2,5/2,3)	(2/7,1/3,2/5)	(2,5/2,3)	0.26
SS	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	0
AR	(5/2,3,7/2)	(2,5/2,3)	(1,1,1)	(5/2,3,7/2)	0.74
TN	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(1,1,1)	0

Table 5.45 Pair-wise comparison matrix to determine the relative importance of strategies under Gate-keeping function – Company B

GK	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)	(2,5/2,3)	(1,1,1)	0.64
NT	(2/7,1/3,2/5)	(1,1,1)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.31
EC	(2/7,1/3,2/5)	(1,1,1)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0
SA	(2/7,1/3,2/5)	(1/3,2/5,1/2)	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2/7,1/3,2/5)	0
KM	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	0
VR	(1,1,1)	(1/3,2/5,1/2)	(1,1,1)	(5/2,3,7/2)	(2,5/2,3)	(1,1,1)	0.05

Table 5.46 Pair-wise comparison matrix to determine the relative importance of strategies under Sorting and Storing function – Company B

SS	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2/7,1/3,2/5)	(5/2,3,7/2)	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	0
NT	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)	(2,5/2,3)	(1,1,1)	(5/2,3,7/2)	0.50
EC	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0
SA	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(1,1,1)	(1,1,1)	(2,5/2,3)	0.12
KM	(5/2,3,7/2)	(1,1,1)	(2,5/2,3)	(1,1,1)	(1,1,1)	(5/2,3,7/2)	0.38
VR	(5/2,3,7/2)	(2/7,1/3,2/5)	(1,1,1)	(1/3,2/5,1/2)	(2/7,1/3,2/5)	(1,1,1)	0

Table 5.47 Pair-wise comparison matrix to determine the relative importance of strategies under Asset Recovery function – Company B

AR	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	0.26
NT	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.02
EC	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
SA	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.25
KM	(2,5/2,3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.22
VR	(2,5/2,3)	(2,5/2,3)	(3/2,2,5/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0.25

Table 5.48 Pair-wise comparison matrix to determine the relative importance of strategies under Transportation function – Company B

TN	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.32
NT	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	0.33
EC	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0
SA	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.22
KM	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2,5/2,3)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.13
VR	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.49 Pair-wise comparison matrix to determine the relative importance of strategies under Introduction lifecycle stage – Company B

IN	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.43
NT	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.34
EC	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0
SA	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.18
KM	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	(2/5,1/2,2/3)	(1,1,1)	(3/2,2,5/2)	0.05
VR	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.50 Pair-wise comparison matrix to determine the relative importance of strategies under Growth lifecycle stage – Company B

GR	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	0.37
NT	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(1/3,2/5,1/2)	(3/2,2,5/2)	(2,5/2,3)	0.02
EC	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(3/2,2,5/2)	0
SA	(3/2,2,5/2)	(2,5/2,3)	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.43
KM	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2,5/2,3)	(2/5,1/2,2/3)	(1,1,1)	(2,5/2,3)	0.18
VR	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.51 Pair-wise comparison matrix to determine the relative importance of strategies under Maturity lifecycle stage – Company B

MA	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.47
NT	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.26
EC	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(1/3,2/5,1/2)	0
SA	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2,5/2,3)	(1,1,1)	(3/2,2,5/2)	(2/5,1/2,2/3)	0.08
KM	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	0
VR	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2,5/2,3)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	0.19

Table 5.52 Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage – Company B

DE	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.13
NT	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/5,1/2,2/3)	0.25
EC	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	(2,5/2,3)	(2,5/2,3)	0.03
SA	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(1/3,2/5,1/2)	0.27
KM	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1,1,1)	(1/3,2/5,1/2)	0
VR	(2,5/2,3)	(3/2,2,5/2)	(1/3,2/5,1/2)	(2,5/2,3)	(2,5/2,3)	(1,1,1)	0.32

Table 5.53 Pair-wise comparison matrix to determine the relative importance of strategies under Obsolete lifecycle stage – Company B

OB	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	0
NT	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.47
EC	(2,5/2,3)	(1/3,2/5,1/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	0
SA	(2,5/2,3)	(1/3,2/5,1/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	0.27
KM	(2,5/2,3)	(1/3,2/5,1/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	(2,5/2,3)	0.20
VR	(2,5/2,3)	(1/3,2/5,1/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	0.06

Table 5.54 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Customer Satisfaction strategy – Company B

Customer Satisfaction (CS)	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.44
GR	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.53
MA	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.03
DE	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0
OB	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.55 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under New Technology Implementation strategy – Company B

New Technology Implementation (NT)	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.36
GR	(2/5,1/2,2/3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.36
MA	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.23
DE	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.05
OB	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

Table 5.56 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Eco-Compatibility strategy – Company B

Eco-Compatibility (EC)	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2,5/2,3)	0.02
GR	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(2,5/2,3)	(2,5/2,3)	0.43
MA	(2,5/2,3)	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	(3/2,2,5/2)	0.52
DE	(2,5/2,3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1/3,2/5,1/2)	0
OB	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2,5/2,3)	(1,1,1)	0.03

Table 5.57 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Strategic Alliance Formation strategy – Company B

Strategic Alliance Formation (SA)	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(1/3,2/5,1/2)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.36
GR	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.52
MA	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(3/2,2,5/2)	0.12
DE	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(3/2,2,5/2)	0
OB	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	0

Table 5.58 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Knowledge Management strategy – Company B

KM	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.50
GR	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(2,5/2,3)	0.36
MA	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.14
DE	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	0
OB	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	0

Table 5.59 Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Value Recovery strategy – Company B

VR	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2,5/2,3)	0
GR	(3/2,2,5/2)	(1,1,1)	(1/3,2/5,1/2)	(3/2,2,5/2)	(3/2,2,5/2)	0.29
MA	(3/2,2,5/2)	(2,5/2,3)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	0.52
DE	(3/2,2,5/2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(2,5/2,3)	0.19
OB	(1/3,2/5,1/2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1/3,2/5,1/2)	(1,1,1)	0

The process of determining the normalized weights is followed by populating these weights in the appropriate columns of the supermatrix based on the interdependencies. In case of the RL functions and the strategies interdependencies, there is also an additional step of calculating the z-vector to include the relative importance among the RL functions on a third RL function under each competitive strategy (See figure 4.6). Tables 5.60 and 5.61 depict the contributions among RL functions to obtain the real importance of the functions (z-vector). These steps should be repeated for every RL enabling strategy to calculate their respective z-vectors. Tables 5.60 and 5.61 illustrate this for one strategy. The final super matrix is formed by combining the z-vectors and importance weight vectors of the strategies and the lifecycle stages. The supermatrix is raised to the power of M^{2k+1} to achieve convergence.

Table 5.60 Z-vector to determine the total contribution of RL functions with respect to a particular strategy for Company A

GK	SS	AR	TN		CS		Z-Vector
1	0.53	0.57	0.29		0.73		0.86
0.29	1	0.43	0.32	X	0	=	0.31
0.36	0.38	1	0.39		0.17		0.47
0.35	0.09	0	1		0.1		0.35

Table 5.61 Z-vector to determine the total contribution of RL functions with respect to a particular strategy for Company B

GK	SS	AR	TN		CS		Z-Vector
1	0.77	0.77	0.4		0.32		0.85
0.66	1	0.23	0	X	0.36	=	0.64
0.34	0.23	1	0.6		0.32		0.51
0	0	0	1		0		0

The super matrices for both Company A and Company B are depicted in Tables 5.62 and 5.64. The next step is to make them column stochastic to determine the final relative importance weights of each of the attributes. This step involves normalizing the super matrix by dividing each weight in the column by the sum of that column (Tables 5.63 and 5.65). For convergence to a final set of weights, the super matrix is raised to a large power until stabilization of weights occurs (i.e. when values in the super matrix do not change when it is multiplied by itself again). It occurred at 225th and 171st power for Company A and Company B respectively. For this research, to calculate the large powers a web based publicly available software called Quick Math was used (http://www.quickmath.com/www02/pages/modules/matrices/index.shtml).

Table 5.62 Super Matrix (M) – Company A

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.23	0.42	0	0.30	0.73	0.70	0	0	0	0
GR	0	0	0	0	0	0.42	0.33	0.33	0.36	0.27	0.15	0	0	0	0
MA	0	0	0	0	0	0.33	0.22	0.35	0.25	0	0.15	0	0	0	0
DE	0	0	0	0	0	0.02	0.03	0.30	0.09	0	0	0	0	0	0
OB	0	0	0	0	0	0	0	0.02	0	0	0	0	0	0	0
CS	0.39	0.39	0.27	0	0	0	0	0	0	0	0	0.23	0.03	0.02	0.3
NT	0.15	0	0	0	0	0	0	0	0	0	0	0.25	0.32	0.22	0.23
EC	0	0.03	0.08	0.27	0.4	0	0	0	0	0	0	0	0.25	0.02	0
SA	0.14	0.1	0.07	0.16	0.03	0	0	0	0	0	0	0.05	0	0.05	0.05
KM	0.32	0.16	0.22	0.18	0	0	0	0	0	0	0	0.29	0.19	0.33	0.16
VR	0	0.32	0.36	0.39	0.57	0	0	0	0	0	0	0.18	0.21	0.36	0.26
GK	0	0	0	0	0	0.43	0.42	0.39	0.38	0.38	0.37	0	0	0	0
SS	0	0	0	0	0	0.15	0.27	0.21	0.18	0.28	0.17	0	0	0	0
AR	0	0	0	0	0	0.24	0.18	0.30	0.37	0.24	0.30	0	0	0	0
TN	0	0	0	0	0	0.18	0.13	0.10	0.07	0.10	0.16	0	0	0	0

Table 5.63 Column Stochastic Super Matrix – Company A

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.11	0.21	0	0.15	0.365	0.35	0	0	0	0
GR	0	0	0	0	0	0.21	0.17	0.17	0.18	0.135	0.07	0	0	0	0
MA	0	0	0	0	0	0.16	0.11	0.17	0.14	0	0.08	0	0	0	0
DE	0	0	0	0	0	0.01	0.01	0.15	0.05	0	0	0	0	0	0
OB	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0
CS	0.39	0.39	0.27	0	0	0	0	0	0	0	0	0.23	0.03	0.02	0.3
NT	0.15	0	0	0	0	0	0	0	0	0	0	0.25	0.32	0.22	0.23
EC	0	0.03	0.08	0.27	0.4	0	0	0	0	0	0	0	0.25	0.02	0
SA	0.14	0.1	0.07	0.16	0.03	0	0	0	0	0	0	0.05	0	0.05	0.05
KM	0.32	0.16	0.22	0.18	0	0	0	0	0	0	0	0.29	0.19	0.33	0.16
VR	0	0.32	0.36	0.39	0.57	0	0	0	0	0	0	0.18	0.21	0.36	0.26
GK	0	0	0	0	0	0.22	0.21	0.20	0.19	0.19	0.18	0	0	0	0
SS	0	0	0	0	0	0.08	0.14	0.10	0.09	0.14	0.09	0	0	0	0
AR	0	0	0	0	0	0.12	0.09	0.15	0.18	0.12	0.15	0	0	0	0
TN	0	0	0	0	0	0.09	0.06	0.05	0.03	0.05	0.08	0	0	0	0

Table 5.64 Super Matrix (M) – Company B

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.44	0.36	0.02	0.36	0.50	0	0	0	0	0
GR	0	0	0	0	0	0.53	0.36	0.43	0.52	0.36	0.29	0	0	0	0
MA	0	0	0	0	0	0.03	0.23	0.52	0.12	0.14	0.52	0	0	0	0
DE	0	0	0	0	0	0	0.05	0	0	0	0.19	0	0	0	0
OB	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0
CS	0.43	0.37	0.47	0.13	0	0	0	0	0	0	0	0.64	0	0.26	0.32
NT	0.34	0.02	0.26	0.25	0.47	0	0	0	0	0	0	0.31	0.50	0.02	0.33
EC	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
SA	0.18	0.43	0.08	0.27	0.27	0	0	0	0	0	0	0	0.12	0.25	0.22
KM	0.05	0.18	0	0	0.20	0	0	0	0	0	0	0	0.38	0.22	0.13
VR	0	0	0.19	0.32	0.06	0	0	0	0	0	0	0.05	0	0.25	0
GK	0	0	0	0	0	0.42	0.33	0.39	0.46	0.40	0.41	0	0	0	0
SS	0	0	0	0	0	0.32	0.26	0.24	0.39	0.37	0.17	0	0	0	0
AR	0	0	0	0	0	0.26	0.20	0.37	0.15	0.23	0.42	0	0	0	0
TN	0	0	0	0	0	0	0.21	0	0	0	0	0	0	0	0

Table 5.65 Column Stochastic Super Matrix – Company B

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.22	0.18	0.01	0.18	0.25	0	0	0	0	0
GR	0	0	0	0	0	0.27	0.18	0.22	0.26	0.18	0.15	0	0	0	0
MA	0	0	0	0	0	0.01	0.12	0.26	0.06	0.07	0.26	0	0	0	0
DE	0	0	0	0	0	0	0.02	0	0	0	0.09	0	0	0	0
OB	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0
CS	0.43	0.37	0.47	0.13	0	0	0	0	0	0	0	0.64	0	0.26	0.32
NT	0.34	0.02	0.26	0.25	0.47	0	0	0	0	0	0	0.31	0.50	0.02	0.33
EC	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0
SA	0.18	0.43	0.08	0.27	0.27	0	0	0	0	0	0	0	0.12	0.25	0.22
KM	0.05	0.18	0	0	0.20	0	0	0	0	0	0	0	0.38	0.22	0.13
VR	0	0	0.19	0.32	0.06	0	0	0	0	0	0	0.05	0	0.25	0
GK	0	0	0	0	0	0.21	0.17	0.19	0.23	0.20	0.21	0	0	0	0
SS	0	0	0	0	0	0.16	0.13	0.12	0.19	0.18	0.08	0	0	0	0
AR	0	0	0	0	0	0.13	0.10	0.19	0.08	0.12	0.21	0	0	0	0
TN	0	0	0	0	0	0	0.10	0	0	0	0	0	0	0	0

Table 5.66 Converged Super Matrix (M^{2k+1}=M^{225}) – Company A

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC						0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0	0.40	0.40	0.40	0.40	0.40	0.40	0	0	0	0
SS	0	0	0	0	0	0.21	0.21	0.21	0.21	0.21	0.21	0	0	0	0
AR	0	0	0	0	0	0.25	0.25	0.25	0.25	0.25	0.25	0	0	0	0
TN	0	0	0	0	0	0.14	0.14	0.14	0.14	0.14	0.14	0	0	0	0

Table 5.67 Converged Super Matrix ($M^{2k+1}=M^{171}$) - Company B

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC						0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0	0.41	0.41	0.41	0.41	0.41	0.41	0	0	0	0
SS	0	0	0	0	0	0.31	0.31	0.31	0.31	0.31	0.31	0	0	0	0
AR	0	0	0	0	0	0.22	0.22	0.22	0.22	0.22	0.22	0	0	0	0
TN	0	0	0	0	0	0.06	0.06	0.06	0.06	0.06	0.06	0	0	0	0

The results of the process of convergence have been shown in tables 5.66 and 5.67 for both the case studies respectively. It should be noted that only the function weights have been illustrated in tables 5.66 and 5.67 for clarity. The function weights along with the measure weights from the pairwise matrices and the performance ratings developed in chapter 4 for each of the two case studies have been illustrated in table 5.68. In addition, the actual performance metric values obtained from the interview process have also been included. Based on the formulations developed in chapter 4, the performance score of Company A was obtained to be 0.667 or 66.7% and that of Company B to be 0.759 or 75.9 % of the industry average standards. In the case of this research, it is important to note here that the data used is skewed and that these figures do not accurately represent the consumer electronics industry standards due toa number of reasons such as:

- Only two companies were used for data collection
- The methodology was not implemented and hence the metrics are not an accurate representation of their performance
- The ratings are based on the feedback from just two companies

Ideally, in order to validate the results, a bigger survey sample size is necessary and also no results are accurate unless the PEARL methodology is deployed with in their organizations. Based on the results generated from this research we can clearly see that the performance of Company B is closer to industry standards than Company A. Both the companies agree that gate-keeping is the most important RL function in improving the performance of the overall reverse supply chain. However, the results also illustrate that transportation is the least important function. This could be due to the fact that both companies outsourced their transportation function to a third party logistics provider (3PL) and do not consider transportation to be a core business function within their reverse supply chains. Table 5.68 provides a snapshot to consumer electronics organizations around the world on the overall performance scores of other firms in the industry and helps them to benchmark their performance and close the gap in their weak areas against the competitors. It also provides an insight in identifying potential areas for process improvement and plan for mobilization of resources to their weak areas. The next section discusses the revised methodology and the company recommendations in successful deployment of PEARL methodology in a consumer electronics organization.

Table 5.68 Comparison of RLOPI for two case studies

	Companies		**Performance Rating across electronics industry (PR_X)**		**Measure Weight (W_{mX})**		**RL Function Weight (W_{FX})**		**Performance score at the measure (S_{mX})**	
	C-A	C-B	PR-A	PR-B	W_{mXA}	W_{mXB}	W_{FXA}	W_{FXB}	S_{mXA}	S_{mXB}
GK							**0.40**	**0.41**		
RV	144	0	0	1	0	1			0	0.41
GE	10	10	1	1	1	0			0.40	0
SS							**0.21**	**0.31**		
WE	10	10	1	1	1	1			0.21	0.31
RC	5	0	0	1	0	0			0	0
AR							**0.25**	**0.22**		
RE	25	0	1	0	0.23	0.82			0.057	0
RR	26	0	0	1	0.77	0.18			0	0.039
EE	10	9	1	0.9	0	0			0	0
TN							**0.14**	**0.06**		
VE	10	10	1	1	0	1			0	0.06
RT	17	0	0	1	1	0			0	0
									RLOPI $= \sum S_{mX1}$ = **0.667**	RLOPI $=\sum S_{mX2}$ = **0.759**

5.4 Revised Methodology and Company Recommendations

The feedback from the organizations was useful in fine tuning the methodology. As suggested earlier, both the companies agreed on the overall structure and usefulness of PEARL, and hence the structure of the methodology has been preserved as before.

1. Construct a decision makers committee
2. Determine the goals and objectives of the organization pertaining to the RL
3. Identify the various actors and functions that compose the organization's RSC
4. Design a reverse logistics network of the organization
5. Identify the lifecycle stages and market status of the product mix of the organization (Conduct market survey)
6. Identify the main drivers of returns in the consumer electronics industry, and analyze the current returns to evaluate your returns policy (Conduct Delphi study)
7. Develop the reverse logistics enabling strategies based on steps 2 – 6

8. Develop the reverse supply chain balanced scorecard to aid strategic decision making and performance measurement
9. Develop the appropriate process performance measures supporting the overall goals and strategies
10. Determine the inter-relationships between the various clusters of attributes
11. Establish the hierarchical Analytic Network Process decision framework of different attributes depicting the various clusters and their interdependencies
12. Develop super matrix using fuzzy AHP and ANP decision making approach
    a. Choose the appropriate linguistics terms to express the opinion of the decision makers in linguistic form
    b. Convert the linguistic information into triangular fuzzy numbers (TFN)
    c. Form pair-wise matrices with respect to the inter and intra dependencies between the clusters
    d. Evaluate the weights of each attribute based on their relationships in the hierarchy
    e. Calculate the aggregate weights for each criterion
    f. De-fuzzify the aggregate weights into crisp values
    g. Form the super matrix and converge it to a high power to make it column stochastic
13. Calculate the organization's Reverse Logistics Overall Performance Index (RLOPI)
    a. Determine the performance values at the measures for each RL function within the organization
    b. Collect performance values at the measures for other firms within the industry (commercial sources or trade associations)
    c. Categorize the performance within the electronics industry in the form of scales to assign performance ratings at the measures
    d. Calculate the performance rating of the firm at the measures reflecting it's relative position within the electronics industry

   e. Calculate the performance score at the measure
   f. Determine reverse logistics overall performance index (RLOPI)
14. Perform sensitivity analysis (Go to step 12 and repeat steps 12 - 14)
15. Perform SWOT analysis (Identify strength and weakness areas)
16. Benchmark with industry competitors and feedback the performance and process improvement decisions (Go to step 7 and repeat steps 7 – 16)

However there were some good recommendations and takeaways from both the companies to improve the effectiveness of the methodology. In addition, some of the discussions in the interview process led to further improvement thoughts.

Recommendation # 1: The common goals and objectives (Step 2) suggested by both the participants to be successful in reverse supply chain operations were to reduce cash to cash cycle time and reduce overall costs. These are inline with the actual goals of maximizing revenue and minimizing environmental legislations that were the basis in developing the attributes.

Recommendation # 2: In order to be successful in developing the right Reverse Supply Chain network (Step 4), the participants suggested support and buy off from all the players as a key ingredient. This is essential in maintaining successful relationships across the reverse supply chain.

Recommendation # 3: With regards to Steps 5 and 6, the participants recommended evaluating the revenue potential vs. effort before commencing on market surveys. The Delphi study should identify the key reasons for conducting reverse logistics activities and in order to do so, the members on the Delphi team should have the right mix of people. It should help in bringing out how the policies of the channel master differ from other players within the reverse supply chain.

Recommendation # 4: The process of identification of the lifecycle stage of the returned product was recognized to be extremely difficult. Some of the difficulties aforementioned by the participants were limited knowledge of return inventory in the RSC, traceability issues, and accessibility to right information across the supply chain.

Recommendation # 5: Some of the common obstacles proposed by the companies in developing the right strategies (Step 7) that enable returns management are top management support, budget restrictions and the presence of the right mix of the people. The decision making team should consider these factors into account before embarking on developing the strategies and should get top management buy off on the strategy mix.

Recommendation # 6: During Step 9 of developing the process performance metrics, the case studies approved that the measures should be dynamic with changing competition and customer demands. Both the organizations confirmed on using a tool such as a balanced scorecard very valuable in the development of the metrics. They recommended providing incentives to people who are implementing the right metrics, and to be careful in what one measures and that the lack of proper performance metrics is a major barrier to the implementation of successful reverse logistics programs. Finally, in order to improve the usefulness of any metric it was recommended to survey the customer frequently to understand their return reasons and to continuously improve the returns management process.

Recommendation # 7: In regards to Step 10 of PEARL, both the participants agreed that the process of estimating the inter-relationships between the attributes is arduous and laborious due to the exponential increase in the relationships as the attributes increase. It was suggested to consider sensitivity issues across organizations in identifying the importance of attributes over one another. However, the participants agreed on using ANP and Fuzzy Logic tools as useful in capturing the uncertainties in human judgment while analyzing the inter-relationships.

Recommendation # 8: As suggested in Steps 14-16 of the PEARL methodology, the companies confirmed that process improvement initiative is un-ending and should be a continuous improvement process. The best way to improve performance after calculating the RLOPI is to benchmark with best in class standards. Some of the good sources of getting best in class or industry averages information, as suggested by the participants are publishing companies and market research third party firms. However, there were concerns in obtaining high quality reverse logistics data as very few organizations have implemented reverse supply chain performance evaluation programs in their organizations.

Recommendation # 9: A final takeaway from the case studies was the incorporation of a cost-benefit analysis at the end of every cycle of the PEARL methodology. This helps the organization to analyze the cost effectiveness of the process improvement initiatives.

The implementation workbook in Appendix B of this dissertation provides a step by step guideline to implement the revised PEARL methodology considering all the takeaways from the case studies. The workbook was developed to guide the organizations to successfully incorporate the steps of the methodology and determine the Reverse Logistics Overall Performance Index (RLOPI). The appropriate questions to be asked in the attribute weighing process and the tables to be populated are also provided. This allows the organizations to work through the implementation and formulations with little background of the ANP and Fuzzy theory. For each step in the methodology, the appropriate implementation guideline is provided for easy correspondence and understanding.

CHAPTER 6

CONCLUSION, CONTRIBUTIONS, AND EXTENSIONS

6.1 Summary of Dissertation

Chapter 1 introduced the topic of Reverse Logistics and Reverse Supply Chain Management. It presented a brief understanding of the complexities involved in returns management process and elucidated the background of the problem the research addressed. It described the role of a reliable performance evaluation methodology in reverse logistics and how a performance index is necessary in such a complex scenario. It then defined the problem and objective statements of the research. It offered a justification in addressing the gap in research and finally outlined the approach taken to achieve the research objective.

Chapter 2 of this dissertation reviewed and summarized the current literature related to this research. It discussed the differences between forward and reverse logistics and the motivation for focusing the research specifically on consumer electronics industry. A brief understanding into the desirable aspects of a reverse supply chain performance measurement system was also conducted. Finally, it discussed the various tools such as the Analytical Hierarchy/Network Process (AHP/ANP) and fuzzy theory that the research used in developing the methodology. In chapter 3, the dissertation work plan and the research approach details were provided. Specifically, the dissertation tasks and deliverables at each stage of this research were briefly discussed.

Chapter 4 subsequently presented the development of the Performance Evaluation Analytic for Reverse Logistics (PEARL) methodology. The basic reverse logistics network structure that the methodology based on was discussed, and the various reverse supply chain players and their functions were elaborated. A detailed treatment of the four major attributes: Product Lifecycle Stages, Reverse Logistics Enabling Strategies, Reverse Logistics Processes, and Key Process Performance Metrics was provided. In specific, the strategies to be a successful reverse supply chain and the right mix of the key performance indicators were constructed. Finally the initial PEARL methodology algorithm was laid out and each step was discussed in detail. The use of AHP/ANP and fuzzy theory in the development of the Reverse Logistics Overall Performance Index (RLOPI) was illustrated. The importance of the balanced scorecard in the development of the 9 key performance indicators from various dimensions was highlighted. The major components of the RLOPI are the process weights (obtained from the strategy and the lifecycle weights), the metric weights, and the performance rating of the organization across the consumer electronics industry. The technique to develop the weights using ANP and Fuzzy Theory, the scales to build the performance ratings and the formulations to calculate the RLOPI were demonstrated. An Input/Output diagram showing the actual process of developing the index was also explained.

Chapter 5 discussed the demonstration of the PEARL methodology in two case studies (Company A and Company B). It helped in the validation and refinement of the methodology to make it emulate real world complexities. Also the interview questionnaire and implementation workbook that are necessary to implement PEARL in companies are also provided in the appendices (Appendix A and Appendix B) with reference to the revised methodology.

6.2 Research Contributions

This dissertation addresses the lack of a structured benchmarking framework to evaluate reverse supply chain performance across the consumer electronics industry. It develops a quantitative methodology called PEARL – Performance Evaluation Analytic for Reverse Logistics to assist organizations in developing the right attributes of reverse supply chain performance and thereby integrating them into a performance score called the RLOPI – Reverse Logistics Overall performance Index. The methodology provides organizations a step by step algorithmic approach to analyze the various inter-relationships between the attributes that encompass the RLOPI.

This research identified 4 major attributes as key to evaluating the performance of a reverse supply chain system: Product Lifecycle Stages, Reverse Logistics Enabling Strategies, Reverse Logistics Functions, and Reverse Logistics Process Performance Metrics. The PEARL methodology helps in identifying the cause and effect relationships between these attributes through analysis tools such as Analytical Network Process and Fuzzy Theory to capture the real world uncertainties and thereby synthesize them into RLOPI. The organizations can then use the performance index and benchmark their RL performance across the industry and best in class standards and feedback process improvement decisions to continuously monitor and improve their reverse supply chain operations.

The application of ANP in the methodology provides the user with a more accurate and realistic performance score by considering all the interdependencies and feedbacks associated with the decision making process. Moreover, the application of fuzzy logic in the decision making process helps in negating the vagueness associated with the human assessment in real world. In a possible application of the model, a firm engaging in reverse logistics operations can gauge its overall performance, detect its strength and weakness areas through a sensitivity analysis, benchmark with its competitors, and develop necessary programs to close the performance gaps in the weak areas. The model will help the reverse logistics managers in assessing which measures and RL functions are supporting the strategies and the overall goals of the organizations

In addition this research highlights the importance of the implementation of a reverse supply chain performance evaluation methodology such as PEARL to maximize revenue within the technical and environmental constraints that encompass the dynamic consumer electronics industry. The right mix of the attributes varies across firms and industries, but once achieved, it can help organizations to benchmark and continuously improve their performance. Furthermore, to make the implementation user friendly, an interview questionnaire and an implementation workbook have also been developed. The Reverse Logistics Overall Performance Index is a valuable tool for organizations to model their reverse supply chain operations. It provides a numerical index indicating a firm's returns management capabilities and helps them to prioritize their resources and process improvement efforts in the right areas and optimize their reverse supply chains.

6.3 Extensions and Future Research Directions

Results from this dissertation raise new questions for several potential directions for future research. Although the methodology has been developed specifically for consumer electronics industry, a comprehensive study analyzing its applicability to other industries could be a potential extension of this research. Research should be undertaken to develop and corroborate the template across a range of industries. A potential disadvantage of the application of ANP approach is that the identification of relevant attributes, determining their relative importance in the selection process and combining them to get a single RLOPI requires extensive brainstorming sessions and the accumulation of expertise within the organization. Moreover, it requires numerous calculations and formation of pair-wise comparison matrices, and hence one has to keep track of the comparisons carefully. Research to automate these tasks would provide great opportunity to simplify the entire process and make it easy to implement the methodology. It was also assumed that the products consisted of only end consumer returns and a centralized recovery center is responsible for all collection and sorting operations. Relaxing these assumptions and checking the eligibility of the methodology can be a potential research opportunity.

The two case studies conducted provided valuable insight into the application of the methodology and resulted in its refinement. A comprehensive study involving more companies to increase the sample size will be a reasonable extension to this research.

The performance index was developed based on a multi criteria approach, without which it is not possible to overcome the problem of heterogeneity of the measurement units that makes it difficult to compare performances across industries. Another possible extension could be to develop attributes that have not been delved in this research and include them in the ANP hierarchy. Finally, a neural network can be developed to simulate the decision makers thinking process and when combined with fuzzy logic and ANP can prove to be efficient in modeling the complexities as the number of attributes increase in developing the performance index.

APPENDIX A

INTERVIEW QUESTIONNAIRE

Overview

Reverse Logistics is the "the process of planning, implementing, and controlling the efficient, cost effective flow of materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". Reverse logistics encapsulates practices such as collection, asset recovery, sorting, storing, re-transportation and distribution. Every organization faces returns handling some time in the product lifecycle, and needs to be adept in reverse supply chain practices. Understanding the challenges of product returns management across the product lifecycle, developing and adopting the right strategies, implementing the right metrics are essential for a successful reverse supply chain. In case of short lifecycle and high return variability time sensitive product such as consumer electronics, a large value of the product value erodes due to erroneous returns processing. In light of increasing profit making opportunities and stringent legislations supply chains have to adopt best practices in returns management.

The overall objective of this interview session is to validate the reverse supply chain performance methodology developed in my research, which assists in determining the appropriate reverse logistics strategies, developing the right measures, which have the most significant impact on the firm's ability to conduct successful reverse supply chain operations. The information garnered from this interview session will work towards enhancing the methodology with real world information, and providing an implementation guide for your organization to implement the PEARL methodology and developing the reverse logistics overall performance index that can be used to compare your reverse supply chain performance with industry leaders. The interview will last for

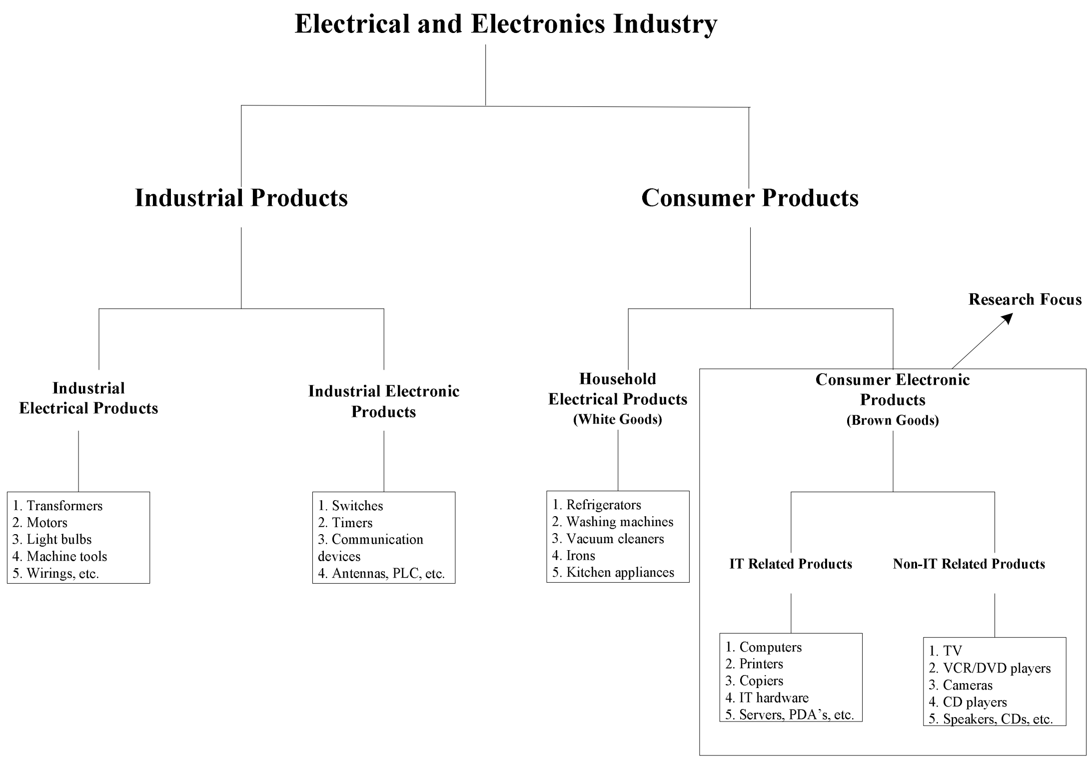
4-5 hours with intervals between sessions. The interview questionnaire will focus on validation of the following issues:

A. Electronic product classification structure
B. Reverse logistics network and processes, Reverse logistics drivers
C. PEARL (Performance Evaluation Analytic for Reverse Logistics) methodology
D. Return product lifecycle analysis
E. Reverse logistics strategies
F. Reverse logistics performance metrics and calculations
G. Inter-relationships and hierarchy between the various attributes involved in the decision making process
H. Pairwise comparison of various attributes
I. Reverse logistics overall performance index formulations

Each issue is covered as a section of questions for better understanding.

Section A: Questions 1 - 2

The purpose of this set of questions is to test the validity of the consumer electronics product classification scheme developed for this research. The following figure represents the classification of the electrical and electronic industry. It depicts the various types of products and highlights the research focus.



1. Does the figure capture the classification of products within the electrical and electronics industry?

☐ Yes ☐ No ☐ Somewhat Captures

2. If the answer to question 1 was "No" or "Somewhat captures", please list some of the additional products or classifications that should have been included in the classification scheme to represent real world.

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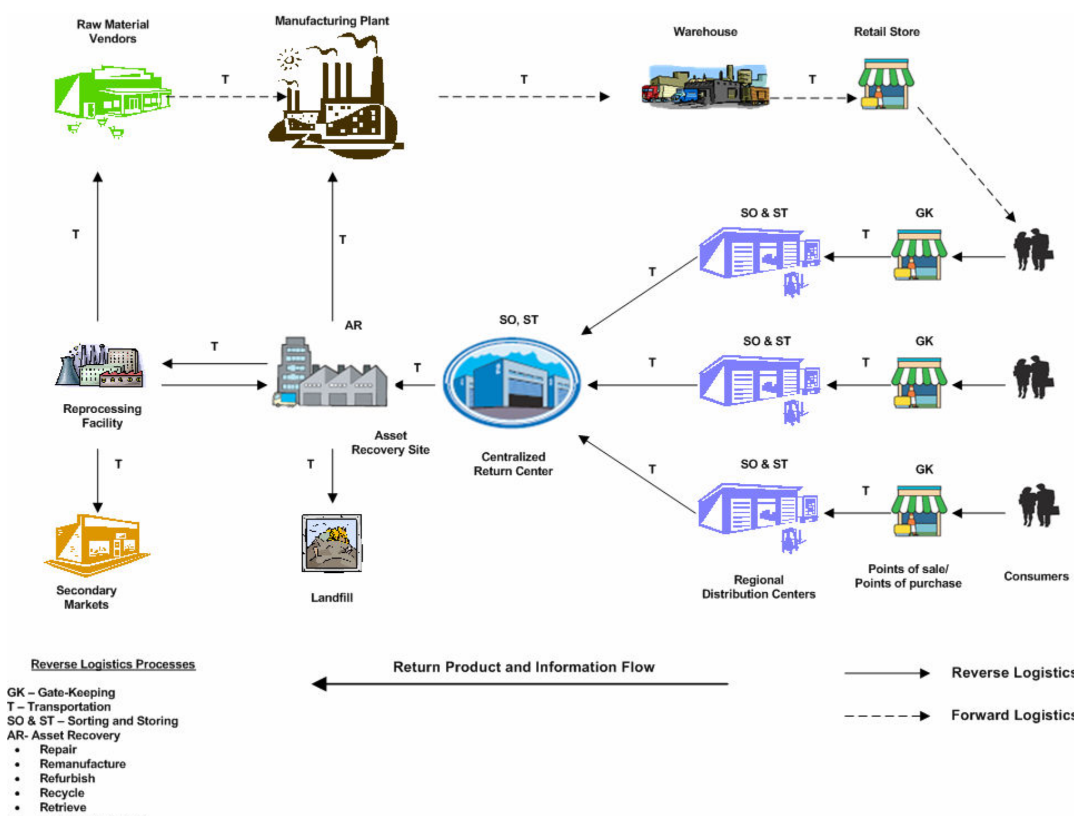
Section B: Questions 1 – 6

The purpose of this set of questions is to investigate the validity of the reverse logistics network developed for this research. The network forms the basis of this research, depicting the various actors and their associated functions. The structure has the capability to account for the longest path of product and information flow. In other words, this "maximum node" network structure would take into account the worst case scenario where the product and the information have to flow through the maximum number of nodes. The channel master is assumed to be the one responsible for taking reverse logistics initiatives across the reverse supply chain. The section also explores the driving forces behind reverse supply chain operations.



1. Does the network capture the longest possible path of product and information flow across the reverse supply chain?

☐ Yes ☐ No ☐ Somewhat Captures

2. If the answer to question 1 was "No", or "Somewhat captures", please list some of the additional players and functions that should have been included in the network above.

Reverse Supply Chain Players	*Functions*
______________________________	______________________________
______________________________	______________________________
______________________________	______________________________
______________________________	______________________________

3. The network above assumes the following:

a) Products consist of only end consumer returns
b) Product and information flow through the maximum number of nodes
c) The channel master is responsible for initiating the reverse logistics activities
d) A centralized recovery center is responsible for all collection, sorting and storing operations as opposed to a decentralized structure

How appropriate is the network in capturing real world information based on these assumptions? Use a scale of 1-5 with 1 with being "not appropriate" and 5 being "very appropriate".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

4. How does the network change of we remove the constraints or assumptions? Please comment in the space provided below.

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5. The major drivers for undertaking reverse logistics activities across organizations and industries are (Check those applicable)

☐Legislation ☐Corporate Citizenship

☐Customer service initiatives ☐Economic initiatives

6. In addition to the driving forces mentioned in question 5, are there any additional forces that drive you to undertake reverse logistics operations? Please comment in the space below.

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Section C: Questions 1 – 33

The purpose of this set of questions is to examine the validity of the PEARL – (Performance Evaluation Analytic for Reverse Logistics) methodology developed in this research to evaluate the performance of reverse logistics and deploying efficient processes, performance metrics, and product information in supportive of the strategies and goals of the organization. The PEARL methodology has the following 16 steps. *Please read the steps and answer the questions that follow.*

1. Construct a decision makers committee
2. Determine the goals and objectives of the organization pertaining to the RL
3. Identify the various actors and functions that compose the organization's RSC
4. Develop a reverse logistics network of the organization
5. Identify the lifecycle stages and market status of the product mix of the organization (Conduct market survey)
6. Identify the main drivers of returns in the consumer electronics industry, and analyze the current returns to evaluate your returns policy (Conduct Delphi study)
7. Identify the reverse logistics enabling strategies based on the product and market data, organizational goals and drivers of returns in consumer electronics industry
8. Develop the reverse supply chain balanced scorecard to aid strategic decision making and performance measurement
9. Determine the appropriate process performance measures supporting the overall goals and strategies
10. Determine the inter-relationships between the various clusters of attributes that aid in performance evaluation of reverse logistics
11. Establish the hierarchical Analytic Network Process decision framework of different attributes depicting the various clusters and their interdependencies
12. Develop super matrix using fuzzy AHP and ANP decision making approach

a. Choose the appropriate linguistics terms to express the opinion of the decision makers in linguistic form
b. Convert the linguistic information into triangular fuzzy numbers (TFN)
c. Form pair-wise matrices with respect to the inter and intra dependencies between the clusters
d. Evaluate the weights of each attribute based on their relationships in the hierarchy
e. Calculate the aggregate weights for each criterion
f. De-fuzzify the aggregate weights into crisp values
g. Form the super matrix and converge it to a high power to make it column stochastic

13. Develop organizations Reverse Logistics Overall Performance Index (RLOPI)
    a. Determine the performance values at the measures for each RL function within the organization
    b. Collect performance values at the measures for other firms within the industry (commercial sources or trade associations)
    c. Categorize the performance within the electronics industry in the form of scales to assign performance ratings at the measures
    d. Calculate the performance rating of the firm at the measures reflecting it's relative position within the electronics industry
    e. Calculate the performance score at the measure
    f. Determine reverse logistics overall performance index (RLOPI)
14. Perform sensitivity analysis (Go to step 12 and repeat steps 12 - 6)
15. Perform SWOT analysis (Identify strength and weakness areas)
16. Benchmark with industry competitors and transfer the performance feedback and process improvement decisions (Go to step 7 and repeat steps 7 – 16)

1. How important is the formation of decision makers committee before embarking on any reverse logistics undertaking? Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2. How important is the decision makers committee to be inter-organizational and inter functional?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. Is it necessary to have clear cut and well defined goals and objectives pertaining to reverse logistics for your organization?

☐ Yes ☐ No

4. If the answer to question 3 is "yes", comment on some of the common goals and objectives of an organization to be successful in reverse logistics.

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5. How essential it is to identify the actors and their relevant functions and thereby developing an organizational reverse supply chain? Use a scale of 1 through 5 with 1 being "not essential" and 5 being "very essential".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

6. What are some of advantages of developing a RL network before embarking on evaluating and improving the performance of your reverse supply chain?

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7. Comment on step 5 of the methodology, namely, conducting market surveys at all times to have real time product lifecycle and market status information of the entire product mix of the organization. Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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8. How important is it to continuously identify the main drivers of returns in consumer electronics industry? Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

9. Remark on some of the advantages and disadvantages of conducting a Delphi study in order to identify the main drivers and thereby evaluating organization's returns policy

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10. Based on the product lifecycle and market data, organizational goals and objectives, how vital is it to develop the right strategies to be successful in reverse logistics. Use a scale of 1 through 5 with 1 being "not vital" and 5 being "absolutely vital".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

11. What are some of the obstacles in developing the right strategies that enable reverse logistics in your organization?

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12. Does your organization use a strategic measurement tool such as the balanced scorecard to evaluate the reverse supply chain performance? Use the following definition of a balanced scorecard

"*It is a strategic management system that forces managers to focus on the important performance metrics that drive success. It balances a financial perspective with customer, internal process, and learning & growth perspectives. The system consists of four processes: 1. Translating the vision into operational goals; 2. Communicate the vision and link it to individual performance; 3. Business planning; 4. Feedback and learning and adjusting the strategy accordingly*"

☐ Yes ☐ No

13. If the answer to question 12 is “yes”, what kind of enhancements (if made) to the actual balanced scorecard did your organization perform?

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14. Comment on the importance of using a balanced scorecard in evaluating your reverse supply chain performance.

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15. Comment on the criticality of developing and implementing the right performance metrics for reverse supply chain operations.

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16. How important is it to align the performance measures with the overall goals and objectives of the organization? Use a scale of 1 through 5 with 1 being “not important” and 5 being “absolutely important”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

17. “Lack of the proper performance metrics is a major barrier to the reverse logistics programs”. Comment on this statement.

18. How critical it is to identify the right attribute mix and their relationships, to evaluate your organizational performance (such as product lifecycle, RL enabling strategies etc.). Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

19. Does your organization establish the inter-relationships between the various attributes that are important to evaluating your organizational reverse logistics performance?

☐ Yes ☐ No

20. If the answer to question 19 is "yes", what tool do you use to analyze the relationships between the various attributes, and establish the decision hierarchy among the attributes? What do you think are some of the pros and cons of the tool in use?

21. What are some of the potential barriers to analyzing the relationships between the various attributes?

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22. Step 12 dictates the use of Analytical Network Process (ANP) as a tool to develop and analyze the inter-relationships, and henceforth develop a decision framework for developing the reverse logistics performance index. How useful is the ANP in capturing these intricate relationships? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

"*ANP is an analytical tool for strategic decision making involving dependence and feedback. It involves the principle of decomposition, pair wise comparison, priority vector generation and synthesis*".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

23. The methodology suggests using fuzzy logic in dealing with vagueness and uncertainty of human thought. Do you believe fuzzy theory is useful in capturing and modeling uncertainty arising from mental phenomena which are neither random nor stochastic? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

24. The methodology suggests the best method to improve performance is to benchmark with competitors or best in class standards. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

25. If your answer to question 24 is “No” or “Somewhat agree”, what other technique of performance improvement do you follow? Elaborate.

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26. If your answer to question 24 is “Yes”, what sources of competitor’s performance data do you utilize?

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27. How important is it not to stop at the benchmarking stage, and instead performing sensitivity analysis to understand the affects of the various attributes on each other on the overall reverse supply chain performance? Use a scale of 1 through 5 with 1 being “not important” and 5 being “absolutely important”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

28. Do you think SWOT analysis is important to any process improvement initiative, as it highlights the strengths and weaknesses of the organization in certain areas?

☐ Yes ☐ No ☐ somewhat agree

29. If the answer to question 28 is “No” or “Somewhat agree”, please comment below.

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30. How important is it to feedback the performance and process improvement decisions at the end of every reverse supply chain performance improvement initiative and thereby engage in a continuous improvement process? Use a scale of 1 through 5 with 1 being “not important” and 5 being “absolutely important”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

31. On an overall basis, how structured is the PEARL methodology? Does it need any additional steps? Do you think that any steps are redundant?

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32. Do you think PEARL can be used as a tool by reverse logistics managers across organizations to evaluate and quantify their overall reverse supply chain performance, to decide on what processes to improve, what measures to implement, and what strategies to pursue to close the gap with the competitors in terms of RL capabilities?

☐ Yes ☐ No ☐ somewhat agree

33. If the answer to question 32 is “No” or “Somewhat agree”, please comment below

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Section D: Questions 1 - 8

The rationale behind this section of questions is to explore the return product lifecycle analysis and its applicability in successful returns management of an organization.

1. Do you agree that the product lifecycle analysis plays a major role in the decision making of evaluating a reverse supply chain?

☐ Yes ☐ No ☐ somewhat agree

2. If you answer "No" or "Somewhat agree" to question 1, please explain the basis for the reasoning.

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3. The lifecycle stages of a product can be classified into (Check those applicable)

☐ Introduction ☐ Growth ☐ Maturity

☐ Decline ☐ Obsolete

4. Does you organization classify the product lifecycle differently? If so please explain.

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5. The stage where a product is located in its lifecycle is significantly related to the volume and the variability of units returned through its RL network. The following table summarizes the typical lifecycle characteristics of returns management process.

Characteristics	Introduction	Growth	Maturity	Decline	Obsolete
Sales	Slow but increasing	Increasing rapidly	High and stable	Decreasing	Sales only from aftermarket sources, if at all
Return Volumes	Low	High	High and Stable	Low	Low
Variability of returns	Low	Very High	High	Low	Low

Do you agree with the data in the above table?

☐ Yes ☐ No ☐ somewhat agree

6. If you answer "No" or "Somewhat agree" to question 5, please explain the basis for the reasoning.

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7. The process of identification of the lifecycle stage of a returned product is extremely difficult? In your opinion, what are the possible difficulties that arise in doing so?

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8. How important is identifying a returned product lifecycle stage to adopting the correct strategy for returns management? Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Section E: Questions 1 - 8

The purpose of this section is to test the validity of the selection of strategies developed in this research that propose successful reverse logistics handling in an organization.

1. Do you agree that adopting the right reverse logistics strategy plays a critical role in running a successful returns management process in any organization?

☐ Yes ☐ No ☐ somewhat agree

2. If you answer “No” or “Somewhat agree” to question 1, please explain the basis for the reasoning.

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3. With the proper strategies in place, reverse logistics can serve as a foundation for establishing customer loyalties and increasing market share. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

4. If you answer “No” or “Somewhat agree” to question 1, please explain the basis for the reasoning.

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5. The six core business strategies for successful reverse supply chains are (Check those applicable):

☐ Customer Satisfaction ☐ New Technology Implementation ☐ Eco-Compatibility

☐ Strategic Alliance Formation ☐ Knowledge Management ☐ Value Recovery

6. In addition to the strategies mentioned above, does your organization implement any other core business strategy to be successful in reverse logistics? If so please explain below.

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7. "With the proper strategies in place, reverse logistics can serve as a foundation for establishing customer loyalties and increasing market share". Do you agree? If so, comment.

☐ Yes ☐ No ☐ somewhat agree

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8. How important are the product lifecycle stage, organizational goals and objectives in developing the right strategies? Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Section F: Questions 1 - 38

This section intends to investigate the validity of the process performance metrics developed in this research. The lack of performance metrics is considered to be a major barrier to the successful implementation of reverse logistics programs.

1. Do you agree that very few standard reverse supply chain performance metrics are available, and most of the existing forward supply chain metrics are little applicable to reverse supply chains?

☐ Yes ☐ No ☐ somewhat agree

2. If you answer "No" or "Somewhat agree" to question 1, please explain the basis for the reasoning.

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3. The value of returns entering the reverse supply chain per unit time (RV) is calculated as:

$$\mathbf{RV} = \sum_{i=1}^{n}\left[\sum_{D=1}^{D_{max}}\left(\sum_{OD=1}^{OD_{max}}(N_i * C_i) + \sum_{TD=1}^{TD_{max}}(N_i * C_i)\right) + \sum_{I=1}^{I_{max}}\left(\sum_{OI=1}^{OI_{max}}(N_i * C_i) + \sum_{TI=1}^{TI_{max}}(N_i * C_i)\right)\right]$$

where,

$i = 1,2,..,n$ is the number of product categories in the company

N_i is the number of returned products in a product category

C_i is the cost of returned products in a product category

(*Assumption*: The maximum value of a return is equal to the manufacturing cost of the product)

D is the number of domestic locations

D_{max} is the maximum number of domestic locations

I is the number of international locations

I_{max} is the maximum number of international locations

OD is the number of online domestic locations

OD_{max} is the maximum number of online domestic locations

OI is the number of online international locations

OI_{max} is the maximum number of online international locations

TD is the number of traditional domestic locations

TD_{max} is the maximum number of traditional domestic locations

TI is the number of traditional international locations

TI_{max} is the maximum number of traditional international locations

The value of returns entering the reverse supply chain is identified as a key analytic in performing a health check of the overall reverse logistics. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

4. How useful is an analytic such as value of returns/unit time to measure gate-keeping? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5. Please calculate your organization's value of returns/unit time (RV) using the equation in question 3. Use the space below.

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6. In the formulation for RV, the sources of returns have been classified into domestic and international, and consequentially into online and traditional locations. Do you suggest any other means of classification? If so, comment.

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7. A qualitative aggregate measure helps an organization to compare its practices to some of the best practices obtained from academic research and industry. This research has developed a metric called as Gate-keeping Effectiveness (GE) to reflect the importance of gate-keeping to the organization's successful reverse logistics strategies.

Best Practice	
Clear and visible return policies to reduce the number of defective products into RSC	□
Use of dedicated skilled labor for return product inspection and testing at gate-keeping site	□
Use of latest test equipment for checking the reliability of the product	□
Use of IT and information software for generating a return good authorization	□
Devote necessary utilities, supervision and maintenance requirements for proper administration	□
Use of multiple channels such as phone and internet to provide support and troubleshooting	□
Employ programs to reduce idle time of trucks and products at gate-keeping	□
Presence of economic benchmarks for acceptance / rejection of returned items	□
Develop EDI linkages for the return goods management	□
Established business rules to assist customer representatives for faster customer credit	□

The table above suggests some of the best practices that constitute Gate-Keeping Effectiveness. Check all those that apply.

8. Do you suggest some other best practices that need to comprise GE? Do you find any practices suggested above redundant?

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9. How useful is an analytic such as gate-keeping effectiveness? Use a scale of 1 through 5 with 1 being “not useful” and 5 being “absolutely useful”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

10. To qualitatively measure sorting and storing operations, the research has developed a qualitative measure called as Warehousing Effectiveness (WE). It is an aggregate measure of warehousing performance of an organization in handling returns. The following is the list of best practices that comprise warehousing effectiveness. Check all that apply.

Best Practice	
Real time updating of inventory in warehouses	□
Application of RFID technologies for tracking stored return products	□
Availability of detailed shipping and receiving data for the proper handling and management of returned items	□
Use of existing warehousing functions and resources	□
Use of current warehousing methods and equipment	□
Improvements in warehousing layout design for the physical separation of virgin and returned items	□
Use of separate CRCs to handle returns	□
Compliance with OSHA and ISO 14000	□
Provision of special handling requirements	□
Use of full time employees dedicated to handling returns	□
Adherence of outsourced return centers to service level agreements	□

11. Do you suggest some other best practices that need to comprise WE? Do you find any practices suggested above redundant?

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12. How useful is an analytic such as warehousing effectiveness? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

13. The cost to carry return products, measures the overhead that an organization carries to support its inventory. Carrying cost is usually expressed as a percentage that represents the cents per dollar that will be spent on inventory overhead per year.

$$\text{Carrying Cost Percentage (RC)} = \frac{\text{Fixed costs} + \text{Variable costs}}{\text{Average value of return inventory}}$$

$$= \frac{[(S + E + P) + (M + T + I + O + P)]}{Q}$$

$$= \frac{\left\langle \sum_{i=1}^{n} [(S + E + P) + (M + T + I + O + P)] * R_i \right\rangle}{\sum_{i=1}^{n} (R_i * C_i)}$$

where,

i = 1,2,..,n is the number of product categories in the company

R_i is the number of returned products in a product category located in the warehouse

C_i is the cost of returned products in a product category

S is the cost of space per unit return

E is the cost of equipment needed to handle a unit return

P is the cost of personnel to handle a unit return

M is the cost of money tied up in a unit return

T is the cost of taxes on a unit return

I is the insurance cost per unit return

O is the obsolescence and shrinkage cost per unit return

P is the pilferage cost involved in a unit return

Q is the average value of inventory in the warehouse

This research identifies this as a crucial measure for improving sorting and storing operations in the reverse supply chain. Do you concur?

☐ Yes ☐ No ☐ somewhat agree

14. If the answer to question 13 is “No” or “Somewhat agree”, please explain below.

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15. How useful is an analytic such as carrying cost percentage to measure gate-keeping? Use a scale of 1 through 5 with 1 being “not useful” and 5 being “absolutely useful”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

16. Please calculate your organization's carrying cost percentage (RC) using the equation in question 13. Use the space below.

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17. Asset Recovery, arguably, is the most important operation in the whole reverse supply chain. The research developed an analytic called Recovery Efficiency (RE), defined as:

$$RE = \frac{\text{Value recovered}}{\text{Resources used} + \text{Environmental impact}}$$

The value recovered can be considered to be equivalent to the sales generated from the returned products. The resources used are the costs incurred in product recovery that can again be divided into fixed (space, labor, and equipment) and variable (taxes, insurance, etc.). The environmental impact is the charges incurred due to pollution of environment due to the discharge of gases such as CO_X, NO_X, SO_X, etc. Ideally, every organization must strive to keep this figure as high as possible. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

18. If the answer to question 17 is "No" or "Somewhat agree", please explain below.

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17. Does your organization employ a different method of calculating Recovery Efficiency? If so please explain.

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18. How useful is an analytic such as recovery efficiency to measure asset recovery? Use a scale of 1 through 5 with 1 being “not useful” and 5 being “absolutely useful”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

19. Please calculate your organization’s carrying recovery efficiency (RE) using the equation in question 17. Use the space below.

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20. Another quantitative measure recognized to measure asset recovery is the Recovery Rate (RR) defined as:

$$RR_j = 1 - \left(\sum_{i=1}^{n} S_{ij} / N_j\right)$$ where,

S_{ij} is the number of units of item *j* scrapped in time period *i*, and

N_j is the total number of item *j* inducted into the asset recovery process

How important do you think is it to calculate the recovery rate in high clock-speed industries such as consumer electronics? Use a scale of 1 through 5 with 1 being “not important” and 5 being “absolutely important”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

21. Does your organization employ a different method of calculating Recovery Rate? If so please explain.

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22. How useful is an analytic such as recovery rate in capturing asset recovery effectiveness? Use a scale of 1 through 5 with 1 being “not useful” and 5 being “absolutely useful”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

23. Please calculate your organization’s carrying recovery rate (RR) using the equation in question 20. Use the space below.

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24. A third and final qualitative measure devised to measure asset recovery is Environmental Effectiveness (EE). Asset recovery operation should ensure that the environmental and green issues are taken into account. It is an aggregate measure of asset recovery performance of an organization. The following is the list of best practices that comprise environmental effectiveness. Check all that apply.

Best Practice	
Presence of educational and training programs to employees	□
Use of employee incentive programs related to environmental goals	□
Use of supplier environmental audits and assessments	□
Presence of emergency response programs	□
Compliance with regulations such as WEEE, EPA, ISO 14001 and RoHS	□
Use of eco-friendly product and packaging materials	□
Use of recycle materials to manufacture virgin products	□
Promotion of industry wide cooperative efforts on environmental issues	□
Develop tools that assist in designing products for environment	□
Support end-of-life processing by tracking product data from design through end-of-life (significant for products with long lifecycles)	□
Use of compliance reporting and material declaration sheets for all products manufactured	□

25. Do you suggest some other best practices that need to comprise Environmental Effectiveness? Do you find any practices suggested above redundant?

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26. How useful is an analytic such as environmental effectiveness? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

27. Transportation forms the major part of any reverse logistics cost and every organization should strive to keep it low. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

28. If the answer to question 27 is "No" or "Somewhat agree", please explain below.

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29. This research develops a qualitative analytic to measure transportation, namely, Overall Vehicle Effectiveness (VE). VE is an aggregate qualitative measure that helps the company to compare its transportation with some of the best practices in the industry. Check all that you think are applicable.

Best Practice	
Use of existing transportation routes and schedules	□
Use of inter-modal transportation on a timely basis	□
Use of shipping in bulk and cube utilization	□
Use of computer network technology to track return products from gate-keeping to disposal	□
Availability of detailed shipping and receiving data for the proper handling and management of returned items	□
Use of special bins for distinction between virgin and returned items	□
Use of automated systems for generating return good authorization (RGA) and other shipping documentation	□
Provision of online web capability to schedule returns pickups	□
Use of rate engines that allow selection of the lowest shipping cost across multiple carriers	□
Coordinate returns shipments to get lower transportation costs and improve vehicle and mileage utilization	□

30. Do you suggest some other best practices that need to comprise Overall Vehicle Effectiveness? Do you find any practices suggested above redundant?

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31. How useful is an analytic such as overall vehicle effectiveness? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

32. A quantitative metric developed in this study for gauging transportation effectiveness is the Average Return Transit Time (RT). It is measured by the number of days (or hours) from the time a returned product spends in transit, after it enters the

reverse supply chain at the gate-keeping site, to the point it leaves the reverse supply chain. The average return transit time can be expressed as

$$RT = \frac{\sum_{i=1}^{N} T_i}{N}$$ where,

i=1, 2… N is the number of products entering the reverse supply chain

T_i is the total time spent by a product return in transit

How important do you think is it to calculate the Average Return Transit Time (RT) in high clock-speed industries such as consumer electronics? Use a scale of 1 through 5 with 1 being "not important" and 5 being "absolutely important".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

33. Does your organization employ a different method of calculating Average Return Transit Time (RT)? If so please explain.

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34. How useful is an analytic such as Average Return Transit Time (RT) in capturing transportation effectiveness? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

35. Please calculate your organization's carrying Average Return Transit Time (RT) using the equation in question 32. Use the space below.

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36. Overall, how resourceful are the analytics developed in this research in capturing the performance of an organization in different reverse supply chain operations?

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37. Does your organization any different measures more effective than those prescribed in this section? If so please elaborate below.

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38. Do you believe that any of the measures discussed in this section are redundant or can be modified in a better approach? Please discuss below.

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Section G: Questions 1 – 14

The purpose of this section of questions is to verify the validity of the inter-relationships between the various attributes such as the product lifecycle stages, reverse logistics enabling strategies, reverse supply chain processes, and the key performance analytics, that are involved in the decision making process of evaluating a reverse supply chain performance.

1. This study identifies four major attributes that constitute the decision making framework to measure the reverse logistics performance of a consumer electronics organization. Check those you believe are applicable.

☐Return Product Lifecycle Stages ☐Reverse Logistics Enabling Strategies

☐Reverse Logistics Functions ☐Reverse Logistics Performance Metrics

2. The attributes vary across organizations and industries. Do you suggest any other key attributes that need to be included in the decision making process? If so, please recommend.

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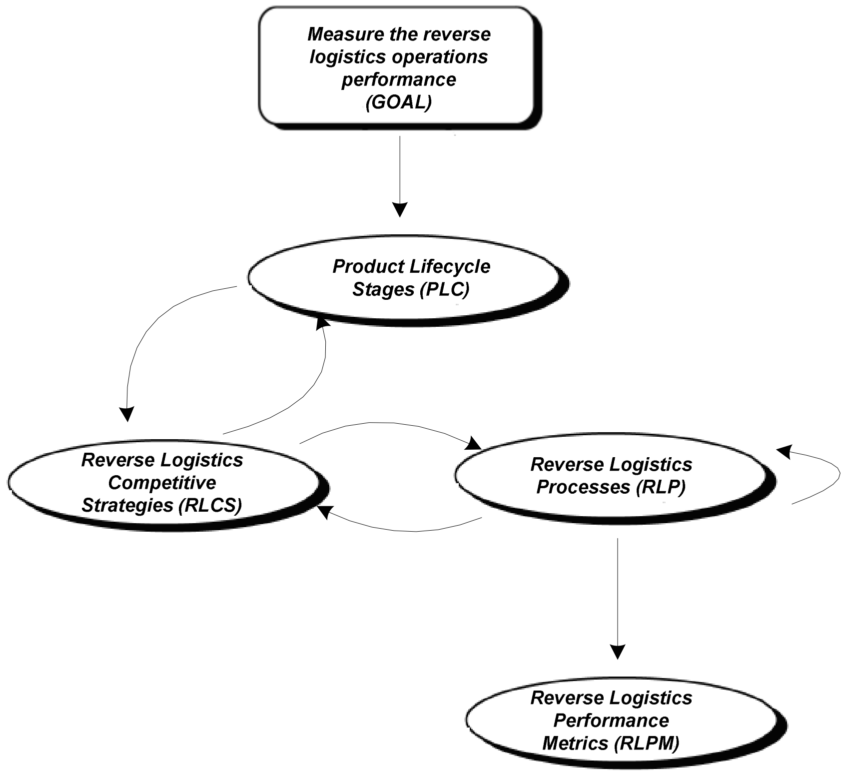
In the figure below, the inter relationships between the four attributes is depicted. Please take time to look at the figure and answer the questions that follow. (Note: One way arrows indicate unidirectional relationships and two way arrows indicate bi-directional relationship).



3. The figure depicts a bi-directional relationship between product lifecycle stages and reverse logistics enabling competitive strategies (The strategy an organization adopts depends on which stage a returned product is in its lifecycle. Similarly the strategy adopted determines which lifecycle needs more consideration). Do you agree?

☐ Yes ☐ No ☐ somewhat agree

4. If the answer to question 3 is “No” or “Somewhat agree”, please explain below.

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5. The figure shows a bi-directional inter dependent relationship between reverse logistics enabling competitive strategies and reverse logistics functions clusters (The importance of the strategies differs for each RL function. Similarly the importance of reverse logistics function differs for each strategy the organization adopts). Do you agree?

☐ Yes ☐ No ☐ somewhat agree

6. If the answer to question 5 is “No” or “Somewhat agree”, please explain below.

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7. Another form of interdependency the figure portrays is the internal cluster interdependency by the looped arc (For each strategy the relative importance of the function varies). In your opinion, does this exist?

☐ Yes ☐ No ☐ somewhat agree

8. If the answer to question 7 is “No” or “Somewhat agree”, please explain below.

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9. Finally, there is a direct unidirectional relationship between the functions and the metrics, as each function has its corresponding performance analytics. Do you agree?

☐ Yes ☐ No ☐ somewhat agree

10. If the answer to question 9 is “No” or “Somewhat agree”, please explain below.

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11. On the whole, do you agree with the hierarchy of the decision making framework?

☐ Yes ☐ No ☐ somewhat agree

12. If the answer to question 11 is “No” or “Somewhat agree”, please explain below.

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13. Do you agree with the inter-relationships between the various clusters of attributes that make up the decision making framework?

☐ Yes ☐ No ☐ somewhat agree

14. If the answer to question 13 is “No” or “Somewhat agree”, please explain below.

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Section H: Questions 1 - 249

This section aims to understand the relationship between the various attributes that are important in the decision making process of evaluating a reverse supply chain. Read the following questions and put check marks on the pairwise comparison matrices. If an attribute on the left side is more important than the one matching on the right, put your check mark to the left of the importance "Equal" under the importance level you prefer. If an attribute on the left side is less important than the one matching on the right, put your check mark to the right of the importance "Equal" under the importance level you prefer.

With respect to reverse logistics function "Gate-keeping"

1) How important is *value of returns entering the RSC per unit time (RV)* when it is compared with *gate keeping effectiveness (GE)*?

With respect to: Gate-keeping	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
1	RV										GE

With respect to reverse logistics functions "Sorting and Storing"

2) How important is *warehousing effectiveness (WE)* when it is compared with *carrying cost percentage of returned goods in a CRC per unit time (RC)*?

With respect to: Sorting & Storing	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
2	WE										RC

With respect to reverse logistics function "Asset Recovery"

3) How important is *recovery efficiency (RE)* when it is compared with *recovery rate (RR)*?
4) How important is *recovery efficiency (RE)* when it is compared with *environmental conformance effectiveness (EE)*?
5) How important is *recovery rate (RR)* when it is compared with *environmental conformance effectiveness (EE)*?

With respect to: Asset Recovery	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
3	RE										RR
4	RE										EE
5	RR										EE

With respect to reverse logistics function "Transportation"

6) How important is *overall vehicle effectiveness (VE)* when it is compared with *average return transit time (RT)?*

With respect to: TN	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
6	VE										RT

With respect to reverse logistics function "Gate-keeping"

7) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

8) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

9) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Gate-keeping	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
7	SS										AR
8	SS										TN
9	AR										TN

With respect to reverse logistics function "Sorting and Storing"

10) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

11) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

12) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Sorting & Storing	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
10	GK										AR
11	GK										TN
12	AR										TN

With respect to reverse logistics function "Asset Recovery"

13) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

14) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

15) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

With respect to: Asset Recovery	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
13	GK										SS
14	GK										TN
15	SS										TN

With respect to reverse logistics function "Transportation"

16) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

17) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

18) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

With respect to: TN	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
16	GK										SS
17	GK										AR
18	SS										AR

With respect to reverse logistics strategy "Customer Satisfaction"

19) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

20) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

21) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

22) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

23) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

24) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Customer Satisfaction	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
19	GK										SS
20	GK										AR
21	GK										TN
22	SS										AR
23	SS										TN
24	AR										TN

With respect to reverse logistics strategy "New Technology Implementation"

25) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

26) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

27) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

28) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

29) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

30) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: NT	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
25	GK										SS
26	GK										AR
27	GK										TN
28	SS										AR
29	SS										TN
30	AR										TN

With respect to reverse logistics strategy "Eco-compatibility"

31) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

32) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

33) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

34) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

35) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

36) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: EC	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
31	GK										SS
32	GK										AR
33	GK										TN
34	SS										AR
35	SS										TN
36	AR										TN

With respect to reverse logistics strategy "Strategic Alliances Formation"

37) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

38) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

39) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

40) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

41) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

42) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Strategic Alliances Formation	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
37	GK										SS
38	GK										AR
39	GK										TN
40	SS										AR
41	SS										TN
42	AR										TN

With respect to reverse logistics strategy "Knowledge Management"

43) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

44) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

45) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

46) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

47) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

48) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: KM	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
43	GK										SS
44	GK										AR
45	GK										TN
46	SS										AR
47	SS										TN
48	AR										TN

With respect to reverse logistics strategy "Value Recovery"

49) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

50) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

51) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

52) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

53) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

54) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Value Recovery	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
49	GK										SS
50	GK										AR
51	GK										TN
52	SS										AR
53	SS										TN
54	AR										TN

With respect to reverse logistics function "Gate-keeping"

55) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

56) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

57) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

58) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

59) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

60) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

61) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

62) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

63) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

64) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

65) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

66) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

67) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

68) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

69) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Gate-keeping	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
55	CS										NT
56	CS										EC
57	CS										SA
58	CS										KM
59	CS										VR
60	NT										EC
61	NT										SA
62	NT										KM
63	NT										VR
64	EC										SA
65	EC										KM
66	EC										VR
67	SA										KM
68	SA										VR
69	KM										VR

With respect to reverse logistics function "Sorting and Storing"

70) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

71) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

72) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

73) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

74) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

75) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

76) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

77) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

78) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

79) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

80) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

81) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

82) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

83) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

84) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Sorting & Storing	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
70	CS										NT
71	CS										EC
72	CS										SA
73	CS										KM
74	CS										VR
75	NT										EC
76	NT										SA
77	NT										KM
78	NT										VR
79	EC										SA
80	EC										KM
81	EC										VR
82	SA										KM
83	SA										VR
84	KM										VR

With respect to reverse logistics function "Asset Recovery"

85) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

86) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

87) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

88) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

89) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

90) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

91) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

92) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

93) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

94) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

95) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

96) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

97) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

98) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

99) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Asset Recovery	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
85	CS										NT
86	CS										EC
87	CS										SA
88	CS										KM
89	CS										VR
90	NT										EC
91	NT										SA
92	NT										KM
93	NT										VR
94	EC										SA
95	EC										KM
96	EC										VR
97	SA										KM
98	SA										VR
99	KM										VR

With respect to reverse logistics function "Transportation"

100) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

101) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

102) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

103) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

104) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

105) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

106) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

107) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

108) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

109) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

110) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

111) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

112) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

113) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

114) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: TN	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
100	CS										NT
101	CS										EC
102	CS										SA
103	CS										KM
104	CS										VR
105	NT										EC
106	NT										SA
107	NT										KM
108	NT										VR
109	EC										SA
110	EC										KM
111	EC										VR
112	SA										KM
113	SA										VR
114	KM										VR

With respect to return product lifecycle stage "Introduction"

115) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

116) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

117) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

118) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

119) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

120) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

121) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

122) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

123) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

124) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

125) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

126) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

127) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

128) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

129) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: IN	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
115	CS										NT
116	CS										EC
117	CS										SA
118	CS										KM
119	CS										VR
120	NT										EC
121	NT										SA
122	NT										KM
123	NT										VR
124	EC										SA
125	EC										KM
126	EC										VR
127	SA										KM
128	SA										VR
129	KM										VR

With respect to return product lifecycle stage "Growth"

130) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

131) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

132) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

133) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

134) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

135) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

136) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

137) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

138) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

139) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

140) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

141) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

142) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

143) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

144) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Growth	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
130	CS										NT
131	CS										EC
132	CS										SA
133	CS										KM
134	CS										VR
135	NT										EC
136	NT										SA
137	NT										KM
138	NT										VR
139	EC										SA
140	EC										KM
141	EC										VR
142	SA										KM
143	SA										VR
144	KM										VR

With respect to return product lifecycle stage "Maturity"

145) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

146) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

147) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

148) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

149) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

150) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

151) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

152) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

153) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

154) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

155) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

156) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

157) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

158) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

159) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Maturity	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
145	CS										NT
146	CS										EC
147	CS										SA
148	CS										KM
149	CS										VR
150	NT										EC
151	NT										SA
152	NT										KM
153	NT										VR
154	EC										SA
155	EC										KM
156	EC										VR
157	SA										KM
158	SA										VR
159	KM										VR

With respect to return product lifecycle stage "Decline"

160) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

161) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

162) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

163) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

164) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

165) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

166) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

167) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

168) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

169) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

170) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

171) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

172) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

173) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

174) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Decline	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
160	CS										NT
161	CS										EC
162	CS										SA
163	CS										KM
164	CS										VR
165	NT										EC
166	NT										SA
167	NT										KM
168	NT										VR
169	EC										SA
170	EC										KM
171	EC										VR
172	SA										KM
173	SA										VR
174	KM										VR

With respect to return product lifecycle stage "Obsolete"

175) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

176) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

177) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

178) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

179) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

180) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

181) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

182) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

183) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

184) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

185) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

186) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

187) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

188) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

189) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Obsolete	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
175	CS										NT
176	CS										EC
177	CS										SA
178	CS										KM
179	CS										VR
180	NT										EC
181	NT										SA
182	NT										KM
183	NT										VR
184	EC										SA
185	EC										KM
186	EC										VR
187	SA										KM
188	SA										VR
189	KM										VR

With respect to reverse logistics strategy "Customer Satisfaction"

190) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

191) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

192) How important is *introduction (IN)* when it is compared with *decline (DE)*?

193) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

194) How important is *growth (GR)* when it is compared with *maturity (MA)*?

195) How important is *growth (GR)* when it is compared with *decline (DE)*?

196) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

197) How important is *maturity (MA)* when it is compared with *decline (DE)*?

198) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

199) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With respect to: CS	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Lifecycle stages
190	IN										GR
191	IN										MA
192	IN										DE
193	IN										OB
194	GR										MA
195	GR										DE
196	GR										OB
197	MA										DE
198	MA										OB
199	DE										OB

With respect to reverse logistics strategy "New Technology Implementation"

200) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

201) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

202) How important is *introduction (IN)* when it is compared with *decline (DE)*?

203) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

204) How important is *growth (GR)* when it is compared with *maturity (MA)*?

205) How important is *growth (GR)* when it is compared with *decline (DE)*?

206) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

207) How important is *maturity (MA)* when it is compared with *decline (DE)*?

208) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

209) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With respect to: NT	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
200	IN										GR
201	IN										MA
202	IN										DE
203	IN										OB
204	GR										MA
205	GR										DE
206	GR										OB
207	MA										DE
208	MA										OB
209	DE										OB

With respect to reverse logistics strategy "Eco-compatibility"

210) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

211) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

212) How important is *introduction (IN)* when it is compared with *decline (DE)*?

213) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

214) How important is *growth (GR)* when it is compared with *maturity (MA)*?

215) How important is *growth (GR)* when it is compared with *decline (DE)*?

216) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

217) How important is *maturity (MA)* when it is compared with *decline (DE)*?

218) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

219) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: EC	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
210	IN										GR
211	IN										MA
212	IN										DE
213	IN										OB
214	GR										MA
215	GR										DE
216	GR										OB
217	MA										DE
218	MA										OB
219	DE										OB

With respect to reverse logistics strategy "Strategic Alliances Formation"

220) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

221) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

222) How important is *introduction (IN)* when it is compared with *decline (DE)*?

223) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

224) How important is *growth (GR)* when it is compared with *maturity (MA)*?

225) How important is *growth (GR)* when it is compared with *decline (DE)*?

226) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

227) How important is *maturity (MA)* when it is compared with *decline (DE)*?

228) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

229) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: SA	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
220	IN										GR
221	IN										MA
222	IN										DE
223	IN										OB
224	GR										MA
225	GR										DE
226	GR										OB
227	MA										DE
228	MA										OB
229	DE										OB

With respect to reverse logistics strategy "Knowledge Management"

230) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

231) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

232) How important is *introduction (IN)* when it is compared with *decline (DE)*?

233) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

234) How important is *growth (GR)* when it is compared with *maturity (MA)*?

235) How important is *growth (GR)* when it is compared with *decline (DE)*?

236) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

237) How important is *maturity (MA)* when it is compared with *decline (DE)*?

238) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

239) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With respect to: KM	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
230	IN										GR
231	IN										MA
232	IN										DE
233	IN										OB
234	GR										MA
235	GR										DE
236	GR										OB
237	MA										DE
238	MA										OB
239	DE										OB

With respect to reverse logistics strategy “Value Recovery”

240) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

241) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

242) How important is *introduction (IN)* when it is compared with *decline (DE)*?

243) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

244) How important is *growth (GR)* when it is compared with *maturity (MA)*?

245) How important is *growth (GR)* when it is compared with *decline (DE)*?

246) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

247) How important is *maturity (MA)* when it is compared with *decline (DE)*?

248) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

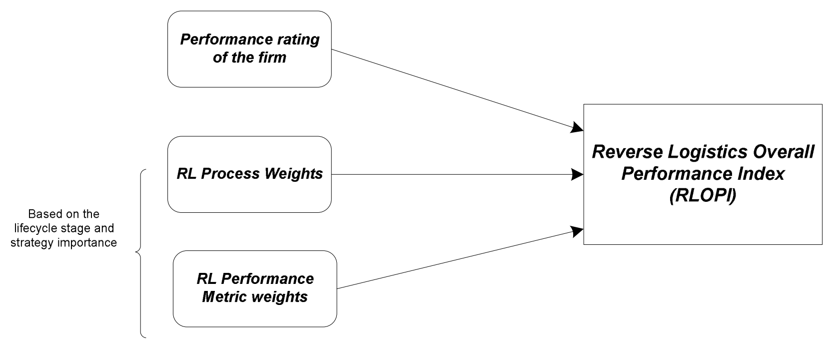
249) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: VR	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Lifecycle stages
240	IN										GR
241	IN										MA
242	IN										DE
243	IN										OB
244	GR										MA
245	GR										DE
246	GR										OB
247	MA										DE
248	MA										OB
249	DE										OB

Section I: Questions 1 - 5

This set of questions aims to validate some of the formulations used in the PEARL methodology to develop the reverse logistics overall performance index (RLOPI).

1. This research identifies three primary components of the RLOPI. They are depicted in the figure below.



The process weights and the performance metric weights are obtained from the fuzzy ANP methodology. The performance rating is calculated by collecting performance scores of competing consumer electronic organizations, and categorizing them into scales. How useful is this formulation? Use a scale of 1 through 5 with 1 being "not useful" and 5 being "absolutely useful".

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2. The performance score at the measure for an organization is formulated as:

$S_{mX} = PR_X * W_{mX} * W_{FX}$ where,

X refers to the company

Measure weight → W_{mX}

RL function weight → W_{FX}

How representative is this of the overall goals and objectives of a consumer electronics organization? Use a scale of 1 through 5 with 1 being “not representative” and 5 being “absolutely representative”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

3. The final RLOPI of a firm is calculated by summing the performance scores of the organization at the various measures.

$$\text{RLOPI} = \sum S_{mX}$$

Do you concur with the method of formulating the RLOPI? Do you suggest any changes?

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____

4. How useful is the calculation of RLOPI in the performance evaluation of a reverse supply chain? Use a scale of 1 through 5 with 1 being “not useful” and 5 being “absolutely useful”.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

5. Do we need to incorporate any modifications to the RLOPI formulation? If so, comment.

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APPENDIX B

IMPLEMENTATION WORKBOOK

Introduction

Performance Evaluation Analytic for Reverse Logistics (PEARL) is a 16 step methodology is designed to be used by consumer electronics organizations around the globe. An interview guide was utilized (Appendix A) in demonstrating the validation of the methodology in real world. The methodology as discussed will result in quantifying the returns management performance through the development of Reverse Logistics Overall Performance Index (RLOPI), and thereby aiding in benchmarking across industry average standards. The methodology is inherently flexible to incorporate best in class standards and also can be extended to other industries. Organizations can use this workbook to simplify the implementation of PEARL and make it user friendly. This section guides the organizations with little background knowledge about tools such as Analytical Network Process and Fuzzy Logic. The work book is designed to correlate with the steps of the PEARL methodology such that each step in the methodology has the corresponding implementation guideline and are numbered from G1 to G 16. The revised and validated 16 step PEARL methodology is enlisted below for reference.

1. Construct a decision makers committee
2. Determine the goals and objectives of the organization pertaining to the RL
3. Identify the various actors and functions that compose the organization's RSC
4. Design a reverse logistics network of the organization
5. Identify the lifecycle stages and market status of the product mix of the organization (Conduct market survey)
6. Identify the main drivers of returns in the consumer electronics industry, and analyze the current returns to evaluate your returns policy (Conduct Delphi study)

7. Develop the reverse logistics enabling strategies based on steps 2 – 6
8. Develop the reverse supply chain balanced scorecard to aid strategic decision making and performance measurement
9. Develop the appropriate process performance measures supporting the overall goals and strategies
10. Determine the inter-relationships between the various clusters of attributes
11. Establish the hierarchical Analytic Network Process decision framework of different attributes depicting the various clusters and their interdependencies
12. Develop super matrix using fuzzy AHP and ANP decision making approach
    a. Choose the appropriate linguistics terms to express the opinion of the decision makers in linguistic form
    b. Convert the linguistic information into triangular fuzzy numbers (TFN)
    c. Form pair-wise matrices with respect to the inter and intra dependencies between the clusters
    d. Evaluate the weights of each attribute based on their relationships in the hierarchy
    e. Calculate the aggregate weights for each criterion
    f. De-fuzzify the aggregate weights into crisp values
    g. Form the super matrix and converge it to a high power to make it column stochastic
13. Calculate the organization's Reverse Logistics Overall Performance Index (RLOPI)
    a. Determine the performance values at the measures for each RL function within the organization
    b. Collect performance values at the measures for other firms within the industry (commercial sources or trade associations)
    c. Categorize the performance within the electronics industry in the form of scales to assign performance ratings at the measures

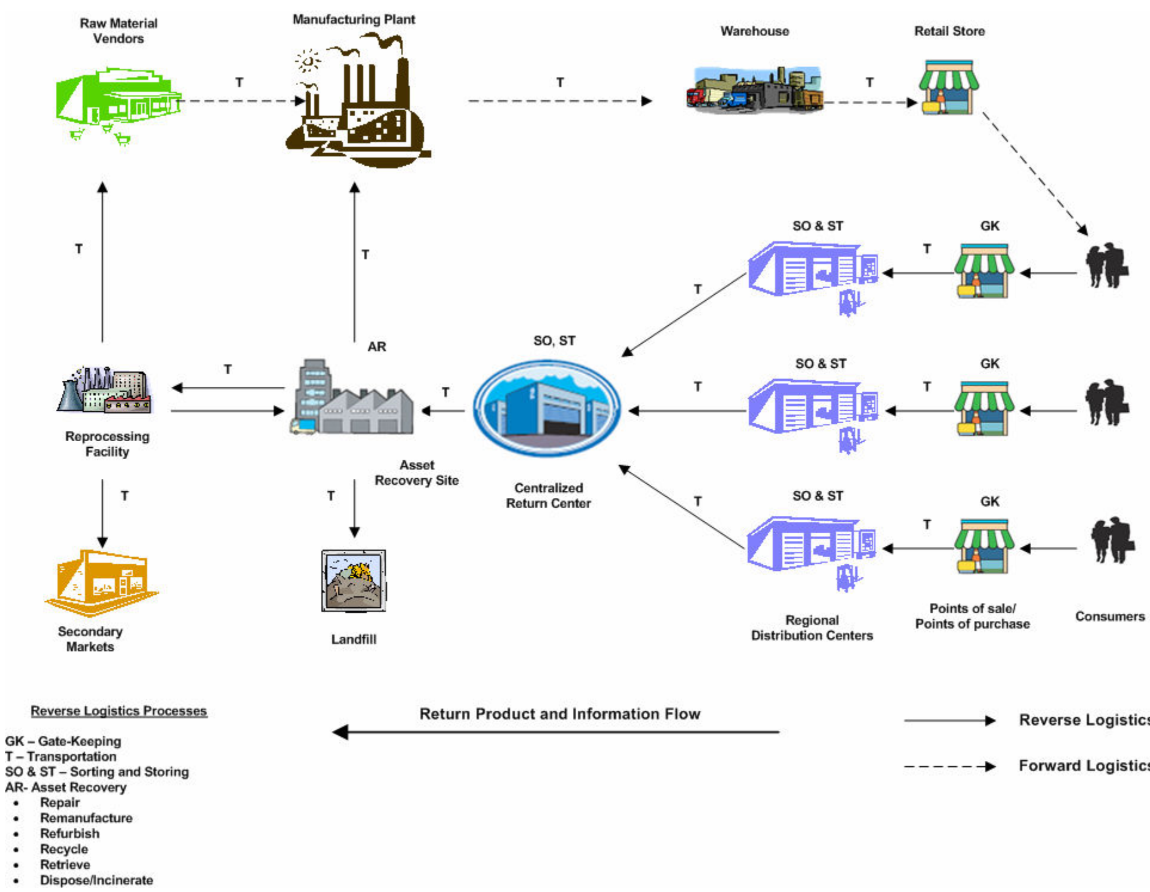
    d. Calculate the performance rating of the firm at the measures reflecting it's relative position within the electronics industry
    e. Calculate the performance score at the measure
    f. Determine reverse logistics overall performance index (RLOPI)
14. Perform sensitivity analysis (Go to step 12 and repeat steps 12 - 14)
15. Perform SWOT analysis (Identify strength and weakness areas)
16. Benchmark with industry competitors and feedback the performance and process improvement decisions (Go to step 7 and repeat steps 7 – 16)

G1: Form a decision makers committee (DMC) that is inter-organizational and comprises inter functional and inter departmental members responsible for handling reverse supply chain activities within each organization of the reverse supply chain either directly or indirectly. Ideally, the reverse logistics manager from the channel master organization in the reverse supply chain is responsible for identifying the members and leading the team to implement the methodology.

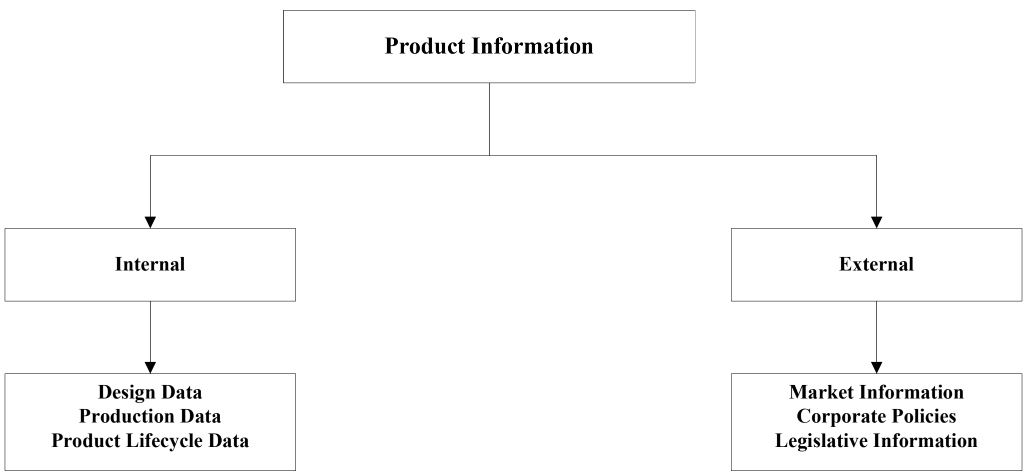
G2: The committee should brainstorm in identifying the overall goals and objectives of the organization to be successful in reverse logistics and build a strong reverse supply chain. The primary goal as determined by this research critical to the success of any reverse supply chain within the technical and environmental constraints is to maximize revenue.

G3: To identify the various actors in the reverse supply chain identify the product mix and identify the product flow from the end customer to the point of disposition. Make a comprehensive list of the various actors to develop the RL network in the next step of the methodology.

G4: Map the major actors and their functions in the forward and reverse supply chains and develop the RL network similar to the one developed in this research as shown below. The network developed should symbolize the longest possible network a returned product can follow. In other words, this "maximum node" network structure would take into account the worst case scenario where the product and the information have to flow through the maximum number of nodes. For example, products may actually reach the "Asset Recovery" center after "gate-keeping" without even passing through the regional distribution centers and the centralized return centers (CRC).

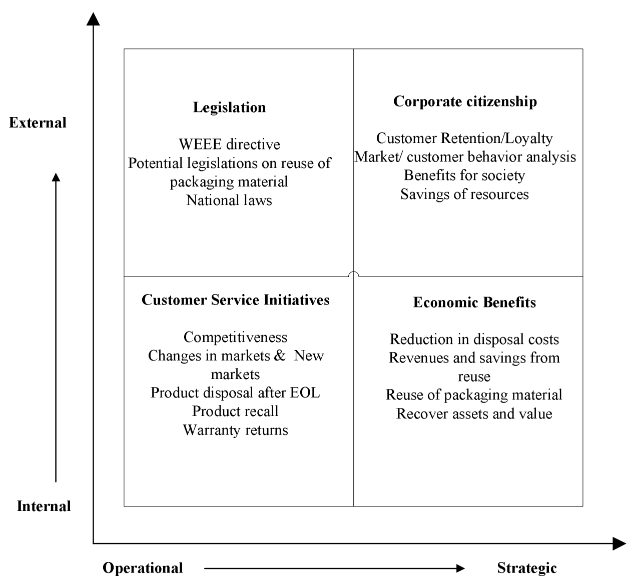


G5: Identify the products that have the highest product returns and enlist the top 20 or 30 that have a major impact on the bottom-line of the company. This could be achieved by market survey. The marketing department is responsible for gathering this information and providing it to the decision makers committee. The length of the product lifecycle affects the variability of expected returns over time. Once products have reached the end of their useful life, they may be able to be remanufactured, refurbished or repaired; thus extending their useful life. These options can provide significant benefits in consumer electronic products due their modular product design. A key prerequisite to identify the lifecycle stages of the return products is to develop a good understanding of the product information (See figure below).



Develop sales vs. return volumes matrix. The product lifecycle stage and length strongly determines the expected amount and the variability of returns for a particular product over time. This information when coupled with the inherent characteristics such as difficult product acquisition; volatile supply and demand rates and prices; and dynamic market conditions aids strategic decision making in classifying the drivers of returns and developing the right strategies in the following steps.

G6: Conduct a Delphi study to brainstorm on the drivers of returns in your organization and industry. Economic benefits, legislation, corporate citizenship and customer service initiatives are the four main drivers or determinants of reverse logistics taken into account in this research. It is important to understand the determinants of a closed economy and reverse logistics before proactively addressing the returns management challenges. As shown in figure below, legislation and customer service initiatives represent the conventional operational drivers, whereas business strategy and economic benefits have major bottom line benefits and can transform returns management to a strategic asset. These four perspectives are briefly described below.



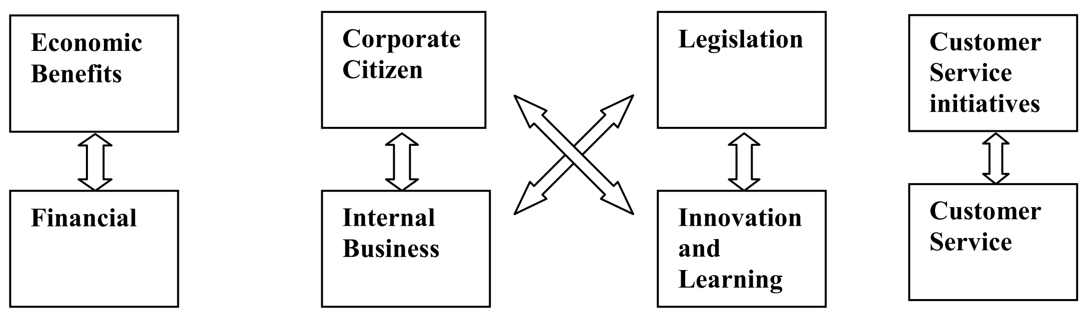
The Delphi study can be in the form of a war room discussion or an internal survey to identify the major drivers. Form a similar matrix as shown above to identify how the drivers fit into the strategic, operational, internal and external classification scheme.

G7: The critical step in the methodology is to develop the right strategies for the year. The reverse logistics manager should convene committee meetings to develop the strategy plan for the year and identify the major strategies based on the organizational goals and objectives, product lifecycle stages, and drivers of returns in consumer electronics industry. The deliverable of the meetings is the major strategies that the organization feels are reverse logistics enabling strategies and aid in being competitive in consumer electronics industry. This research has identified six major strategy umbrellas as critical to successful reverse supply chain. They are:

- Customer Satisfaction
- New Technology Implementation
- Eco-Compatibility
- Strategic Alliance Formation
- Knowledge Management, and
- Value Recovery

G8: Linking the balanced scorecard with the drivers of returns to measure the organizations reverse supply chain performance is an essential step in linking the drivers of reverse logistics to the four perspectives of the balanced scorecard. The decision making team can modify the traditional balance scorecard, if necessary, to develop a comprehensive strategic framework for measuring RSC performance. A BSC helps us to organize the objectives, measures, targets and initiatives from all the four perspectives and link them with the drivers of RL management systems. The bond between RL and the four perspectives of the BSC is depicted below in figure below.

The key issue to note is that both business strategy and legislation seem to be the drivers and can be assessed via measures that equate with the internal business and innovation and learning perspectives.

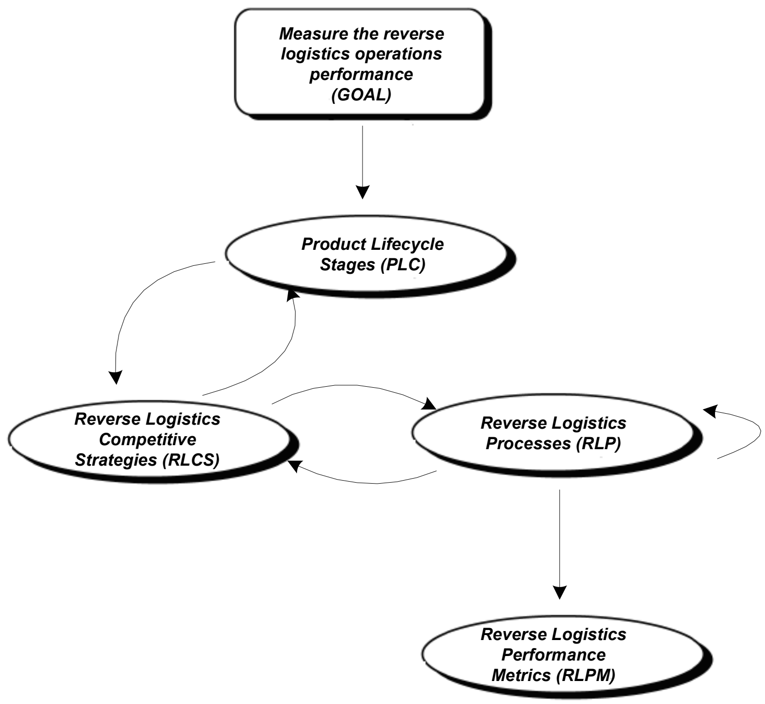


The DMC (Decision Making Committee) can identify how the drivers are affecting the four perspectives of BSC in their organization and thereby construct the scorecard to identify the major sub objectives, targets and initiatives for achieving the overall RL goals and objectives. This analysis helps in developing action plans and translating the strategic goals into tactical information.

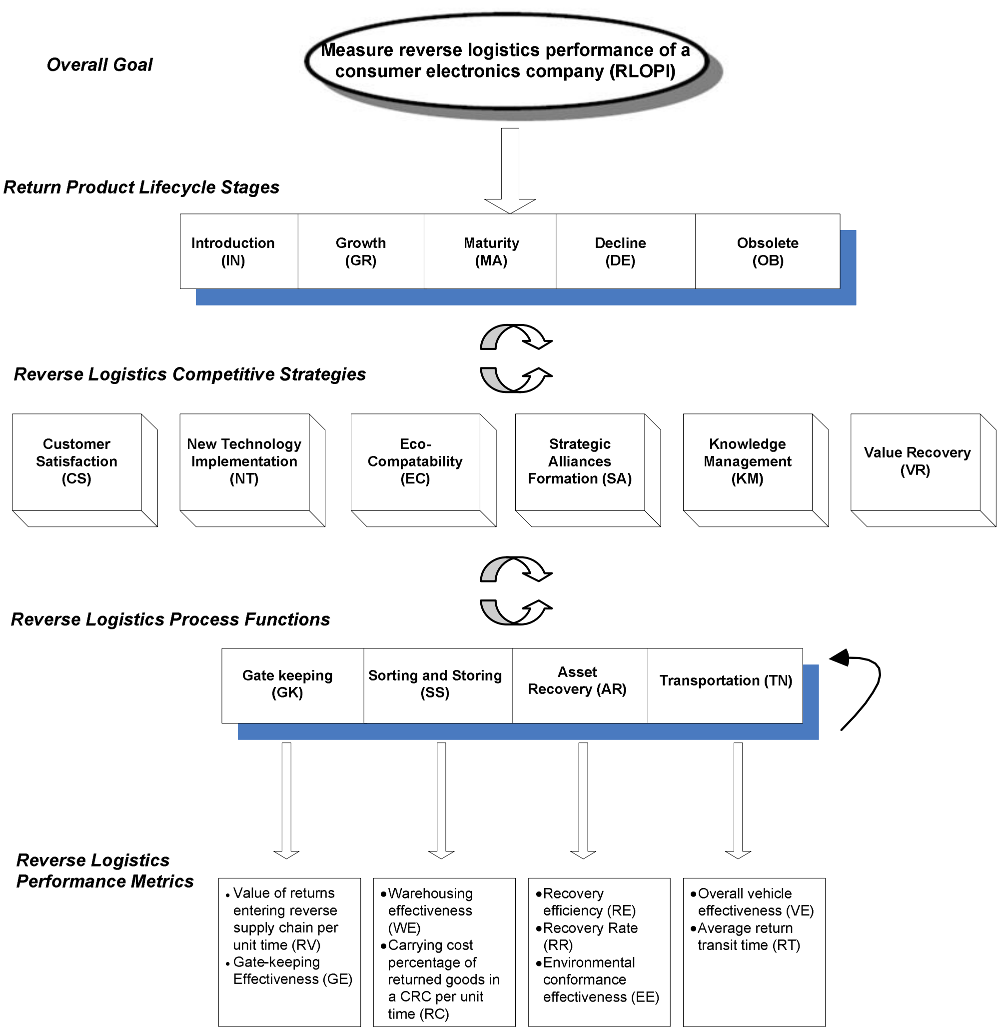
G9: Developing the right key performance indicators to measure the organizations reverse supply chain performance is a key step in developing the RLOPI. This research developed performance measures holistically from a focus (strategic or operational), type (qualitative and quantitative), basis (responsive or efficient), source (internal or external), and frequency (diagnostic or monitoring) perspectives of the balanced scorecard. This kind of approach assists an organization to develop an unbiased performance index that is not skewed with respect to a particular dimension of performance measurement. A similar approach can be consummated by committee in order to perform a health check and make sure that their performance measures are not skewed. The key performance indicators developed in this research and discussed in earlier section are quite comprehensive in evaluating the reverse supply chain performance of a consumer electronics organization. However, no measure is universally true and needs to be tailored to the situation on hand. This research developed some key measures based on the functions identified in the RL network design. They are as following:

- Value of returns/unit time (RV)
- Gate keeping Effectiveness (GE)
- Warehousing Effectiveness (WE)
- Carrying cost percentage in a CRC/unit time (RC)
- Recovery Efficiency (RE)
- Recovery Rate (RR)
- Environmental Conformance Effectiveness (EE)
- Overall Vehicle Effectiveness (VE)
- Average Return Transit Time (RT)

G10: Identify the inter-relationships between the various attributes that are necessary to evaluate the organizational reverse supply chain performance. The attributes identified in this research are the product lifecycle stages, reverse logistics functions, reverse logistics enabling strategies, and the performance measures. The process of analyzing the relationships is an extensive and painstaking process, but very critical with respect to implementing the PEARL and developing the RLOPI. Figure below depicts the various inter and intra relationships between the various attributes developed in this research. The committee should engage in numerous discussions in identifying these relationships and how on attribute affects another in the long term RL performance and success of the organization.



G11: Develop the Analytical Network Process hierarchy of the various decision making attributes. Of the complex and dynamic circumstances surrounding a consumer electronic firm, market and product characteristics provide the starting basis. Depending on the lifecycle stage of the product, the company must adopt competitive RL strategies to guide their priorities in their decisions, which are often complicated by the uncertainty of the product returns. The lifecycle stage and the strategy are inter-dependent. The lifecycle stage determines what strategies to adopt and their relative importance. Similarly, the strategy adopted will determine which lifecycle stage needs more consideration. The importance of strategies differs for each RL function and vice versa. Moreover, there is an inter cluster relationship within the RL process, as for each strategy the relative importance of the functions varies. The performance measures form the last level of the ANP model and these directly tie into their respective RL process. It should be born in mind that metrics should be dynamic, as they need to be updated and changed when needed. Once processes are improved, the frequency and type of metric measurement might change; possibly the metric will become unnecessary as improvements are institutionalized.



The relationship between the functions and their respective performance indicators can be represented in a two-level unidirectional hierarchical structure. Development of these measures varies as per the organizational goals and strategies. The hierarchical structure for decision making and in further developing the Reverse Logistics Overall performance Index (RLOPI) is presented below.

G12: To complete Step 12 of PEARL the DMC has to synthesize all the valuable information collected and analyzed for formulating the RLOPI. The first sub step is to develop the linguistic scale with a set of linguistic terms that are framed to evaluate the relative importance weights of the attributes involved in the decision making process. These linguistic terms are later converted into triangular fuzzy numbers to capture the preferences of the decision makers. The process of assigning membership functions to fuzzy variables is either intuitive or based on some algorithmic or logical operations.

Linguistic scale for importance	**Notation**	**Triangular fuzzy scale**	**Triangular fuzzy reciprocal scale**
Equally important	M_1	(1,1,1)	(1,1,1)
Weakly more important	M_2	(1, 3/2, 2)	(1/2,2/3,1)
Strongly more important	M_3	(3/2,2, 5/2)	(2/5,1/2,2/3)
Very strongly more important	M_4	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	M_5	(5/2,3,7/2)	(2/7,1/3,2/5)

Using the scale above, please answer the following questions and fill the appropriate following tables. If the decision is not unanimous, the responses of the various decision makers can be averaged and then filled into the tables. Read the following questions and put check marks on the pairwise comparison matrices. If an attribute on the left side is more important than the one matching on the right, put your check mark to the left of the importance "Equal" under the importance level you prefer. If an attribute on the left side is less important than the one matching on the right, put your check mark to the right of the importance "Equal" under the importance level you prefer.

With respect to reverse logistics function "Gate-keeping"

1) How important is *value of returns entering the RSC per unit time (RV)* when it is compared with *gate keeping effectiveness (GE)*?

With respect to: Gate-keeping	Importance of one measure over another										
Questions	Measures	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Measures
1	RV										GE

With respect to reverse logistics functions "Sorting and Storing"

2) How important is *warehousing effectiveness (WE)* when it is compared with *carrying cost percentage of returned goods in a CRC per unit time (RC)*?

With respect to: Sorting & Storing	Importance of one measure over another										
Questions	Measures	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Measures
2	WE										RC

With respect to reverse logistics function "Asset Recovery"

3) How important is *recovery efficiency (RE)* when it is compared with *recovery rate (RR)*?
4) How important is *recovery efficiency (RE)* when it is compared with *environmental conformance effectiveness (EE)*?
5) How important is *recovery rate (RR)* when it is compared with *environmental conformance effectiveness (EE)*?

With respect to: Asset Recovery	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
3	RE										RR
4	RE										EE
5	RR										EE

With respect to reverse logistics function "Transportation"

6) How important is *overall vehicle effectiveness (VE)* when it is compared with *average return transit time (RT)?*

With respect to: TN	Importance of one measure over another										
Questions	Measures	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Measures
6	VE										RT

With respect to reverse logistics function “Gate-keeping”

7) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

8) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

9) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Gate-keeping	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
7	SS										AR
8	SS										TN
9	AR										TN

With respect to reverse logistics function “Sorting and Storing”

10) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

11) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

12) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Sorting & Storing	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
10	GK										AR
11	GK										TN
12	AR										TN

With respect to reverse logistics function "Asset Recovery"

13) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

14) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

15) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

With respect to: Asset Recovery	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
13	GK										SS
14	GK										TN
15	SS										TN

With respect to reverse logistics function "Transportation"

16) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

17) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

18) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

With respect to: TN	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
16	GK										SS
17	GK										AR
18	SS										AR

With respect to reverse logistics strategy "Customer Satisfaction"

19) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

20) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

21) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

22) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

23) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

24) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Customer Satisfaction	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
19	GK										SS
20	GK										AR
21	GK										TN
22	SS										AR
23	SS										TN
24	AR										TN

With respect to reverse logistics strategy "New Technology Implementation"

25) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

26) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

27) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

28) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

29) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

30) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: NT	Importance of one function over another										
Questions	Functions	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Functions
25	GK										SS
26	GK										AR
27	GK										TN
28	SS										AR
29	SS										TN
30	AR										TN

With respect to reverse logistics strategy "Eco-compatibility"

31) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

32) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

33) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

34) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

35) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

36) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With Respect to: EC	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
31	GK										SS
32	GK										AR
33	GK										TN
34	SS										AR
35	SS										TN
36	AR										TN

With respect to reverse logistics strategy "Strategic Alliances Formation"

37) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

38) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

39) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

40) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

41) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

42) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Strategic Alliances Formation	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
37	GK										SS
38	GK										AR
39	GK										TN
40	SS										AR
41	SS										TN
42	AR										TN

With respect to reverse logistics strategy "Knowledge Management"

43) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

44) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

45) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

46) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

47) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

48) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: KM	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
43	GK										SS
44	GK										AR
45	GK										TN
46	SS										AR
47	SS										TN
48	AR										TN

With respect to reverse logistics strategy "Value Recovery"

49) How important is *gate-keeping (GK)* when it is compared with *sorting and storing (SS)*?

50) How important is *gate-keeping (GK)* when it is compared with *asset recovery (AR)*?

51) How important is *gate-keeping (GK)* when it is compared with *transportation (TN)*?

52) How important is *sorting and storing (SS)* when it is compared with *asset recovery (AR)*?

53) How important is *sorting and storing (SS)* when it is compared with *transportation (TN)*?

54) How important is *asset recovery (AR)* when it is compared with *transportation (TN)*?

With respect to: Value Recovery	Importance of one function over another										
Questions	Functions	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Functions
49	GK										SS
50	GK										AR
51	GK										TN
52	SS										AR
53	SS										TN
54	AR										TN

With respect to reverse logistics function "Gate-keeping"

55) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

56) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

57) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

58) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

59) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

60) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

61) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

62) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

63) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

64) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

65) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

66) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

67) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

68) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

69) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Gate-keeping	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
55	CS										NT
56	CS										EC
57	CS										SA
58	CS										KM
59	CS										VR
60	NT										EC
61	NT										SA
62	NT										KM
63	NT										VR
64	EC										SA
65	EC										KM
66	EC										VR
67	SA										KM
68	SA										VR
69	KM										VR

With respect to reverse logistics function "Sorting and Storing"

70) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

71) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

72) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

73) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

74) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

75) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

76) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

77) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

78) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

79) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

80) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

81) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

82) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

83) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

84) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Sorting & Storing	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
70	CS										NT
71	CS										EC
72	CS										SA
73	CS										KM
74	CS										VR
75	NT										EC
76	NT										SA
77	NT										KM
78	NT										VR
79	EC										SA
80	EC										KM
81	EC										VR
82	SA										KM
83	SA										VR
84	KM										VR

With respect to reverse logistics function "Asset Recovery"

85) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

86) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

87) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

88) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

89) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

90) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

91) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

92) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

93) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

94) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

95) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

96) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

97) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

98) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

99) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: Asset Recovery	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
85	CS										NT
86	CS										EC
87	CS										SA
88	CS										KM
89	CS										VR
90	NT										EC
91	NT										SA
92	NT										KM
93	NT										VR
94	EC										SA
95	EC										KM
96	EC										VR
97	SA										KM
98	SA										VR
99	KM										VR

With respect to reverse logistics function "Transportation"

100) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

101) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

102) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

103) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

104) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

105) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

106) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

107) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

108) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

109) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

110) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

111) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

112) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

113) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

114) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With Respect to: TN	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
100	CS										NT
101	CS										EC
102	CS										SA
103	CS										KM
104	CS										VR
105	NT										EC
106	NT										SA
107	NT										KM
108	NT										VR
109	EC										SA
110	EC										KM
111	EC										VR
112	SA										KM
113	SA										VR
114	KM										VR

With respect to return product lifecycle stage "Introduction"

115) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

116) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

117) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

118) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

119) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

120) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

121) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

122) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

123) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

124) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

125) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

126) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

127) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

128) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

129) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: IN	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
115	CS										NT
116	CS										EC
117	CS										SA
118	CS										KM
119	CS										VR
120	NT										EC
121	NT										SA
122	NT										KM
123	NT										VR
124	EC										SA
125	EC										KM
126	EC										VR
127	SA										KM
128	SA										VR
129	KM										VR

With respect to return product lifecycle stage "Growth"

130) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

131) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

132) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

133) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

134) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

135) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

136) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

137) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

138) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

139) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

140) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

141) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

142) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

143) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

144) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With Respect to: GR	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
130	CS										NT
131	CS										EC
132	CS										SA
133	CS										KM
134	CS										VR
135	NT										EC
136	NT										SA
137	NT										KM
138	NT										VR
139	EC										SA
140	EC										KM
141	EC										VR
142	SA										KM
143	SA										VR
144	KM										VR

With respect to return product lifecycle stage "Maturity"

145) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

146) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

147) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

148) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

149) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

150) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

151) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

152) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

153) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

154) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

155) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

156) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

157) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

158) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

159) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With respect to: MA	Importance of one strategy over another										
Questions	Strategies	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Strategies
145	CS										NT
146	CS										EC
147	CS										SA
148	CS										KM
149	CS										VR
150	NT										EC
151	NT										SA
152	NT										KM
153	NT										VR
154	EC										SA
155	EC										KM
156	EC										VR
157	SA										KM
158	SA										VR
159	KM										VR

With respect to return product lifecycle stage "Decline"

160) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

161) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

162) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

163) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

164) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

165) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

166) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

167) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

168) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

169) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

170) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

171) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

172) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

173) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

174) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With Respect to: DE	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
160	CS										NT
161	CS										EC
162	CS										SA
163	CS										KM
164	CS										VR
165	NT										EC
166	NT										SA
167	NT										KM
168	NT										VR
169	EC										SA
170	EC										KM
171	EC										VR
172	SA										KM
173	SA										VR
174	KM										VR

With respect to return product lifecycle stage "Obsolete"

175) How important is *customer satisfaction (CS)* when it is compared with *new technology implementation (NT)*?

176) How important is *customer satisfaction (CS)* when it is compared with *eco-compatibility (EC)*?

177) How important is *customer satisfaction (CS)* when it is compared with *strategic alliance formation (SA)*?

178) How important is *customer satisfaction (CS)* when it is compared with *knowledge management (KM)*?

179) How important is *customer satisfaction (CS)* when it is compared with *value recovery (VR)*?

180) How important is *new technology implementation (NT)* when it is compared with *eco-compatibility (EC)*?

181) How important is *new technology implementation (NT)* when it is compared with *strategic alliances formation (SA)*?

182) How important is *new technology implementation (NT)* when it is compared with *knowledge management (KM)*?

183) How important is *new technology implementation (NT)* when it is compared with *value recovery (VR)*?

184) How important is *eco-compatibility (EC)* when it is compared with *strategic alliance formation (SA)*?

185) How important is *eco-compatibility (EC)* when it is compared with *knowledge management (KM)*?

186) How important is *eco-compatibility (EC)* when it is compared with *value recovery (VR)*?

187) How important is *strategic alliance formation (SA)* when it is compared with *knowledge management (KM)*?

188) How important is *strategic alliance formation (SA)* when it is compared with *value recovery (VR)*?

189) How important is *knowledge management (KM)* when it is compared with *value recovery (VR)*?

With Respect to: Obsolete	Importance of one strategy over another										
Questions	Strategies	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Strategies
175	CS										NT
176	CS										EC
177	CS										SA
178	CS										KM
179	CS										VR
180	NT										EC
181	NT										SA
182	NT										KM
183	NT										VR
184	EC										SA
185	EC										KM
186	EC										VR
187	SA										KM
188	SA										VR
189	KM										VR

With respect to reverse logistics strategy "Customer Satisfaction"

190) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

191) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

192) How important is *introduction (IN)* when it is compared with *decline (DE)*?

193) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

194) How important is *growth (GR)* when it is compared with *maturity (MA)*?

195) How important is *growth (GR)* when it is compared with *decline (DE)*?

196) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

197) How important is *maturity (MA)* when it is compared with *decline (DE)*?

198) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

199) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: CS	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
190	IN										GR
191	IN										MA
192	IN										DE
193	IN										OB
194	GR										MA
195	GR										DE
196	GR										OB
197	MA										DE
198	MA										OB
199	DE										OB

With respect to reverse logistics strategy "New Technology Implementation"

200) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

201) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

202) How important is *introduction (IN)* when it is compared with *decline (DE)*?

203) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

204) How important is *growth (GR)* when it is compared with *maturity (MA)*?

205) How important is *growth (GR)* when it is compared with *decline (DE)*?

206) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

207) How important is *maturity (MA)* when it is compared with *decline (DE)*?

208) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

209) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With respect to: NT	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
200	IN										GR
201	IN										MA
202	IN										DE
203	IN										OB
204	GR										MA
205	GR										DE
206	GR										OB
207	MA										DE
208	MA										OB
209	DE										OB

With respect to reverse logistics strategy "Eco-compatibility"

210) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

211) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

212) How important is *introduction (IN)* when it is compared with *decline (DE)*?

213) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

214) How important is *growth (GR)* when it is compared with *maturity (MA)*?

215) How important is *growth (GR)* when it is compared with *decline (DE)*?

216) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

217) How important is *maturity (MA)* when it is compared with *decline (DE)*?

218) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

219) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: EC	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
210	IN										GR
211	IN										MA
212	IN										DE
213	IN										OB
214	GR										MA
215	GR										DE
216	GR										OB
217	MA										DE
218	MA										OB
219	DE										OB

With respect to reverse logistics strategy "Strategic Alliances Formation"

220) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

221) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

222) How important is *introduction (IN)* when it is compared with *decline (DE)*?

223) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

224) How important is *growth (GR)* when it is compared with *maturity (MA)*?

225) How important is *growth (GR)* when it is compared with *decline (DE)*?

226) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

227) How important is *maturity (MA)* when it is compared with *decline (DE)*?

228) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

229) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: SA	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
220	IN										GR
221	IN										MA
222	IN										DE
223	IN										OB
224	GR										MA
225	GR										DE
226	GR										OB
227	MA										DE
228	MA										OB
229	DE										OB

With respect to reverse logistics strategy "Knowledge Management"

230) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

231) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

232) How important is *introduction (IN)* when it is compared with *decline (DE)*?

233) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

234) How important is *growth (GR)* when it is compared with *maturity (MA)*?

235) How important is *growth (GR)* when it is compared with *decline (DE)*?

236) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

237) How important is *maturity (MA)* when it is compared with *decline (DE)*?

238) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

239) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With respect to: KM	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3/7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3/7/2) Absolute	Lifecycle stages
230	IN										GR
231	IN										MA
232	IN										DE
233	IN										OB
234	GR										MA
235	GR										DE
236	GR										OB
237	MA										DE
238	MA										OB
239	DE										OB

With respect to reverse logistics strategy "Value Recovery"

240) How important is *introduction (IN)* when it is compared with *growth* (*GR)*?

241) How important is *introduction (IN)* when it is compared with *maturity (MA)*?

242) How important is *introduction (IN)* when it is compared with *decline (DE)*?

243) How important is *introduction (IN)* when it is compared with *obsolete (OB)*?

244) How important is *growth (GR)* when it is compared with *maturity (MA)*?

245) How important is *growth (GR)* when it is compared with *decline (DE)*?

246) How important is *growth (GR)* when it is compared with *obsolete (OB)*?

247) How important is *maturity (MA)* when it is compared with *decline (DE)*?

248) How important is *maturity (MA)* when it is compared with *obsolete (OB)*?

249) How important is *decline (DE)* when it is compared with *obsolete (OB)*?

With Respect to: VR	Importance of one lifecycle stage over another										
Questions	Lifecycle stages	(5/2,3,7/2) Absolute	(2,5/2,3) Very strong	(3/2,2,5/2) Strong	(1,3/2,2) Weak	(1,1,1) Equal	(1,3/2,2) Weak	(3/2,2,5/2) Strong	(2,5/2,3) Very strong	(5/2,3,7/2) Absolute	Lifecycle stages
240	IN										GR
241	IN										MA
242	IN										DE
243	IN										OB
244	GR										MA
245	GR										DE
246	GR										OB
247	MA										DE
248	MA										OB
249	DE										OB

After the questions have been answered, and the appropriate linguistic importance has been checked, the next task is to transfer that information into the appropriate pairwise comparison matrices depicted below.

Pair-wise comparison matrix and importance of measures for

Gate-keeping function

Gate-keeping (GK)	RV	GE	Weight
RV	(1,1,1)		
GE		(1,1,1)	

Pair-wise comparison matrix and importance of measures for

Sorting and Storing function

Sorting and Storing (SS)	WE	RC	Weight
WE	(1,1,1)		
RC		(1,1,1)	

Pair-wise comparison matrix and importance of measures for

Asset Recovery function

Asset Recovery (AR)	RE	RR	EE	Weight
RE	(1,1,1)			
RR		(1,1,1)		
EE			(1,1,1)	

Pair-wise comparison matrix and importance of measures for

Transportation function

Transportation (TN)	VE	RT	Weight
VE	(1,1,1)		
RT		(1,1,1)	

Pair-wise comparison matrix of relative importance of functions with respect to

Gate-keeping function

Gate-Keeping (GK)	SS	AR	TN	Weight
SS	(1,1,1)			
AR		(1,1,1)		
TN			(1,1,1)	

Pair-wise comparison matrix of relative importance of functions with respect to

Sorting to Storing function

Sorting and Storing (SS)	GK	AR	TN	Weight
GK	(1,1,1)			
AR		(1,1,1)		
TN			(1,1,1)	

Pair-wise comparison matrix of importance of functions with respect to Asset recovery function

Asset Recovery (AR)	GK	SS	TN	Weight
GK	(1,1,1)			
SS		(1,1,1)		
TN			(1,1,1)	

Pair-wise comparison matrix of importance of functions with respect to Transportation function

Transportation (TN)	GK	SS	AR	Weight
GK	(1,1,1)			
SS		(1,1,1)		
AR			(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under Customer Satisfaction strategy

Customer Satisfaction (CS)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under New Technology Implementation strategy

New Technology Implementation (NT)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under Eco-Compatibility strategy

Eco-Compatibility (EC)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under Strategic Alliance Formation strategy

Strategic Alliance Formation (SA)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under Knowledge Management strategy

Knowledge Management (KM)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the effect of RL functions on each other under Value Recovery strategy

Value Recovery (VR)	GK	SS	AR	TN	Weight
GK	(1,1,1)				
SS		(1,1,1)			
AR			(1,1,1)		
TN				(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Gate-keeping function

Gate-Keeping (GK)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Sorting and Storing function

Sorting and Storing (SS)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Asset Recovery function

Asset Recovery (AR)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Transportation function

Transportation (TN)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Introduction lifecycle stage

Introduction (IN)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Growth lifecycle stage

Growth (GR)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Maturity lifecycle stage

Maturity (MA)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage

Decline (DE)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of strategies under Decline lifecycle stage

Obsolete (OB)	CS	NT	EC	SA	KM	VR	Weight
CS	(1,1,1)						
NT		(1,1,1)					
EC			(1,1,1)				
SA				(1,1,1)			
KM					(1,1,1)		
VR						(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Customer Satisfaction strategy

CS	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under New Technology Implementation strategy

NT	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Eco-Compatibility strategy

EC	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Strategic Alliance Formation strategy

SA	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Knowledge Management strategy

KM	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

Pair-wise comparison matrix to determine the relative importance of lifecycle stages under Value Recovery strategy

VR	IN	GR	MA	DE	OB	Weight
IN	(1,1,1)					
GR		(1,1,1)				
MA			(1,1,1)			
DE				(1,1,1)		
OB					(1,1,1)	

The attributes developed in this dissertation were identified to characterize an organization engaging in reverse logistics. Although these do not differ much for most companies, the importance of these attributes changes from firm to firm. Once the weights are determined and the pairwise matrices are filled, the next 2 sub steps is to calculate the aggregate weights for each matrix provided in the last column of every matrix, and to de-fuzzify the weights into crisp values. Both these steps can be achieved using the Chang's extent analysis in section 2.6.3 of this dissertation. It is depicted for one pairwise matrix below for illustration. Follow the same approach for determining the aggregate de-fuzzified crisp weights for each of the pairwise comparison matrix.

Pair-wise comparison matrix and importance of measures for

Gate-keeping function – Company A

Gate-keeping GK)	RV	GE	Weight
RV	(1,1,1)	(1/3,2/5,1/2)	0
GE	(2,5/2,3)	(1,1,1)	1

Performing Step 1 of the analysis and using equations 2.6, 2.7, 2.8 and 2.9 we have

S_1= (1.33, 1.4, 1.5) * (1/5.5, 1/4.9, 1/4.33) = (0.24, 0.28, 0.35)

S_2= (3, 3.5, 4) * (1/5.5, 1/4.9, 1/4.33) = (0.54, 0.71, 0.92)

Performing Step 2 of the analysis and using equations from 2.10 to 2.13 we have

$V(S_1 \geq S_2) = 0$

$V(S_2 \geq S_1) = 1$

Performing Step 3 of the analysis and using equations from 2.14 to 2.17 we have

$d'(A_1) = \min V(S_1 \geq S_2) = \min(0) = 0$

$d'(A_2) = \min V(S_2 \geq S_1) = \min(1) = 1$

Therefore, $W' = (0, 1)^T$

$W = (0, 1)^T$

The process of determining the normalized weights is followed by populating these weights in the appropriate columns of the supermatrix based on the interdependencies. In case of the RL functions and the strategies interdependencies, there is also an additional step of calculating the z-vector to include the relative importance among the RL functions on a third RL function under each competitive strategy. The table below depicts the contributions among RL functions for one strategy to obtain the real importance of the functions (z-vector). These steps should be repeated for every RL enabling strategy to calculate their respective z-vectors. The final super matrix is formed by combining the z-vectors and importance weight vectors of the strategies and the lifecycle stages. The supermatrix is raised to the power of M^{2k+1} to achieve convergence.

Z-vector to determine the total contribution of RL functions with respect to a particular strategy

GK	SS	AR	TN		CS		Z-Vector
	FILL			**X**		**=**	

The last sub step in step 12 is to form the super matrix itself. The two dimensional supermatrix is formed from the relative importance weight vectors to allow for the resolution of the effects of the inter-dependence that exists between clusters within the decision network hierarchy. The supermatrix is a partitioned matrix where each submatrix is composed of a set of relationships between two clusters. After the formation of the supermatrix, the final step is to determine the final relative importance weights that are used in the calculation of RLOPI. To complete this step and guarantee convergence, the columns of the supermatrix must be column stochastic. That is the weights of each column for the supermatrix need to sum to 1. This is achieved by raising the supermatrix to a large power until stabilization of weights occurs (i.e. when values in the supermatrix do not change when it is multiplied by itself again) as illustrated in tables below respectively. For this research, to calculate the large powers web based publicly available software called Quick Math was used (http://www.quickmath.com/www02/pages/modules/matrices/index.shtml).

Super Matrix (M)

	IN	**GR**	**MA**	**DE**	**OB**	**CS**	**NT**	**EC**	**SA**	**KM**	**VR**	**GK**	**SS**	**AR**	**TN**
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0			***FILL***				0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC			***FILL***			0	0	0	0	0	0			***FILL***	
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0							0	0	0	0
SS	0	0	0	0	0							0	0	0	0
AR	0	0	0	0	0			***FILL***				0	0	0	0
TN	0	0	0	0	0							0	0	0	0

Column Stochastic Super Matrix

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0				***FILL***			0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0		***FILL***		
EC			***FILL***			0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0							0	0	0	0
SS	0	0	0	0	0				***FILL***			0	0	0	0
AR	0	0	0	0	0							0	0	0	0
TN	0	0	0	0	0							0	0	0	0

Converged Super Matrix (M^{2k+1})

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0							0	0	0	0
GR	0	0	0	0	0							0	0	0	0
MA	0	0	0	0	0							0	0	0	0
DE	0	0	0	0	0							0	0	0	0
OB	0	0	0	0	0							0	0	0	0
CS						0	0	0	0	0	0				
NT						0	0	0	0	0	0				
EC						0	0	0	0	0	0				
SA						0	0	0	0	0	0				
KM						0	0	0	0	0	0				
VR						0	0	0	0	0	0				
GK	0	0	0	0	0							0	0	0	0
SS	0	0	0	0	0				***FILL***			0	0	0	0
AR	0	0	0	0	0							0	0	0	0
TN	0	0	0	0	0							0	0	0	0

G13: Calculate the performance scores of your organization at the various measures developed in step 9. Calculate the value of returns entering the reverse supply chain per unit time (RV) using the equation below:

$$\mathbf{RV} = \sum_{i=1}^{n}\left[\sum_{D=1}^{D_{max}}\left(\sum_{OD=1}^{OD_{max}}(N_i * C_i) + \sum_{TD=1}^{TD_{max}}(N_i * C_i)\right) + \sum_{I=1}^{I_{max}}\left(\sum_{OI=1}^{OI_{max}}(N_i * C_i) + \sum_{TI=1}^{TI_{max}}(N_i * C_i)\right)\right]$$

where,

$i = 1,2,..,n$ is the number of product categories in the company

N_i is the number of returned products in a product category

C_i is the cost of returned products in a product category

(*Assumption*: The maximum value of a return is equal to the manufacturing cost of the product)

D is the number of domestic locations

D_{max} is the maximum number of domestic locations

I is the number of international locations

I_{max} is the maximum number of international locations

OD is the number of online domestic locations

OD_{max} is the maximum number of online domestic locations

OI is the number of online international locations

OI_{max} is the maximum number of online international locations

TD is the number of traditional domestic locations

TD_{max} is the maximum number of traditional domestic locations

TI is the number of traditional international locations

TI_{max} is the maximum number of traditional international locations

Gate-keeping Effectiveness (GE) reflects the importance of gate-keeping to the organization's successful reverse logistics strategies. The table above suggests some of the best practices that constitute Gate-Keeping Effectiveness. Check all those that apply.

Best Practice	
Clear and visible return policies to reduce the number of defective products into RSC	□
Use of dedicated skilled labor for return product inspection and testing at gate-keeping site	□
Use of latest test equipment for checking the reliability of the product	□
Use of IT and information software for generating a return good authorization	□
Devote necessary utilities, supervision and maintenance requirements for proper administration	□
Use of multiple channels such as phone and internet to provide support and troubleshooting	□
Employ programs to reduce idle time of trucks and products at gate-keeping	□
Presence of economic benchmarks for acceptance / rejection of returned items	□
Develop EDI linkages for the return goods management	□
Established business rules to assist customer representatives for faster customer credit	□

Warehousing Effectiveness (WE) is an aggregate measure of warehousing performance of an organization in handling returns. The following is the list of best practices that comprise warehousing effectiveness. Check all that apply.

Best Practice	
Real time updating of inventory in warehouses	□
Application of RFID technologies for tracking stored return products	□
Availability of detailed shipping and receiving data for the proper handling and management of returned items	□
Use of existing warehousing functions and resources	□
Use of current warehousing methods and equipment	□
Improvements in warehousing layout design for the physical separation of virgin and returned items	□
Use of separate CRCs to handle returns	□
Compliance with OSHA and ISO 14000	□
Provision of special handling requirements	□
Use of full time employees dedicated to handling returns	□
Adherence of outsourced return centers to service level agreements	□

The cost to carry return products, measures the overhead that an organization carries to support its inventory. Carrying cost is usually expressed as a percentage that represents the cents per dollar that will be spent on inventory overhead per year.

$$\text{Carrying Cost Percentage (RC)} = \frac{\text{Fixed costs} + \text{Variable costs}}{\text{Average value of return inventory}}$$

$$= \frac{[(S + E + P) + (M + T + I + O + P)]}{Q}$$

$$= \frac{\left\langle \sum_{i=1}^{n} [(S + E + P) + (M + T + I + O + P)] * R_i \right\rangle}{\sum_{i=1}^{n} (R_i * C_i)}$$

where,

i = 1,2,..,n is the number of product categories in the company

R_i is the number of returned products in a product category located in the warehouse

C_i is the cost of returned products in a product category

S is the cost of space per unit return

E is the cost of equipment needed to handle a unit return

P is the cost of personnel to handle a unit return

M is the cost of money tied up in a unit return

T is the cost of taxes on a unit return

I is the insurance cost per unit return

O is the obsolescence and shrinkage cost per unit return

P is the pilferage cost involved in a unit return

Q is the average value of inventory in the warehouse

Calculate the Recovery Efficiency (RE), defined as:

$$RE = \frac{\text{Value recovered}}{\text{Resources used} + \text{Environmental impact}}$$

Calculate your organizational Recovery Rate (RR) defined as:

$$RR_j = 1 - \left(\sum_{i=1}^{n} S_{ij} / N_j\right)$$ where,

S_{ij} is the number of units of item *j* scrapped in time period *i*, and

N_j is the total number of item *j* inducted into the asset recovery process

A third and final qualitative measure devised to measure asset recovery is Environmental Effectiveness (EE). The following is the list of best practices that comprise environmental effectiveness. Check all that apply.

Best Practice	
Presence of educational and training programs to employees	□
Use of employee incentive programs related to environmental goals	□
Use of supplier environmental audits and assessments	□
Presence of emergency response programs	□
Compliance with regulations such as WEEE, EPA, ISO 14001 and RoHS	□
Use of eco-friendly product and packaging materials	□
Use of recycle materials to manufacture virgin products	□
Promotion of industry wide cooperative efforts on environmental issues	□
Develop tools that assist in designing products for environment	□
Support end-of-life processing by tracking product data from design through end-of-life (significant for products with long lifecycles)	□
Use of compliance reporting and material declaration sheets for all products manufactured	□

This research develops a qualitative analytic to measure transportation, namely, Overall Vehicle Effectiveness (VE). VE is an aggregate qualitative measure that helps the company to compare its transportation with some of the best practices in the industry. Check all that you think are applicable.

Best Practice	
Use of existing transportation routes and schedules	□
Use of inter-modal transportation on a timely basis	□
Use of shipping in bulk and cube utilization	□
Use of computer network technology to track return products from gate-keeping to disposal	□
Availability of detailed shipping and receiving data for the proper handling and management of returned items	□
Use of special bins for distinction between virgin and returned items	□
Use of automated systems for generating return good authorization (RGA) and other shipping documentation	□
Provision of online web capability to schedule returns pickups	□
Use of rate engines that allow selection of the lowest shipping cost across multiple carriers	□
Coordinate returns shipments to get lower transportation costs and improve vehicle and mileage utilization	□

A quantitative metric developed in this study for gauging transportation effectiveness is the Average Return Transit Time (RT). It is measured by the number of days (or hours) from the time a returned product spends in transit, after it enters the reverse supply chain at the gate-keeping site, to the point it leaves the reverse supply chain. The average return transit time can be expressed as

$$RT = \frac{\sum_{i=1}^{N} T_i}{N}$$ where,

i=1, 2… N is the number of products entering the reverse supply chain

T_i is the total time spent by a product return in transit

The next sub step in step 13 is to collect the performances of the various organizations collected from various sources such as trade journals or third party consulting services. Develop rating scales to categorize the performances and assign performance ratings at the measures. In the development of the scales, the average of the performance values of the firms is assigned the performance rating of 0.5. The best and lowest performance values at each measure are respectively assigned 1.0 and 0.0. The performances of the organizations at the nine different performance measures developed in this research based on the two case studies conducted are shown below in tables below for illustration. For qualitative measures, a simpler method similar to a Likert scale was used to calculate the performance score at the measure as depicted in the tables.

Performance scale developed to rate the Gate-keeping performance of an organization in the consumer electronics industry

Gate-Keeping (GK)			
RV ($/unit time)		GE	
Value	Rating	Range	Rating
0	1.00	GE=10	1.00
72	0.50	GE=9	0.90
144	0.00	GE=8	0.80
		GE=7	0.70
		GE=6	0.60
		GE=5	0.50
		GE=4	0.40
		GE=3	0.30
		GE=2	0.20
		GE=1	0.10

Performance scale developed to rate the Sorting and Storing performance of an organization in the consumer electronics industry

Sorting and Storing (SS)			
WE		RC (%)	
Range	Rating	Value	Rating
WE=10	1.00	0	1.00
WE=9	0.90	2.5	0.50
WE=8	0.80	5	0.00
WE=7	0.70		
WE=6	0.60		
WE=5	0.50		
WE=4	0.40		
WE=3	0.30		
WE=2	0.20		
WE=1	0.10		

Performance scale developed to rate the Asset Recovery performance of an organization in the consumer electronics industry

Asset Recovery (AR)					
RE (%)		RR (days)		EE	
Value	Rating	Value	Rating	Range	Rating
25	1.00	0	1.00	EE=10	1.00
12.5	0.50	13	0.50	EE=9	0.90
0	0.00	26	0.00	EE=8	0.80
				EE=7	0.70
				EE=6	0.60
				EE=5	0.50
				EE=4	0.40
				EE=3	0.30
				EE=2	0.20
				EE=1	0.10

Performance scale developed to rate the Transportation performance of an organization in the consumer electronics industry

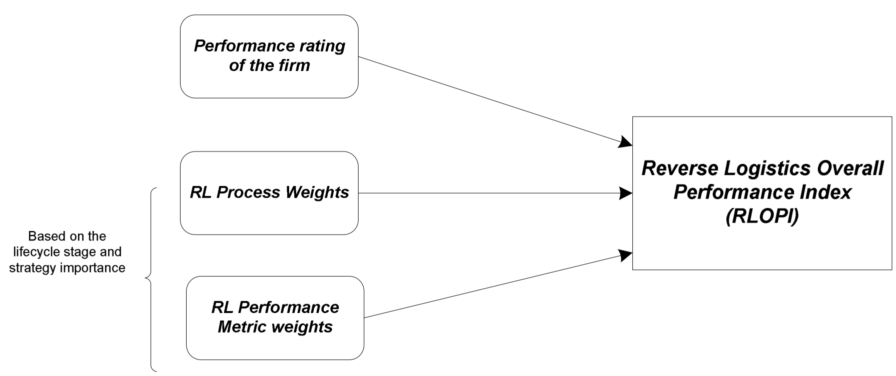
Transportation (TN)			
VE		RT (days)	
Range	Rating	Value	Rating
VE=10	1.00	0	1.00
VE=9	0.90	8.5	0.50
VE=8	0.80	17	0.00
VE=7	0.70		
VE=6	0.60		
VE=5	0.50		
VE=4	0.40		
VE=3	0.30		
VE=2	0.20		
VE=1	0.10		

The final sub step in step 13 is to calculate the reverse logistics overall performance index that has three primary components as shown in figure below. These are the

1. Performance rating of the firm across the consumer electronics industry,

2. Function weights, and

3. Performance measure weights



The RLOPI for the firm can be calculated using equations shown below. The relative importance weights of the RL functions (from the supermatrix) and the relative importance weights of the measures from the pairwise comparison matrices are placed in the columns entitled RL function weight (W_{FX}) and Measure weight (W_{mX}) respectively (see Table below). The performance of the firm at a measure can be calculated by multiplying the performance rating at the measure (PR_X), the measure weight and the RL function weight. The calculated performance scores of the firm at the measures are placed in the column titled Performance score at the measure. The final RLOPI of a firm is calculated by summing the performance scores of the firm at the measures (a column sum).

Performance Score at the RL measure $S_{mX} = PR_X * W_{mX} * W_{FX}$

Reverse Logistics Overall Performance Index RLOPI $= \sum S_{mX}$

Calculation of the Reverse Logistics Overall Performance Index

	Companies		**Performance Rating across electronics industry (PR_X)**		**Measure Weight (W_{mX})**		**RL Function Weight (W_{FX})**		**Performance score at the measure (S_{mX})**	
	C-1	C-2	PR-1	PR-2	W_{mX1}	W_{mX2}	W_{FX1}	W_{FX2}	S_{mX1}	S_{mX2}
GK										
RV										
GE										
SS										
WE										
RC										
AR										
RE										
RR										
EE										
TN										
VE										
RT										
									RLOPI $= S_{mX1}$	RLOPI $=\sum S_{mX2}$

G14 – G16: Perform a sensitivity analysis to determine how the changes in measure weights and function weights are affecting the overall performance of the firm. In order to do so, steps 12 to 16 need to be iterated until the areas that have the greatest influence on the RLOPI are marked for immediate attention. This step highlights the strengths and weaknesses of the organization with respect to the industry and helps it prioritize improvement projects.

Gather the knowledge accumulated from the sensitivity analysis and perform a SWOT – Strength, Weakness, Opportunity, Threat analysis. This is a critical step before taking any process improvement decision as it helps the organization to underscore the various strength and weak areas, discover new opportunities for process improvement and identify the threats as to what the obstacles are and what the competition is doing. Strengths and weaknesses are internal to your organization**.** Opportunities and threats relate to external factors. For this reason the SWOT Analysis is sometimes called Internal-External Analysis and the SWOT Matrix is sometimes called an IE Matrix Analysis Tool. This analysis aids in answering other questions such as:

- What advantages does your company have?
- What do you do better than anyone else?
- What unique or lowest-cost resources do you have access to?
- What should you avoid?
- Where are the good opportunities facing you?
- What is your competition doing?
- Could any of your weaknesses seriously threaten your business?

Finally in step 16, the DCM can evaluate and benchmark with their competitor's performance and feedback their improvement decisions and repeat steps 7 to 16 of the PEARL methodology. No process is 100% accurate and needs continuous improvement and so is returns management. This workbook demonstrates a step by step procedure of implementing the methodology and developing the RLOPI with all the formulations. This allows an organization to work through the development of Reverse Logistics Overall Performance Index with little background knowledge of the various topics such as AHP and fuzzy theory.

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BIOGRAPHICAL INFORMATION

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He received his Master of Science in Industrial Engineering at The University of Texas at Arlington in August 2003. He also worked for the Texas Manufacturing Assistance Center on five different projects over a span of two years helping small scale firms in Dallas area to compete and sustain at a global level. He also worked as a Business Process Analyst Intern at Sabre Holdings and Travelocity in Southlake, Texas. His primary area of interest is Supply Chain Management, with strong emphasis in reverse logistics. He received his doctorate in Industrial Engineering from The University of Texas at Arlington in December 2006. Apart from his academic interests, he likes to play tennis, listen to music, and explore different international cooking cuisines. At the time of this writing, he lived with his wife in Plano, Texas.