Methodology for Performance Evaluation of Reverse Supply Chain

K.Arun Vasantha Geethan [1], Dr.S.Jose [2] & C.Sunil Chandar [3]
1. Research Scholar, Department of Mechanical Engineering, Sathyabama University, Chennai, India.
Email: kavgeeth@yahoo.co.in.

2. Principal, Loyola-ICAM College of Engineering & Technology, Chennai, India.

3. Graduate Engineer Trainee, Engineering & Technology Department, Regen Powertech Private Limited, Chennai, India.

Abstract- 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. 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 research, Performance Evaluation Analytic for Reverse Logistics Methodology 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. Deployment of this 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 Performance Value, thereby allowing them to continuously improve their returns management capabilities.

Keywords: reverse supply chain, shrinking, performance evaluation analytic, reverse logistics functions, strategies, product lifecycle stages, reverse logistics performance value.

I. INTRODUCTION

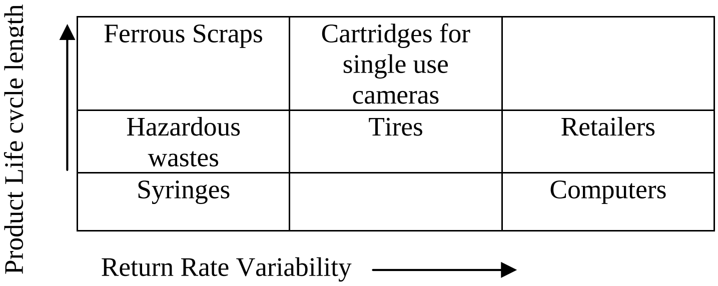
A Reverse Supply Chain represents the products collected from consumers and businesses and returned back to manufacturers, often via distributors.Reverse logistics is the process of planning, implementing and controlling the efficient, cost effective low of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal [1]. A reverse logistics defines a supply chain that is redesigned to efficiently manage the flow of products or parts destined for remanufacturing, recycling, or disposal and to effectively utilize resource. According to a recent study, reverse logistics is one of the twenty one top warehousing trends in the twenty first century (Brockmann,1999). Industries have started to realize that the reverse logistics can be used to gain competitive advantage. An evaluation framework, which incorporates determinants and dimensions of reverse logistics, would be useful in configuring the post activities associated with the EOL computers. There are number of variables affecting the reverse logistics, some of these are interdependent among each other. **The objective of our research is to develop a quantitative methodology for evaluating the reverse supply chain performance in the consumer electronics industry in order to improve revenue in the chain.** The quantitative methodology was developed with the help of Analytic Network Process. Analytic Network Process (ANP) is a technique that captures the interdependencies between the criteria under consideration, hence allowing for a more systematic analysis [2]. It can allow inclusion of criteria, both tangible and intangible, which has some bearing on making the best decision. Further, many of these factors have some level of interdependency among them, thus making ANP modeling better fit for the problem under study. The ANP model presented in this paper structures the problem related to selection of an alternative for the reverse logistics option for EOL computers in a hierarchical form and links the determinants, dimensions and enablers of reverse logistics with different alternatives.

II. LITERATURE REVIEW

Stock (1992) recognized the field of reverse logistics as being relevant for business and society in general. Kopicki, Berg, Legg, Dasappa, and Maggioni (1993) paid attention to the field and pointed out opportunities on reuse and recycling. Fleischmann, Bloemhof-Ruwaard, Dekker, van der Laan, van Nunen, and Van Wassenhove (1997) had given a comprehensive review of literature of the quantitative models in reverse logistics. A reverse logistics defines a supply chain that is redesigned to efficiently manage the flow of products or parts destined for remanufacturing, recycling, or disposal and to effectively utilize resources (Dowlatshahi, 2000).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. Reverse logistics has been used in many industries like photocopiers (Krikke, van Harten, & Schuur, 1999a; Thierry, Salomon, Nunen, & Wassenhove, 1995; 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), automotive parts (van der Laan, 1997) and refillable containers (Kelle & Silver, 1989). In all the cases, one of the major concerns is to assess whether or not the recovery of used products is economically more attractive than the disposal of the products [3]. Reverse logistics are also extensively practiced in the computer hardware industry. IBM and Dell Computer Corporation have embraced 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 McDonell (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. Moyer and Gupta (1997) have conducted a comprehensive survey of previous works related to environmentally conscious manufacturing practices, recycling, and the complexities of disassembly in the electronics industry. Gungor and Gupta (1999) have presented the development of research in environmentally conscious manufacturing and product recovery (ECMPRO) and provided a state-of-the-art survey of the published work in this area. 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 disassembly and disposal on environment. Nagel and Meyer (1999) discuss a novel method for systematically modeling end-of-life networks and show ways of improving the existing and new systems with ecological and economical concerns. Boon, Isaacs, and Gupta (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. Lambert (2003) presented a state-of-the-art survey of recently available literature on disassembly sequencing and the papers closely related to this topic. Krikke, van Harten, and Schuur (1999b) have discussed a case of the recycling PC-monitors as a part of a broader pilot project at Roteb (the municipal waste company of Rotterdam, The Netherlands) where by using the model developed, it achieved a reduction of recycling costs by about 25%. Ferguson and Browne (2001) discussed the issues in EOL product recovery and reverse logistics. Knemeyer, Ponzurick, and Logar (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 [6]. From the literature review, it is observed that there is not much work reported till date for multi-criteria decision making in the decision making related to reverse logistics practices in the case of EOL computers.

III. PROBLEM DESCRIPTION

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. 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. As the consumer electronics industry is more complex than other industries in terms of uncertainty of product returns, this research will concentrate specifically on the consumer electronics industry namely the electronic products such as computers and laptops. 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.



Ferrous Scraps	Cartridges for single use cameras	
Hazardous wastes	Tires	Retailers
Syringes		Computers

Fig.1. Lifecycle- Variability Matrix for different industries

IV. METHODOLOGY

The case study approach was selected because it is an ideal method when a holistic, in-depth investigation is needed. This case study approach helps to gather the facts from the real world and explain the linkages between causes and effects. 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.

A. Algorithm

Step 1: Start

Step 2: Determine the goals and objectives of the organization pertaining to RL

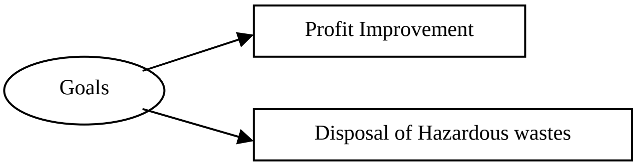


Fig.2. Goals

In order to improve the profit, one has to improve the efficiency of the system which is achieved only by measuring the performance of the system.

Step 3: Drivers of Reverse Logistics are determined

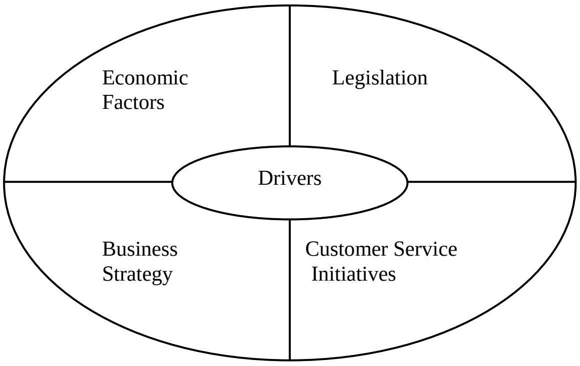


Fig.3. Drivers

Step 4: Identify the product life-cycle stages

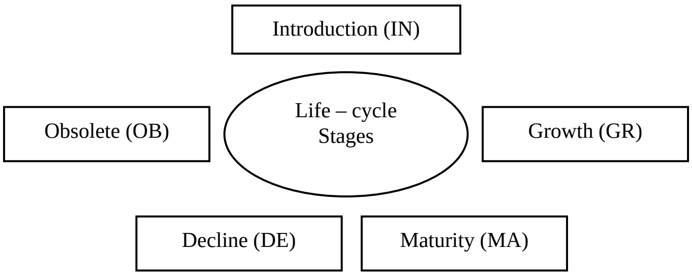


Fig.3. Life cycle stages

Step 5: Determination of competitive strategies involved in RL

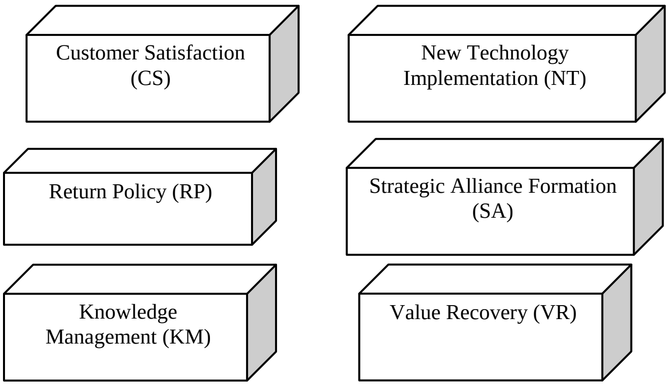


Fig 4. Strategies

Step 6: The various functions involved in RL and their performance metrices are identified

Gate Keeping (GK)	Sorting & Storing (SS)	Asset Recovery (AR)	Transportation (TN)
↓	↓	↓	↓
Return Value (RV)	Warehousing Effectiveness (WE)	Recovery Efficiency (RE)	Overall Vehicle effectiveness (VE)
Gate-keeping Effectiveness (GE)	Carrying cost percentage (RC)	Recovery Rate (RR)	Return Transit Time (RT)
		Environmental Effectiveness (EE)	

Fig 5. Functions and Performance Metrices

Step 7: Form pair-wise matrices with respect to the inter and intra dependencies between the clusters.

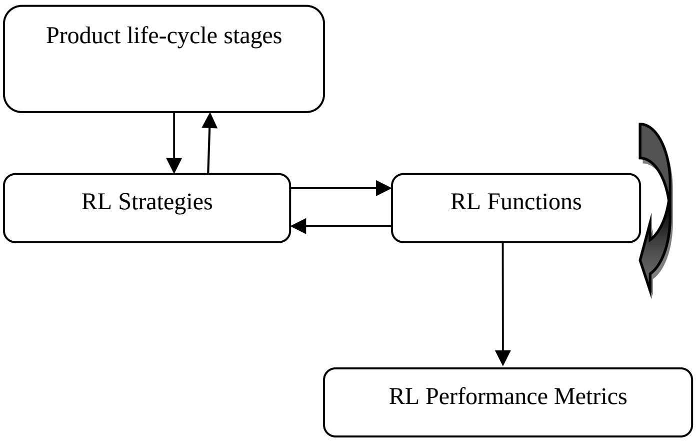


Fig 6. Cluster Relationship diagram for pair wise matrices

Therefore it is clear that pair-wise comparison matrices have to be formed between:

i) The performance metrices with respect to various functions

This gives the metrices weight which is used for the evaluation of RLPV

ii) The RL functions with respect to a particular function

iii) The RL functions with respect to various strategies

iv) The RL strategies with respect to various functions

v) The RL strategies with respect to various product life cycle stages

vi) The product life-cycle stages with respect to various strategies

Step 7: Once the weights are calculated, the next sub step is to determine the Z-Vector value for the reverse logistics process with respect to all the strategies

Step 8: Develop Super matrix from Pair-wise comparison matrices of interdependencies

Step 9: Converge the Super matrix using WIMS software available at http://wims.unice.fr/wims/wims.cgi. Converging is the process of multiplying the matrix by itself repeatedly till constant results are obtained. It occurs only at an odd $(2k+1)^{th}$ iteration (k is any integer).

Step 10: Determine the performance values at the measures for each RL function within the organization. This is found out from the Converged Super matrix

Step 11: Calculation of performance metrices – formulae

i) Return Value (RV)

$$\boxed{RV = n * N * C}$$

Where,
n is the Number of Reverse Logistics Locations

N is the Number of returned products

C is the cost of one returned product

ii) Gate keeping Effectiveness (GE)

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.

iii) Warehousing Effectiveness (WE)

Warehousing Effectiveness is an aggregate measure of warehousing performance of an organization in handling returns.

iv) Carrying cost Percentage (RC)

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

v) Recovery Efficiency (RE)

$$\mathbf{RE} = \frac{\textbf{Value Recovered}}{\textbf{Resources used}}$$

vi) Recovery Rate (RR)

$$\mathbf{RR = 1-(S/N)}$$

Where, S is the number of items scrapped per unit time

N is the total number of items inducted into the asset recovery process

vii) Environmental Effectiveness (EE)

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

viii) Overall Vehicle Effectiveness (VE)

It is also a qualitative measure.

ix) Return Transit Time (RT)

$$\mathbf{RT} = \frac{\mathbf{T}}{\mathbf{N}}$$

Where,
T is the total time spent by a product return in transit

N is the number of products entering the reverse supply chain

Step 12: Categorize the performance within the electronics industry in the form of scales to assign performance ratings at the measures

TABLE I. Performance Scale for GK

GATE-KEEPING (GK)			
RV (Rs/day)		GE	
Value	Rating	Range	Rating
0	1.00	GE=5	1.00
12000	0.50	GE=4	0.80
24000	0.00	GE=3	0.60
		GE=2	0.40
		GE=1	0.20

TABLE II. Performance Scale for SS

SORTING AND STORING (SS)			
WE		RC (%)	
Range	Rating	Value	Rating
WE=5	1.00	0	1.00
WE=4	0.80	2.5	0.50
WE=3	0.60	5	0.00
WE=2	0.40		
WE=1	0.20		

TABLE III. Performance Scale for AR

ASSET RECOVERY					
RE (%)		RR (days)		EE	
Value	Rating	Value	Rating	Range	Rating
25	1.00	0	1.00	EE=5	1.00
12.5	0.50	0.35	0.50	EE=4	0.80
0	0.00	0.70	0.00	EE=3	0.60
				EE=2	0.40
				EE=1	0.20

TABLE IV. Performance Scale for TN

TRANSPORTATION (TN)			
VE		RT (mins)	
Range	Rating	Value	Rating
VE=5	1.00	40	1.00
VE=4	0.80	50	0.50
VE=3	0.60	60	0.00
VE=2	0.40		
VE=1	0.20		

Step 13: Calculate the performance score at the measure

Performance Score at the RL measure: $S_m = PR * W_m * W_f$

where,
PR – Performance rating of the firm
W_m- Metrices weight
W_f – Functions weight

Step 14: Compute the reverse logistics performance value (RLPV) by summing up all the performance scores at the RL measures

Step 15: Stop

V. CASE ILLUSTRATION

The model presented in this paper has been evaluated in an actual computer manufacturing company, which was interested in the implementation of the reverse logistics practices.

A. Metrices weight

TABLE V. Metrices weight for Gate keeping function

GK	**RV**	**GE**	**Weight**
RV	0.10	0.10	0.10
GE	0.90	0.90	0.90

B. Functions weight- formation of super matrix

The pair wise comparison matrices for various strategies as mentioned in methodology is calculated.

TABLE VI Pair-wise comparison matrix of relative importance of functions with respect to Gate-keeping function

GK	**SS**	**AR**	**TN**	**Weight**
SS	1	1/4	1/3	0.12
AR	4	1	2	0.56
TN	3	1/2	1	0.32

TABLE VII.Pair-wise comparison matrix to determine the effect of RL functions on each other under Customer Satisfaction strategy

CS	**GK**	**SS**	**AR**	**TN**	**Weight**
GK	1	9	6	7	0.65
SS	1/9	1	1	1/4	0.07
AR	1/6	1	1	4	0.16
TN	1/7	4	1/4	1	0.12

TABLE VIII. Pair-wise comparison matrix to determine the relative importance of strategies under Gate-keeping function

GK	CS	NT	RP	SA	KM	VR	Weight
CS	1	1/2	7	4	1/2	2	0.20
NT	2	1	5	4	½	3	0.26
RP	1/7	1/5	1	1	1/5	1/3	0.05
SA	¼	1/4	1	1	1/4	1/5	0.05
KM	2	2	5	4	1	2	0.30
VR	½	1/3	3	5	1/2	0.12	0.14

TABLE IX. Pair-wise comparison matrix to determine the relative importance of strategies under Introduction lifecycle stage

IN	CS	NT	RP	SA	KM	VR	Weight
CS	1	6	9	6	1	9	0.41
NT	1/6	1	4	2	1	4	0.15
RP	1/9	1/4	1	1/4	1/6	1	0.04
SA	1/6	1/2	4	1	1/3	6	0.11
KM	1	1	6	3	1	8	0.26
VR	1/9	1/4	1	1/6	1/8	1	0.03

TABLE X. 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	1/5	1/3	7	8	0.18
GR	5	1	3	7	8	0.47
MA	3	1/3	1	6	7	0.25
DE	1/7	1/7	1/6	1	2	0.05
OB	1/8	1/8	1/7	1/2	1	0.04

Table XI. Z-Vector to determine the total contribution of RL functions with respect to Customer Satisfaction strategy

GK	SS	AR	TN		CS		Z-Vector
1.00	0.68	0.67	0.2		0.65		0.83
0.12	1.00	0.27	0.31	*	0.07	=	0.23
0.56	0.26	1.00	0.49		0.16		0.60
0.32	0.06	0.06	1.00		0.12		0.34

Z-Vector value for GK function with respect to CS strategy = [(1*0.65) + (0.68*0.07) + (0.67*0.16) + (0.2*0.34)]

TABLE XII. Super matrix

	IN	GR	MA	DE	OB	CS	NT	RP	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.18	0.47	0.04	0.29	0.64	0.65	0	0	0	0
GR	0	0	0	0	0	0.47	0.28	0.27	0.38	0.18	0.12	0	0	0	0
MA	0	0	0	0	0	0.25	0.16	0.41	0.22	0.06	0.12	0	0	0	0
DE	0	0	0	0	0	0.05	0.06	0.22	0.07	0.06	0.07	0	0	0	0
OB	0	0	0	0	0	0.04	0.03	0.05	0.03	0.06	0.04	0	0	0	0
CS	0.41	0.35	0.23	0.03	0.04	0	0	0	0	0	0	0.2	0.05	0.05	0.28
NT	0.15	0.06	0.03	0.03	0.04	0	0	0	0	0	0	0.26	0.37	0.17	0.22
RP	0.04	0.06	0.08	0.24	0.3	0	0	0	0	0	0	0.05	0.28	0.04	0.03
SA	0.11	0.09	0.05	0.12	0.06	0	0	0	0	0	0	0.05	0.04	0.04	0.08
KM	0.26	0.17	0.22	0.13	0.06	0	0	0	0	0	0	0.3	0.11	0.34	0.14
VR	0.03	0.27	0.38	0.45	0.49	0	0	0	0	0	0	0.14	0.15	0.36	0.24
GK	0	0	0	0	0	0.42	0.43	0.42	0.38	0.41	0.39	0	0	0	0
SS	0	0	0	0	0	0.12	0.20	0.13	0.13	0.22	0.12	0	0	0	0
AR	0	0	0	0	0	0.30	0.25	0.33	0.40	0.26	0.35	0	0	0	0
TN	0	0	0	0	0	0.17	0.13	0.13	0.10	0.12	0.16	0	0	0	0

TABLE XIII. Column stochastic super matrix (M)

	IN	GR	MA	DE	OB	CS	NT	RP	SA	KM	VR	GK	SS	AR	TN
IN	0	0	0	0	0	0.09	0.24	0.02	0.15	0.32	0.33	0	0	0	0
GR	0	0	0	0	0	0.24	0.14	0.14	0.19	0.09	0.06	0	0	0	0
MA	0	0	0	0	0	0.13	0.08	0.21	0.11	0.03	0.06	0	0	0	0
DE	0	0	0	0	0	0.03	0.03	0.11	0.04	0.03	0.04	0	0	0	0
OB	0	0	0	0	0	0.02	0.02	0.03	0.02	0.03	0.02	0	0	0	0
CS	0.41	0.35	0.23	0.03	0.04	0	0	0	0	0	0	0.2	0.05	0.05	0.28
NT	0.15	0.06	0.03	0.03	0.04	0	0	0	0	0	0	0.26	0.37	0.17	0.22
RP	0.04	0.06	0.08	0.24	0.3	0	0	0	0	0	0	0.05	0.28	0.04	0.03
SA	0.11	0.09	0.05	0.12	0.06	0	0	0	0	0	0	0.05	0.04	0.04	0.08
KM	0.26	0.17	0.22	0.13	0.06	0	0	0	0	0	0	0.3	0.11	0.34	0.14
VR	0.03	0.27	0.38	0.45	0.49	0	0	0	0	0	0	0.14	0.15	0.36	0.24
GK	0	0	0	0	0	0.21	0.22	0.21	0.19	0.21	0.2	0	0	0	0
SS	0	0	0	0	0	0.06	0.1	0.07	0.07	0.11	0.06	0	0	0	0
AR	0	0	0	0	0	0.15	0.13	0.17	0.2	0.13	0.18	0	0	0	0
TN	0	0	0	0	0	0.09	0.07	0.07	0.05	0.06	0.08	0	0	0	0

TABLE XIV. Converged Super Matrix ($M^{2K+1} = M^{369}$)

	IN	GR	MA	DE	OB	CS	NT	EC	SA	KM	VR	GK	SS	AR	TN
IN															
GR															
MA															
DE															
OB															
CS															
NT															
EC															
SA															
KM															
VR															
GK						0.42	0.42	0.42	0.42	0.42	0.42				
SS						0.13	0.13	0.13	0.13	0.13	0.13				
AR						0.31	0.31	0.31	0.31	0.31	0.31				
TN						0.15	0.15	0.15	0.15	0.15	0.15				

C. Performance value of the firm

Return Value for the case company;

RV = n * N * C

Where,

n is the number of reverse logistic centre = 8

N is the number of return products in Gate-keeping per unit day = 10

C is the cost of a single returned product = Rs.150

Therefore, RV = 8 * 10 * 150

RV = Rs.12000/ day

TABLE XV. Gate keeping Effectiveness (GE)

BEST PRACTICE	
Clear and visible return policies to reduce the number of defective products into the RSC	✓
Use of dedicated and skilled labour for return product inspection	✓
Use of latest equipment for checking the reliability of the product	✓
Use of multiple channels such as phone and internet to provide support	
Employ programs to reduce idle time of trucks and products at Gate Keeping	✓

Checklist for evaluating performance rating of Gate-keeping Effectiveness:

We have rated each parameter in the check list as 0.2 according to likert's scale.

Therefore, performance rating of GE for the case company = 4 * 0.2 = 0.8

D. Calculation of RLPV

TABLE XVI. RLPV

	Value	**PR**	**W_m**	**W_f**	**S_m**
GK				0.42	
RV	Rs.12000	0.50	0.10		0.021
GE	4	0.80	0.90		0.302
SS				0.13	
WE	3	1.00	0.90		0.117
RC	4%	0.00	0.10		0.000
AR				0.31	
RE	17.19%	0.50	0.17		0.026
RR	0.3 days	0.50	0.76		0.1178
EE	3	0.60	0.06		0.0111
TN				0.15	
VE	4	0.80	0.10		0.012
RT	51 mins	0.50	0.90		0.0675
RLPV					**0.6744**

VI. CONCLUSION

The reverse logistics practices may cost in millions of dollars for company. The implementation of these may be a risky endeavor for the top management as it involves financial and operational aspects, which can determine the performance of the company in the long run. However, with the legislative measures tightening up, there are not many options. The question now is not whether to go for it or not but which framework to pick up.

For the case undertaken in this study, Based on the formulations developed in chapter IV, the performance score of Company was obtained to be **0.6744 or 67.44%** of the industry average standards. Ideally, in order to validate the results, a bigger survey sample size is necessary.

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 RLPV 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.

VII. REFERENCES

[1] He, B., Yang, C., Ren, M. M. A Fuzzy Multi-objective programming for optimization of reverse logistics for solid waste through genetic algorithms. *In Fourth international conference on fuzzy systems and knowledge discovery.* China 2007, pp. 416-420.

[2] Kärkkäinen, M. Increasing efficiency in the supply chain for short shelf life goods using RFID tagging. *International Journal of Retail and Distribution Management*, 31(10), 2003, pp 526-536.

[3] Lee, D. H., & Dong, M. A heuristic approach to logistics network design for end-of-lease computer products recovery. Transportation Research Part E: Logistics and Transportation Review, 44(3), 2008, pp 455-474.

[4] Caruso, C., Colorni, A., & Paruccini, M. . The regional urban solid waste management system: A modeling approach. *European Journal of Operational Research*, 70(1), 1993, pp 16-30.

[5] Aras, H., Erdogmus, S., & Koc, E. Multi-criteria selection for a wind observation station location using analytic hierarchy process. *Renewable Energy*, 29, (2004) pp 1383-1392.

[6] Bian, W., & Yu, M.. Location analysis of reverse logistics operations for an international electrical manufacturer in Asia Pacific using the analytic hierarchy process. *International Journal of Services Operations and informatics,* 1 (1/2), 187-201. *Management and Decision Making,* 9 (4), (2006), 350-365.