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WORLD MARITIME UNIVERSITY

Shanghai, China

**RESEARCH ON DECISION-MAKING ON
TAKE-BACK MODES IN REVERSE LOGISTICS
FOR END-OF-LIFE ELECTRONIC PRODUCTS
FOR Z COMPANY**

By

WANG YIWEI

China

A research paper submitted to the World Maritime University in partial
Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

INTERNATIONAL TRANSPORT AND LOGISTICS

2009

DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

(Signature):

(Date):

Supervised by:

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Professor of Shanghai Maritime University

Assessor

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
BSC	Balanced Scorecard
CI	Consistence Index
CR	Consistence Ratio
E-product	Electronic product
EOL	End-of-Life
EU	European Union
HP	Hewlett-Packard Development Company
IBM	International Business Machine
PTM	Pooled Take-back Mode
R & D	Research & Development
REVLOG	The European Working Group on Reverse Logistics
RI	Random Consistence Index
RL	Reverse Logistics
RoHS	Restriction of Hazardous Substances Directive
STM	Self-running Take-back Mode
TTM	Third-party Take-back Mode
WEEE	Waste Electrical and Electronic Equipment

CHAPTER 1 INTRODUCTION

1.1 Background & Significance

The sharp increase of population together with the dramatic development of the industry and continuous improvement of human living standards have led to large amount of wastes in the world, which has seriously deteriorated the ecological environment and resulted in mass pollution. Furthermore, with the rapid development of electronic technique, more and more advanced e-products have been used in almost all aspects of our life. When people in the full enjoyment of convenience of high-tech, they also produced massive modern trash—electronic wastes. The inappropriate disposals of a large number of End of Life (EOL) e-products have become the major pollution source to ecological environment and drawn full attention from governments and enterprises throughout the world.

In terms of the normal service life of e-products is 10-15 years, since 2003, China has entered the peak period of EOL e-products. According to the National Bureau of Statistics of China, at least 4 million refrigerators, 5 million TV sets, 5 million washing machines, 5 million computers and over 10 million mobile phones are scrapped every year¹. From these figures, it can be predicted that the amounts of EOL e-products will grow at an unprecedented rate in the next period of time. The more troubling one is, at present our country has not formed a specialized system which

¹ <http://www.china-esc.org.cn/news.asp?id=624>

merged recycling, testing and disposing. Only two channels are available for EOL e-products: sold to hawkers, burned or buried directly.

How to change this situation and keep sustainable development forms into the main issue of government. In order to achieve this goal, the RL draw widespread concerns in recent years. Reinforcing the study on take-back modes in RL, and providing an rational choice of take-back mode in RL for EOL e-products will lead to a win-win results in the respects of both economic and social benefits: improving the customer service level, lowering raw material costs, protecting the environment, promoting the corporate image, improving the product design, increasing the product quality, etc. Due to the cut-throat competition and globalization strategy, many far-sighted enterprises have taken RL as a competitive tool such as IBM, HP and Johnson & Johnson which have gained the benefits from above mentioned points.

In China, RL in terms of theoretical research or commercial practice is just beginning. To put all into a nutshell, the hot topic links environmental friendly and sustainable development. The research of RL has great significance to promote the development of RL in our country and realize the economical sustainable development.

1.2 Literature Review

Through study and research, the author found that both scholars at home and abroad have done a great many researches on RL in various perspectives.

① First, research on basic theory of RL is abundant.

1) Definition of Reverse Logistics

Dr Stock J R is the earliest scholars to study on RL. Stock (1992) defined in *Reverse*

Logistics: White Paper “Reverse Logistics as a process of logistics activities which contains return of product, material of replacement, reusing of goods, treatment of waste, re-treatment, maintenance and re-manufacturing.” In 1998, RL has been defined as “...the term most often used to refer to the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal, and refurbishing, repair and remanufacturing.”(Stock J R, 1998, p6)

Rogers and Tibben-Lembke (1998) defined RL as “the process of planning, implementing, and controlling the efficient, cost effective flow 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 of proper disposal” (p. 2).

REVLOG (2004) defines RL as “the process of planning, implementing and controlling flows of raw materials, in process inventory and finished goods, from the point of use back to a point of recovery or point of proper disposal”.

All in all, RL is exactly the opposite direction toward the forward logistics. It can start at any point from the node of consumption to the node of origin.

2) Motivations for Reverse Logistics

Carter and Ellram (1998) mentioned that there are four points influence the reverse logistics: “legislation, supplier, customer and competitor.” Dekker (2003) considered the three motivations: “economic, corporate citizenship, and legislation”. *In Reverse Logistics: A Second Chance to Profit*, Andle (1997) mentioned that “RL is a strategic tool that can bring economic benefit and competitive advantages to enterprises.”

② Second, various take-back modes have been introduced to different enterprises based on different scenarios.

In China, RL is an emerging business in logistics field as well as a quite thorny aspect. However, a big problem is that many enterprises don't know how many modes exist. Here, the following scholars both in China and foreign have introduced a lot.

A.J. Spicer & M.R. Johnson in *Third-party demanufacturing as a solution for extended producer responsibility* analyzed the enterprises can choose three modes under the restriction of Extended Producer Responsibility: 1. "OEM take-back mode, under this mode the original equipment manufacturer is responsible for recycling and disposing the EOL products; 2. Pooled take-back mode which means the Producer Responsibility Organization will recycle and dispose the EOL products for all the members; 3. Third-party take-back mode, for this type the enterprise will pay charges to third-party logistics company who will responsible for the recycling and disposing."

V. Ravi suggested as follows: "1. Third-Party Demanufacturing mode; 2. Symbiotic Logistics Concept mode; 3. Virtual Reverse Logistics mode." The author also analyzed advantages & disadvantages of each mode respectively.

In China, Yao Weixin (2004) in *Comparison of Different Take-Back Modes in Reverse Logistics* studied take-back modes such as "Third-Party take-back, Retail take-back and Manufacturing take-back in RL". The research analyzed and compared three modes through setting up mathematical model. The author offered theoretical principle for enterprises to choose suitable take-back mode.

Wei Jie (2005) in *The Different Take-back Models in Reverse Logistics with the Restriction of EPR* analyzed three take-back mode under the restriction of Extended Producer Responsibility (EPR): "Original Equipment Manufacturer (OEM) take-back, Producer Responsibility Organization (PRO) take-back and Third-party (TP) take-back". The author provided theoretical basis for the production enterprises to choose appropriate take-back mode in RL through analyzing costs, feedback ability

and so on by setting up mathematical models and giving examples.

Chang Xiangyun (2006) in *The Management Modes in Reverse Logistics based on EPR* analyzed characteristics of the “Government mode, OEM mode and Third-party mode” respectively. The author suggested that in the current China, it’s necessary to diversify the management channel of RL.

From abovementioned, it can be summarized three main take-back modes in RL: 1. STM; 2. PTM; 3. TTM. Each mode has its own strengths and weaknesses, and different enterprises should apply them depend on themselves situations.

③ Third, another problem rising is: how to select the most appropriate one from so many take-back modes? As we know, an appropriate take-back mode will bring so many benefits like reducing cost, saving materials. For that, the author digs further into the research.

Dennis W. Krumewiedea in *A mode for reverse logistics entry by third-party providers* mentioned the definition and cost (inventory cost, transport cost and disposal cost) of RL. According to the competition between the third-party logistics enterprise and customers, the author divided the process of RL into three steps: “recycling, transportation and decision-making.” The author set up the decision-making model for RL.

In China, Li Yuhong in the paper of *Study the Reverse Logistics mode for Enterprise* also mentioned a new method to evaluate the take-back modes. Through the analysis of main factors that influence the selection of operation modes, the author applied the FCE to choose the optimum operation mode.

Lu Jie in paper of *Research on Choosing the Reverse Logistics mode of end of life*

appliances—in views of electrical home appliances introduced the modes in RL for electrical appliances industries. The author analyzed the characteristics and conditions of three take-back modes, and made a comparison between these modes. The author applied ANP to set up the evaluation system.

Zhou Lingyun, Yu Ang in *The Application of the Third-Party Reverse Logistics in the Treatment of the Waste Electrical and Electronic Equipment* analyzed the current recycling situation of EOL e-products in China and their hazardous to environment. After referring to management methods of dealing with WEEE in developed countries, and meanwhile based on the Chinese circumstance, the application of the third-party take-back mode for EOL e-products is better.

From what have studied, it can be noticed that evaluation for most appropriate take-back mode is very important for enterprises.

1.3 Dissertation Objective

The objective of this paper is to provide a tool that allows enterprises making the better decision on take-back mode under specific situation. Hence, it's important for enterprises to choose an appropriate take-back mode because this will decide their reverse logistics business success or failure. A suitable take-back mode in RL for EOL e-products will bring many benefits such as reduce production cost, save resources etc. In order to achieve this objective, and combine with quantitative and qualitative analysis, the author will support the enterprises to select the most appropriate mode.

All in all, the research meanings are listed below:

- a) *Make the paper based on EOL e-products.* It will introduce the characteristics of

EOL e-products, RL for EOL e-products and so on.

- b) *Work out how to do the decision-making on take-back modes.* Indicators like cost, profit, service will be fully analyzed, and AHP, BSC methods will be applied.
- c) *Link the practical meaning with research methods on take-back modes in RL for EOL e-products.* Decision-making methods will be applied to Z Company so as to check the validity and correctness of the research of this paper.

1.4 Framework and Content of Dissertation

For the research content, this paper is mainly about decision-making on take-back modes in RL for EOL e-products. The main contents of the paper are as follows:

First Chapter: Introduction—It focus on the research background and significance, clarify the purpose of the research and the content as well as the framework. It also mentions some researches of relevant literatures at home and abroad.

Second Chapter: Theoretical Analysis of RL for EOL E-products—The author will study the RL through comparison with forward logistics, introduce the characteristics of RL for EOL e-products, motivations for RL for EOL e-products and analyze the current situation of RL in China.

Third Chapter: Take-back Modes in RL for EOL E-products for Z Company—The author will give brief introduction of Z company and discuss the three widely used take-back modes in RL: 1. STM, 2. PTM, 3. TTM. The author will analyze the strengths and weaknesses of each mode respectively. Last, the author will point out problems which puzzle Z Company to select an appropriate mode.

Fourth Chapter: Decision-making Methodology on Take-back Modes in RL for EOL E-products for Z Company—The author will discuss how to choose the appropriate take-back mode. In order to fulfill the task, the author will apply BSC, and AHP model will be introduced. Last design the questionnaire.

Fifth Chapter: Application of Evaluation Indicators System in Z Company—The author will apply the above mentioned methods to support Z Company solve problem. Through the mathematical calculation, the author will give the final results.

Sixth Chapter: Conclusion & Suggestion—Last chapter will summarize all the text and make some suggestion for further research.

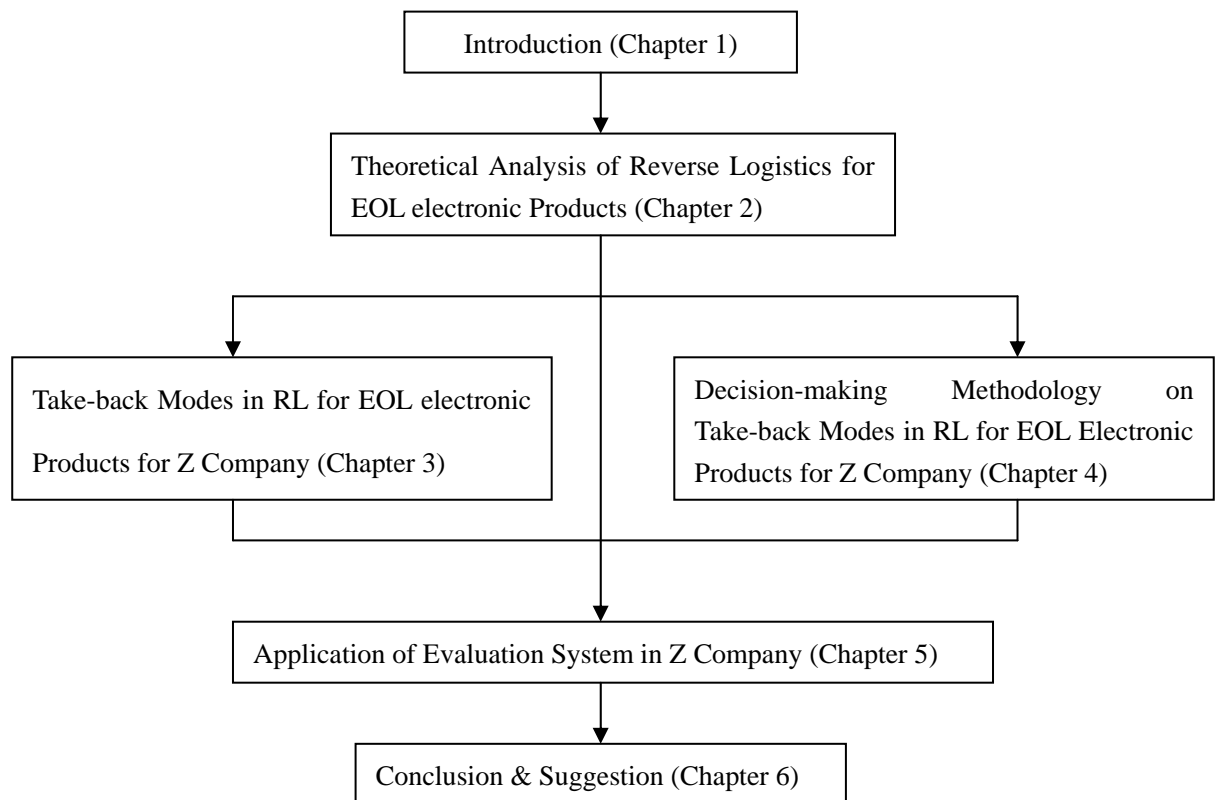


Figure 1 Structure of the Dissertation

Source: Drawn on my own

CHAPTER 2 THEORETICAL ANALYSIS OF REVERSE LOGISTICS FOR EOL ELECTRONIC PRODUCTS

2.1 Reverse Logistics & Reverse Logistics for EOL Electronic Products

The rapid replacement of products and increasingly shortened product lifecycle result in a large number of EOL products. It's essential for recycling and remanufacturing through reverse logistics so as to save materials and make full use of the value of these products.

2.1.1 Comparative Analysis of Reverse Logistics & Forward Logistics

2.1.1.1. Definition of Reverse Logistics

In the entire logistics supply chain system, there are two different logistics flow channels: one is the main channel of logistics flow, called forward logistics which means products through production→circulation→distribution to meet the consumer demand. Another one is RL that discussed in this paper which carries on backflow of EOL products in order to restore the value and take appropriate disposing.

In the past, enterprises usually don't consider the after sales reclaim & dispose service

because majority of them think this kind of service will bring one more burden to the operating cost, so most products are buried or burned directly after use. Actually, RL can enable EOL products to be reused and entrust new value to the product. Therefore, enterprises should pay great attention to RL and consider it as important as the forward logistics, then make further integration of forward logistics and RL.

In recent years, with the increasing pressure of environmental laws & regulations, the growing awareness of environmental protection, RL has drawn great attention from more enterprises and scholars. Under such a cut-throat competitive situation, especially the nowadays financial crisis, it's essential for us to study and develop RL which can reduce more operating cost and bring more unexpected benefits.

Rogers and Tibben-Lembke (1998) defined RL as “the process of planning, implementing, and controlling the efficient, cost effective flow 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 of proper disposal” (p. 2). The following figure shows RL network:

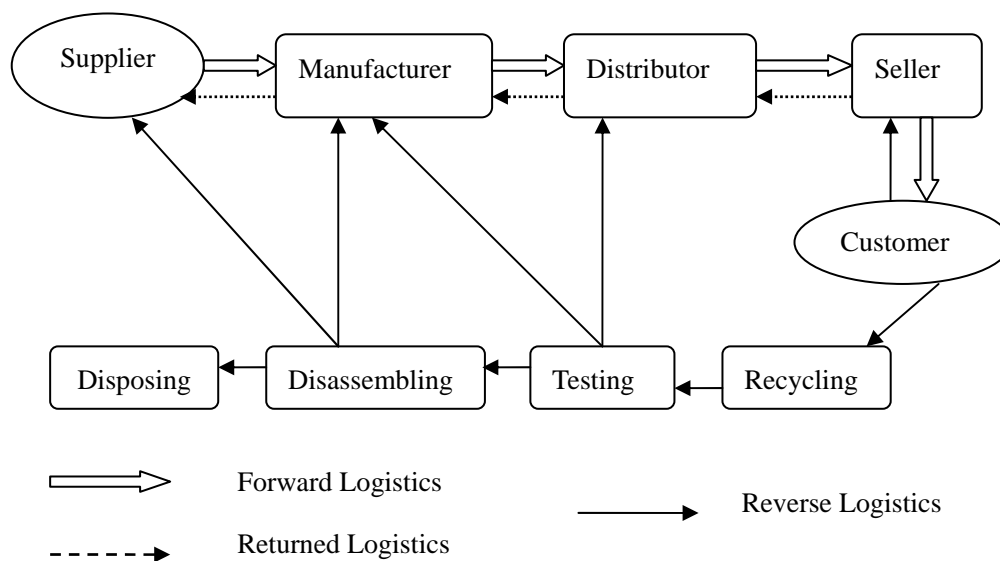


Figure 2-1 Reverse Logistics Network

Source: Drawn on my own

2.1.1.2 Characteristics of Reverse Logistics

From aforementioned analysis, it has reflected some differences between these two kinds of logistics, and the following paragraphs will focus on the key characteristics:

- ① Reverse. The flow of EOL products in RL is in this way: consumer→intermediary →disposal center→manufacturer→supplier. Hence, RL is in opposite direction and has completely opposite initial point to forward logistics. It can be summarized that all the physical and information flows are arisen by the last section in RL system or the final consumers.
- ② Uncertainty. Due to the EOL products have various conditions which cause the starting point of RL is often scattered, sometimes in production field, sometimes in distribution field or maybe in consumption market. Therefore, the uncertainty of RL firstly display by uncertain and dispersion of initial point. Next one is uncertain of demand period and quantities of RL that result in hard to foresee. In addition, the destination of RL is also uncertain, the EOL products may be sent to vendors, suppliers and manufacturers. However, fixed quantity, punctuality and designated initial point is three basic requirements of forward logistics.

Except these two key characteristics, there also exist many other differences. And these differences will be listed in the following table so that we can learn the reverse logistics and forward logistics better.

Table 2-1 Differences between Reverse Logistics & Forward Logistics

Differences Between Forward and Reverse Logistics		
	Reverse Logistics	Forward Logistics
Quantity	Small quantities	Large quantities of standardized items
Forecasting	Forecasting more difficult	Forecasting relatively straightforward

Distribution channel	Many to one distribution point	One to many distribution points
Product flow	One way (“pull”)	Two way (“push and pull”)
Product quality	Product quality not uniform	Product quality uniform
Product value	High product value	Moderate to low product value
Disposition option	Disposition not clear	Disposition options clear
Speed	Speed often not considered a priority	Importance of speed recognized
Inventory management	Inventory management not consistent	Inventory management consistent
Product life cycle	Product life cycle issues by several factors	Product life cycle manageable
Information tracking	Automated information systems used to track items	Combination of automated and manual information systems used to track items

Source: <http://www.rlec.org/> & Adapted and modified from Shear et al. “The warehousing link of reverse logistics.”

To sum up, first, the goal of RL has two, one is to obtain the residual value from EOL products, and another is to carry on the proper disposal to eliminate the environment hazards. Second, the object of RL include products, packaging units, materials and related information flow from final destination into each node along supply chain channel in reverse direction. Third, the activity of RL is to realize the purpose of RL. It consists of recycling, reusing, testing, refurbishing and remanufacturing, etc.

2.1.2 Reverse Logistics for EOL Electronic Products

2.1.2.1 Definition of Reverse Logistics for EOL Electronic Products

RL for EOL e-products, as its name implies that it’s a recycling and disposing process through RL when e-products leave the consumer market at their mid and later stage of life cycle. It mainly integrates the recycling, dismantling, sorting, disposal, inventory, transportation, distribution, reusing and many other steps. Furthermore, from the entire supply chain point of view, RL for EOL e-products also links with the raw

materials procurement, manufacturing as well as sales. The recycling and disposing of EOL e-products can transform some into reusable raw materials and reenter the raw materials procurement section, some will be as usable spare parts to support production and some will enter the low-end consumer market through simple repair.

2.1.2.2 Characteristics of EOL Electronic Products

The e-products are featured as high technique, short life cycle, and quick update speed. Electronic wastes generate large amount of toxic trashes every year and has been the biggest source of pollution. It also contains large quantities of recyclable non-ferrous metals, ferrous metals, plastics, glass, and some useful spare parts. Therefore, we can notice that recycling and reusing of EOL e-products has the broad prospects.

Compared with the common wastes, EOL e-product enjoys dualism: the common characteristics and special ones. Listed below are several main peculiarities:

1. High value of EOL e-products

According to the research, the typical EOL e-products usually compose of 40% metals, 30% plastics and 30% oxide compounds². Although it contains large amount of poisonous and harmful substances, meanwhile it also contains a great deal of recyclable non-ferrous metals, ferrous metals, plastics, glass and some useful components. Therefore, in following table, it can be clearly noticed that they have higher recyclable value than other wastes. Some reusable or valuable substances such as Iron, Copper, Gold, Tin, Steel, Aluminum and Lead can be refined from EOL e-products after proper disposal. And enterprises can sell gold, plastics and metals or supplement the raw materials.

² <http://www.chinaep.net/index.htm>

Table 2-2 Main Components and Weight ratio of five household E-products

	TV	Refrigerator	Air Conditioner	Washing Machine	Computer
Aluminum	2	3	7	3	14
Copper	3	4	17	4	7
Iron	10	50	55	53	20
Plastic	23	40	11	36	23
Glass	57	-	-	-	-
Others	5	3	10	4	36
Total	100	100	100	100	100

Source: Li Jinhui, & Wen Xuefeng, & Liu Tongzhou (2005). Management Policies, Technologies and Facilities for the Treatment of Waste Electrical and Electronic Equipments (WEEE) in China. *Science Technology*.

2. High contaminating & hazardous of EOL electronic products

EOL e-product is harmful to human and surrounding environment when mixed with other kind wastes to carry out burning or burying directly. As we know, EOL e-product contains massive toxic and hazardous substances. Here, take computer as example. The manufacturing of a personal computer needs nearly 700 kinds of chemical raw materials, whereas around half of them are harmful to people. For instance, the plastic crust is coated with toxin fireproof- painting; the screen contains 1 kg of Lead. In addition, in following table, we can see it also includes Cadmium, Lead, Chromium, Hydrargyrum and other toxic substances. These poisonous metals once enter into the environment will be long-term detained in ecosystem and threat human health through various channels at any time. Therefore, the improper disposal of EOL e-products will destroy the environment.

Table 2-3 Main Components and Percentages of Computer

Name	Proportion (%)	Weight (pound)
Lead	6.2988	3.8

Cadmium	0.0094	<0.1
Hydrargyrum	0.0063	<0.1
Chromium	0.0022	<0.1

Source: Li Jinhui, & Wen Xuefeng, & Liu Tongzhou (2005). Management Policies, Technologies and Facilities for the Treatment of Waste Electrical and Electronic Equipments (WEEE) in China. *Science Technology*.

3. Sharp increase of EOL electronic products

With the rapid rise of electronic industry as well as the expansive demand of e-products, the elimination of e-products is much faster, and people produce more and more e-wastes. Studied a lot of reports and got the summary that those EOL e-products every five year increased by 16% to 28% which is 3 times quicker than all wastes. According to the report of Chinese government in 2006, there were about 220 million refrigerators, 260 million washing-machines, 490 million TV sets and 80 million computers³, more detailed statistics can be see in following table. Thus, it can be predicted that the EOL e-products will further grow due to the fact that e-products have permeated into all aspects of people's lives.

Table 2-4 Forecasting of Annual Volume of EOL E-appliances in China

Year	Annual Wasted Amounts (unit: 0000)				
	Color TV	Refrigerator	Washing Machine	Air Conditioner	Computer
2009	3718.75	924.22	1187.42	1089.14	4782.64
2010	5833.94	966.81	1158.85	1235.02	7190.08
2011	3251.85	973.45	1280.54	3668.45	10796.10
2012	3917.88	1086.99	2530.44	2524.40	16190.75
2013	4041.73	2094.18	1374.37	3875.04	24251.37
2014	4251.48	1242.00	1673.12	2992.61	90491.88

Source: Li Jinhui, & Wen Xuefeng, & Liu Tongzhou (2005). Management Policies, Technologies and Facilities for the Treatment of Waste Electrical and Electronic Equipments (WEEE) in China. *Science*

³ <http://www.e-waste.org.cn/>

Technology.

From the above three typical characteristics of EOL e-products, the implementation of RL for EOL e-products should be regarded as a very urgent task, especially for China.

2.1.2.3 Characteristics of Reverse Logistics for EOL Electronic Products

Except the common features of RL, RL for EOL e-products enjoys the special characteristics because of the specialties of EOL e-products. In last section, two key points of RL have been listed. In this section, key characteristics of RL for EOL e-products will be listed below:

- 1) **Slowness.** Slowness performs in three aspects: the accumulation speed of EOL e-products, the complexity of disposal and restoring value speed of EOL e-products. Generally speaking, firstly, at the initial stage there are more products categories with few amounts. They form a larger-scale flow only when being continuously collected. Secondly, the process of collection, sorting, and testing of EOL e-products is very complex, it needs to go through the sorting, testing and other steps, sometimes even as raw material enters into production. The whole process clearly tells us the restoring value of EOL e-products need a long period, and its economic value can't be realized immediately.
- 2) **Complexity.** Firstly, the complexities of forecasting demand time and quantities for RL for EOL e-products. As we know, the scattered starting point causes the difficulty in forecasting. It's impossible for one quantitative model to settle the forecasting problem. Second is the complexity of operation. The transportation, inventory and remanufacturing will be varied in corresponding to different situations. Different kinds and status of EOL e-products require different testing methods, operating time and components. Third, the complexity of constituent parts of RL for EOL e-products. In the following figure, it composed of recycling point, inventory, and workshop of demolition/recirculation and material market/

terminal processing. The proper combination of them can guarantee the smooth operation of entire processing of RL for EOL e-products.

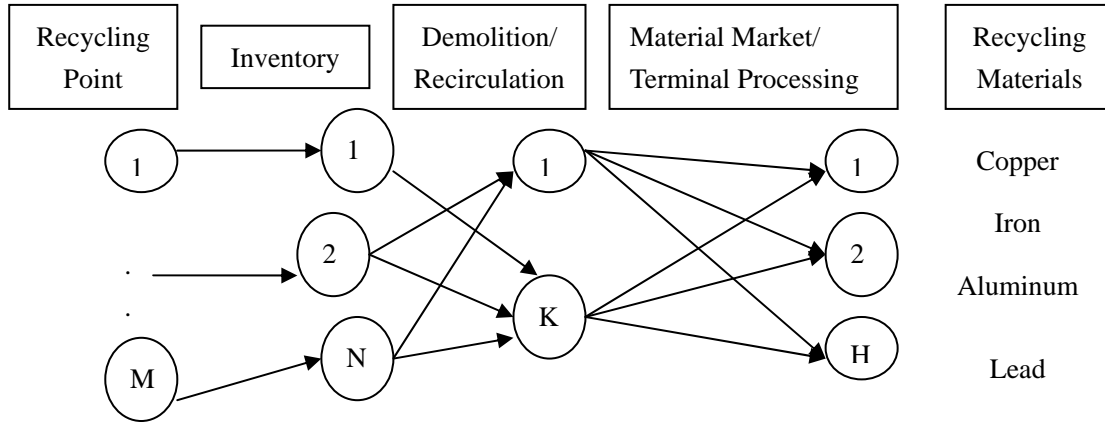


Figure 2-2 Constituent Parts of RL for EOL E-products

Source: Yang Yongchao. (2006). Study on Operational Mode of Reverse Logistics for Electronic Products. Unpublished Master’s Thesis, Jiangxi University of Finance & Economics, Nanchang, China

2.2 Motivations for Reverse Logistics for EOL Electronic Products

Nowadays, China has become one of the largest production and consumption countries of e-products in the world. Every year numerous of e-products are abandoned in China. In one word, it’s time to carry out the RL for EOL e-products. And the motivations for implementation of RL for EOL e-products are as follows:

- A. Sustainable Development. From the view of sustainable development, it requires to reduce the resources consumption, increase the utilization and circulation of resources. The production of e-products needs massive rare metals which are also limited. The recycling function of RL can transfer the EOL e-products from the consumers to manufacturer through its network. Enterprises can obtain many reusable resources from large amounts of EOL e-products, reduce the raw material costs and increase the utilization of resources.

- B. Legislation. With the deterioration of the environment, EOL e-products pollution has drawn more attention. The prevention of this kind pollution has been a major social issue. Based on the above reasons, government enacted laws in limiting and preventing pollution. Like WEEE and ROHS Directives of EU, Chinese national legislation <EOL E-Products Recovery Management Regulation>. These policies have great guiding significance to the current RL for EOL e-products.
- C. Competition among Enterprises. With the constant improvement of productive capacity, market competition situation has developed from complete monopoly into full competition. The low-cost strategy is a very important tool in fierce competition among electronic enterprises. RL can increase the profit by reducing the costs and make full use of the EOL electronic components. With the rapid development of economy and increasingly shortage of resources, the RL will demonstrate more superiority.

2.3 Analysis of Current Situation of Reverse Logistics for EOL E-products

At present, the RL for EOL e-products in China is still in its initial stage. From the laws and regulations, the recycling enterprise's scale and recycling craft, there exists a large gap between China and developed countries. The conclusion can be achieved as follows through questionnaires to different people, investigations in several EOL e-product markets and the talk with recyclers.

1. Problems in related enterprises. At present, the majority recycling enterprises are in small size who can't guarantee having the long-term and stability resources. They all work on their own way with no cooperation among them which results in enormous social resources wastes. Another problem is how to choose the most appropriate take-back mode. Considering that the RL operation has high

requirement on enterprise's productivity, technology, management level, financial resources and so on, an appropriate take-back mode can bring double benefits to the enterprises. It's the core part in this paper.

2. Problems in EOL e-products recycling. There is no relatively complete recycling network. In current China, there are four ways: individual recycler, small EOL e-products vendor, secondary market, and very few production & sales enterprise.
3. Problems in disposal technology. The disposal of EOL e-products is insufficient. Recyclers usually sell reusable products on secondary market or rural area after simple testing and repair, burned and buried those products they can't handle directly. Some small EOL e-products recycling vendors just put some aging components into a relative new packing box then sell it to customers with higher price. All these disposal methods are not only illegal, but also harmful to our living environment.

2.4 Conclusion

As above mentioned views, EOL e-products are essentially a resource used as treasure, while abandoned as evil. The effective organization and implementation of RL for EOL e-products can not only improve environment but also release the resources pressure. It enjoys ecological and economic dual significance.

All in all, the implementation of RL for EOL e-products is the inevitable and common choice of government and enterprises. Therefore, the study of take-back modes in RL for EOL e-products should be strengthened. And how to provide an effective tool to support the enterprises to choose the most appropriate and economic take-back mode has been an urgent and of great practical significance topic.

CHAPTER 3 TAKE-BACK MODES IN REVERSE LOGISTICS FOR EOL E-PRODUCTS FOR Z COMPANY

Z Company knows RL for EOL e-products will bring many benefits, but it unfamiliar with RL and even doesn't know the differences among different take-back modes. In the following paragraphs, three main modes will be introduced to Z Company.

3.1 The Generality of Z Company

Z Electronics Company possesses fixed assets of 500 million Yuan and 500 staffs. Its main products include TV, household e-product, cell phone and computer. The products sales network not only covered the domestic market but also expanded to Europe and America. The annual sales volume amounted to 50 million dollars. Z Company's forward logistics system has already basically sound. The distribution points in domestic market have reached 15. The forward logistics can respond to changes in market immediately and operate smoothly. In recent years, numerous benefits brought by RL have attracted more attention of Z Company. Since August 2005, the e-products enterprises in EU market must bear the expenses of EOL e-products recycling & disposing. And since July 2006, whatever e-products entered into EU market should be forbidden some hazardous substances. Thus, Z Company believes these two legislations will have great impact on its e-products export business to EU market. They must attach great importance to these as soon as possible

in order to avoid or reduce loss to company's export business. After discussion, Z Company decided to implement RL for EOL e-products. There are three take-back modes can be chosen: STM (A_1), PTM (A_2) and TTM (A_3).

3.2 Take-back Modes in Reverse Logistics for EOL Electronic Products

3.2.1 Self-running Take-back Mode

3.2.1.1 Definition of Self-Running Take-back Mode

STM means the electronic enterprises establish an independent RL system to manage and recycle EOL e-products so as to meet their long-term development needs. Under this mode, enterprises not only pay attention to post-sales service, but also to the recycling and disposing of EOL e-products. Enterprise sets up RL network that spread across the whole sales regions in order to facilitate recycling of EOL products and transport them to reclaim & disposal center.

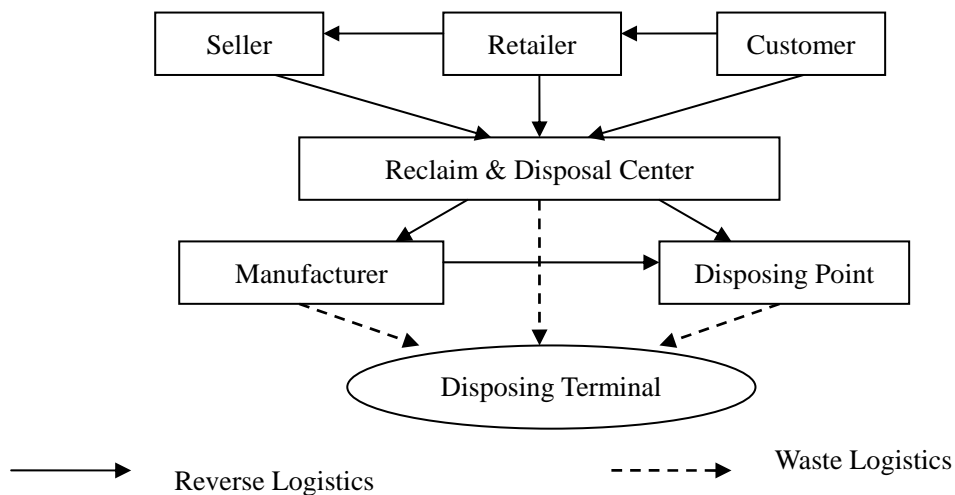


Figure 3-1 Self-running Take-back Mode

Source: Drawn on my own

3.2.1.2 Strengths/Weaknesses of Self-Running Mode

1) Strengths of Self-Running Take-back Mode

- A. Full Control over RL for EOL E-products. Enterprise itself invests and manages the RL. It's convenient for the enterprise to monitor and improve the operation as well as adjust the operation timely according to market condition. Therefore, it will make the operation of enterprise more flexible and efficient.
- B. Quick Information Feedback. Comparing with other take-back modes, STM gains distinct advantages in information feedback and improvement of products design, because the RL system is established by enterprise itself so that the transmission of information is more quickly and accurately. The enterprise recycles the products directly from the customers and gets the first-hand information of products quality and characteristics in time. The transmission of this kind of feedback information between the designing and financial departments is favorable for enterprise to promptly know the drawbacks of products and make improvements in the design and production of the product.
- C. Enhance Corporate Image and Competitiveness. Enterprises take this mode can promote corporate image and enhance competitiveness of enterprises. It can save the resources and reduce the raw material procurement costs, find out the drawbacks of products and continuously improve product quality. Enterprise can get customers rid of worries and increase customer loyalty.

2) Weaknesses of Self-Running Take-back Mode

Although STM can bring a great many social and economic benefits to the enterprises, enterprises may encounter the following weaknesses when operating the RL business:

- A. High Investments & Risks. STM requires massive capital investment. The characteristics of RL make RL very complex. Although STM can reduce the transaction costs, it will, at the same time, result in the increase of inventory costs and transportation costs. Moreover, supervisor's lack of experience will probably lead to the failure of the operation of RL as well.
- B. Waste Resources. Under this mode, enterprises only recycle themselves EOL e-products. It has high degree of specialization but limited kinds of recycled products. For the entire region, different enterprises build their own reclaim & disposal center result in great waste of resources. Meanwhile, the limited recycled products can't achieve the economies of scale and increasing of recycling costs.

STM is one kind of highly specialized modes. Its facilities and staff are just to deal with a limited range of EOL e-products. The equipment utilization is relatively low, the limited products types and amounts may not bring the economies of scale. And it will result in enterprise reducing the numbers of reclaim and dispose center and increasing transportation cost, and further lead to high logistics cost.

3.2.2 Pooled Take-back Mode

3.2.2.1 Definition of Pooled Take-back Mode

PTM refers to enterprises that produce similar e-products in the same industries conglomerate with each other or make pooled investment to set up the pooled RL system (including establishment of pooled recycling center and disposing plants). And

the major function of this mode is to provide RL service to partners or non-partners. The enterprises involved in the PTM include e-products enterprises, disposal enterprises, recycling enterprise, customers and may be even their competitors. Through this collaboration, they will make true the win-win situation, that is, gain mutual complementarities, mutual benefits and common development.

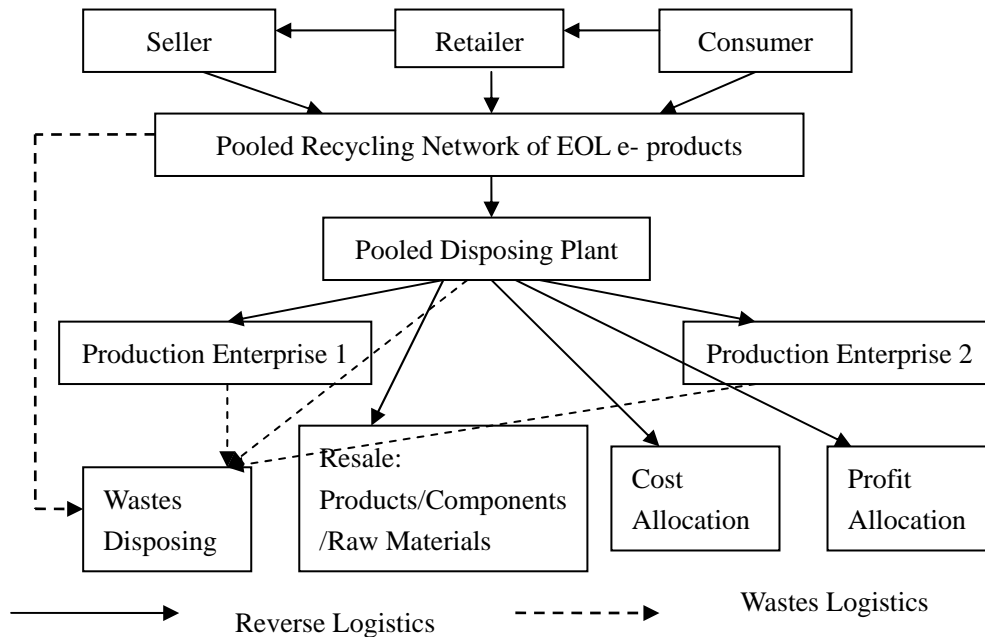


Figure 3-2 Pooled Take-back Mode

Source: Drawn on my own

3.2.2.2 Strengths/Weaknesses of Pooled Take-back Mode

Nowadays, logistics alliance has been a major logistics strategic decision by modern enterprises in the advancement process of modern logistics. Therefore, the set up of PTM in RL for EOL -products can not only relieve the pressure of investment in the building of RL system by single enterprise, form technology advantage and be easy to gain the economies of scale, but also provide cheap raw materials for each pooled enterprise and guarantee raw materials resources for the operation.

1) Strengths of Pooled Take-back Mode

- A. Cost Strength of PTM. PTM needs to undertake the responsibility for recycling of more EOL e-products in certain geographical regions. PTM is supposed to be up to economies of scale, and it can shorten the recycling distance, reduce the logistics cost, and only one information system is needed for recycling similar EOL e-products. Thereby, we can clearly see that through the cooperation between the pooled enterprises, it can reduce the cost and risk drastically.
- B. Professional Strength of PTM. All workers focus their energy and time on RL business, and compared with STM they tend to be more professional and efficient. The effective disposing of EOL e-products at various stages can minimize the wastes and maximize the purpose of recycling and reusing.
- C. Economies of Scale. PTM for EOL e-products is conducive to overcoming the shortage of resources by single enterprise. The large amounts and a wide range of types of recycled EOL e-products enable the enterprises to take full advantage of economies of scale.

2) Weaknesses of Pooled Take-back Mode

- A. Difficulties in Information Feedback. The slow feedback and inaccuracy in information is one of existing major problems of PTM. It will affect the recycling and disposing when enterprises can't be timely informed of the status of EOL e-products accurately. And compared with STM, the adoption of PTM is not favorable to the improvement of product design.

Although PTM is an effective way to improve the RL system, its effect in terms of enhancing the efficiency, reducing the cost of RL is limited in most cases. For instance, pooled enterprises hold different purposes of cooperation and other reasons will lead to the decline in performance of RL. And the integration of RL and existing resources also has a direct impact on the operation of RL for EOL e-products.

3.2.3 Third-party Take-back Mode

3.2.3.1 Definition of Third-party Take-back Mode

TTM indicates the enterprises consign all or parts of the RL business for EOL e-products to a professional RL provider through signing agreement and paying the charges. Under such mode, the third-party logistics provider will be the undertaker.

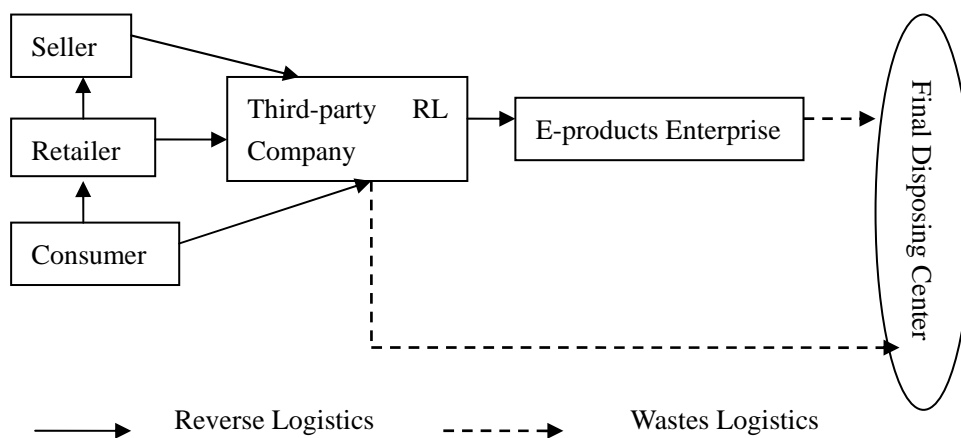


Figure 3-3 Third-party Take-back Mode

Source: Drawn on my own

3.2.3.2 Strengths/Weaknesses of Third-party Take-back Mode

1) Strengths of Third-party Take-back Mode

A. Strengthen Core Competitive Advantages. As a result of increasing competition and economic globalization, many companies primarily focus their attention and resources on its core competitive advantages, and outsource other services to professional businesses. Thus, outsourcing RL business for EOL e-products to a third party, enterprises do not need to input in the construction of RL infrastructures, and they can make full use of the capitals in its core competencies.

In addition, outsourcing RL can not only improve customer service quality and enhance customer satisfaction, but also reduce indirect costs.

B. High Professionalism. With a comprehensive logistics network, abundant experience in RL operations as well as advanced logistics technology and equipment, third-party RL provider possesses high working efficiency and low cost. Therefore, TTM can enhance the efficiency of RL management to a large extent, and third-party RL provider can do better job. In terms of logistics, third-party RL provider will put forward their suggestion on product design and raw materials selection to specific enterprise. It's favorable for enterprises to optimize the product design, and meanwhile, third-party provider will promptly transmit the feedbacks about products to enterprises. Furthermore, third-party provider can carry on the standard and professional operation of EOL e-products such as collection, sorting and disposing. They can also provide value-added services like inventory and transportation.

C. Reduce Cost & Risk. The operation of RL for EOL e-products set a higher requirement for enterprises in production capacity, logistics technology and information technology etc. Outsourcing RL to third-party RL provider, enterprise will save the huge investment in RL equipments and employees, and reduce investment risks. On the other hand, third-party RL provider will achieve economies of scale in management and operation through serving many enterprises. TTM has obvious advantage to STM in this aspect.

2) Weaknesses of Third-party Take-back Mode

A. Unfavorable to Enterprise Trade Security. Enterprises that outsource RL for EOL e-products would mean the loss of a huge portion of its control of EOL e-products. Whether the third-party provider can do an effective sorting, demolition or not will cast a direct impact on enterprise's recycling and reusing

utilization of EOL e-products. Under such circumstances, enterprises often need to provide products design proposal including raw materials, structure, etc. to third-party provider. For some patent products, risks of disclosure of the patents still exists and thus unfavorable for the protection of corporate trade secrets.

B. Shortage of Professional Third-party Reverse Logistics Providers. First, there isn't a particular standard for the selection of third-party RL providers. Second is the shortage of talented persons who command with management knowledge of RL for EOL e-products. It is of utmost importance for an enterprise to choose the right third-party RL provider for its RL business.

3.3 Analysis Z Company problems in Decision-making on Mode

Currently, the main problems of Z Company's decision-making on take-back modes in RL for EOL e-products can be listed below:

- ①. Generally, resource of the EOL e-products is pretty abundant in Z Company.
- ②. Z Company has strong financial background.
- ③. Z Company has successful operation experience in forward logistics.
- ④. Z Company has no professionals in relation to the RL of EOL e-products, and the employees are still unfamiliar with this particular aspect.
- ⑤. The level of information technology in Z Company can be proven as limited.

Through the above analysis, Z Company fully understands strengths and weaknesses

of three take-back modes. From the qualitative point of view, Z Company is able to select one take-back mode, however, the accuracy of the result can be an issue to be further discussed and the decision-making process can be very complex. As the result, a comprehensive analysis from various aspects should be applied in so as to reach a more appropriate decision for Z Company. For instances, Z Company has good financial background but without professionals. So the questions can be raised whether to choose STM or TTM and it can be proven that it's not an issue that can be solved by only understanding of strengths and weaknesses. On the basis of good understanding of three modes, quantitative analysis need to be combined and decompose the complex issue into hierarchy as well as consider the importance of various indicators of three take-back modes. All these indicators are the key factors for Z Company to make a right decision on take-back modes in RL for EOL e-products. All in all, it's the necessary step to provide a comprehensive analysis tool for Z Company to help its selection of most appropriate one.

3.4 Conclusion

Generally speaking, small enterprises are fit for TTM. On one side it can help enterprises reduce the RL costs, on the other side it can help to avoid risks. Enterprises with abundant logistics resources and strong economic power are more suitable to adopt STM. Other enterprises may be suitable for PTM. Therefore, Z Company carry on the decision-making on take-back modes in RL should carefully consider all aspects of factors, and inoculate its own resources condition and strategic development direction to decide the most appropriate mode.

CHAPTER 4 DECISION-MAKING METHODOLOGY ON TAKE-BACK MODES IN RL FOR EOL E-PRODUCTS

4.1 Steps of Decision-making on Take-back Modes in RL for EOL E-products for Z Company

When Z Company needs to make decision on take-back modes, first of all, what Z Company should take into account is to start from the strategic perspective of RL in enterprise, then to appraise the three take-back modes in order to make it clear whether RL will be the core competitiveness of enterprise or not. Last, under the prerequisite conditions of fully considering the various factors that can bring good return, Z Company will decide to implement the RL for EOL e-products.

Next is the analysis into the characteristics of Z Company's products and its logistics system. The suitable take-back mode is most often determined by the characteristics, numbers and categories of products. For example, in order to control over the entire recycling flow Z Company tends to choose the STM instead of other ones for business secret to reduce the reproductive and sale possibility of some products by the third party. On the other hand, the inherent logistics system of Z Company also has a considerable amount of importance as well. It's very difficult for the non-logistics companies to gain advanced RL management system and experience, advanced logistics technology and equipments and even the professionals, so TTM is a better.

Last, after Z Company deeply understands the characteristics of its own products and logistics system, the following step is to compare their respective strengths and weaknesses of three take-back modes (Chapter 3), and find one corresponds to Z Company's product and logistics system.

After the completion of above-mentioned three steps, Z Company can set up evaluation indicators system according to the analytical results and then use the simple assessment method to select the most appropriate take-back mode.

The steps of decision-making on take-back modes in RL for EOL e-products can be indicated by following figure. As we can see from following figure, the establishment of evaluation indicators system and the determination of selection methodology are the two key steps, which not only directly determines the accuracy of final selection but also have a direct impact on the success or failure of Z Company's investment in RL for EOL e-products.

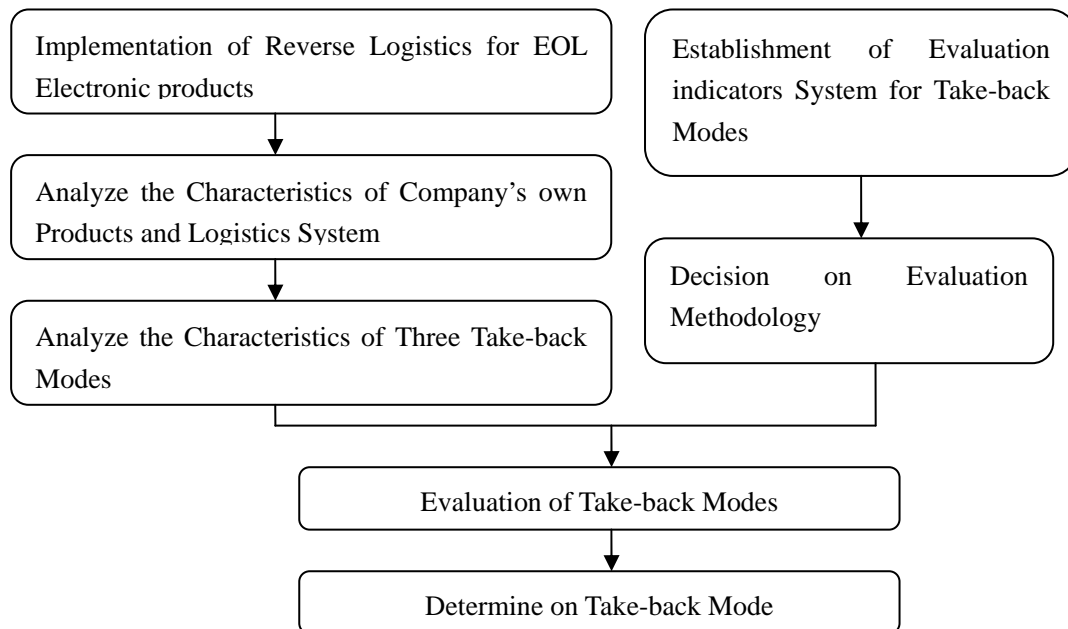


Figure 4-1 Steps of Decision-making on Take-back Modes in RL for EOL E-products

Source: Drawn on my own

4.2 BSC Ideology for Take-back Modes in RL for EOL E-products

BSC has four aspects: finance, customer, internal process and innovation & learning. When apply BSC into establishing evaluation indicators system for take-back modes in RL for EOL e-products, it can get the following corresponding relationship.

- 1) Financial Indicator. It corresponds to the finance of BSC. Finance is not only an independent aspect with its own characteristics, but also the starting point and foothold of other measurements. The success or failure of improvements is supposed to be reflected by the finance. It doesn't serve any purpose even if Z Company get the maximum result with the minimum effort just as followed: improvement of e-product quality or enhancement customer satisfaction can not be transformed into the reduction of operating cost, increase of profit etc.
- 2) Service Indicator. It refers to the customer perspective of BSC. The main services are in the following: recycling & disposing of EOL e-products, products testing / demolishing etc. Therefore, high service level can not only attract more new customers but also enhance the Z Company's reputation and reflect the technology level. So, the service indicator is interrelated and mutually traction.
- 3) Flexibility Indicator. It reflects the internal process aspect of the BSC. Flexibility means the reactive ability of RL system to any changes such as changes in customer demands, changes of the products. In the initial design stage of RL system, Z Company must allow for forecasting function in order to take timely adjustment for any changes.
- 4) Growth Indicator. It means the innovation and learning perspective in BSC. It deals with several factors: staff quality, external communication skills and environmental protection etc.

4.3 AHP Method for the Evaluation System of Take-back Modes

The Analytic Hierarchy Process (AHP), originally advanced by T.L. Saaty in 1970s. “AHP is a structured technique that combines the qualitative and quantitative analysis, which can provide a comprehensive framework for varieties of multi-criterion decision-making problems, for representing and quantifying the relative priorities specify to overall criteria, and for evaluating the alternative solutions.”⁴

Specific processes are just as follows:

1. Model the Problem as a Hierarchy: hierarchy will be showed in the 5.2.
2. Construct Judgment Matrices

Construct judgment matrix is the core part of utilization of AHP. Suppose the attribute A_k in upper level is related with n different attributes ($B = \{B_1, B_2, \dots, B_n\}$) in lower level, and then records the expression of relative importance between attribute B_i and attribute B_j in terms of element A_k as b_{ij} , all the results can yield the following

matrix $B = (b_{ij})_{n \times n}$, that is $B = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \vdots & \vdots & & \vdots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{bmatrix}$ (5-1), this is called the

judgment matrix of influencing element A_k .

The value usually takes Thomas L. Saaty’s scale (1-9). It’s a quantitative grading scale. The fundamental scale of values usually uses cardinal numbers 1, 2, . . . 9 or reciprocals, and they were listed in following table.

⁴ http://en.wikipedia.org/wiki/Analytic_hierarchy_process

Table 4-1 The Fundamental Scale

Value Scale for Alternative Decision-making Comparison		
Comparison Intensity	Definition	Explanation
1	Equally important	Two decision-makings equally influence the upper-level objectives
3	Moderately more important	One decision-making is moderately more favorable to the upper-level objective fulfillment
5	Strongly more important	One decision-making is strongly more favorable for the upper-level objective fulfillment
7	Very strongly more important	One decision-making is significantly more favorable for the upper-level objective fulfillment
9	Extremely more important	The difference between influences of the two decision-makings is extremely significant
2,4,6,8	Intermediate judgment values	When a compromise is necessary to give an intermediary judgment between the previous values
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j , then j has the reciprocal value when compared with i	A reasonable assumption

Source: Thomas L. Saaty, & Luis G. Vargas, Models, methods, concepts, and applications of the analytic hierarchy process. *Springer*

3. Synthesize Judgments to Yield a set of Weights in Level & Check Consistency

The calculation steps are as follows:

- 1) Normalized Pairwise Comparison Matrices B to get B^* . For each of the columns of B, divide each entry in column by sum of the entries in column. This yields a new matrix in which the sum of the entries in each column is 1.

$$b_{ij}^* = \frac{b_{ij}}{\sum_{i=1}^n b_{ij}}, j = 1,2,\dots,4 \quad (5-2)$$

- 2) Estimate the Weight for Criterion i . Estimate weight for objective i , as the average of entries in row i of B^* , get weight eigenvector: $W = [w_1, w_2, \dots, w_n]^T$,

w_i is the weight of attribute i in lower level

$$w_i = \frac{\sum_{j=1}^n b_{ij}^*}{n}, i = 1, 2, \dots, n \quad (5-3)$$

- 3) Calculate Largest Eigenvalue λ_{\max} . Find the ratio of each element of BW to the corresponding weight in w and average these ratios. $(BW)_i$ is the i^{th} element of vector BW .

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{(BW)_i}{w_i}, i = 1, 2, \dots, n \quad (5-4)$$

- 4) Consistency Test: Compute the consistency index: $CI = \frac{\lambda_{\max} - n}{n - 1}$ (5-5)

Saaty has introduced random index (RI) in order to take further test. It was listed in following table:

Table 4-2 Average Random Consistence Index (R.I.)

n	1	2	3	4	5	6	7
RI	0	0	0.58	0.9	1.12	1.24	1.32

Source: Thomas L. Saaty, & Luis G. Vargas, Models, methods, concepts, and applications of the analytic hierarchy process. *Springer*

Consistency ratio, expressed as CR , namely: $CR = CI/RI$ (5-6)

If $n > 2$ and $CR < 0.1$, the matrix is consistency and acceptable. If $CR \geq 0.1$, the matrix need to be adjusted until the judgment matrix meet the $CR < 0.1$.

4. Synthesize Judgments to Yield Overall Weights & Check the Consistency

1). Assuming weight vector of criteria layer: $W_C = [w_{c1}, w_{c2}, w_{c3}, w_{c4}]^T$, weight vector of sub-criteria layer: $W_{S_i} = [w_{S_{i1}}, w_{S_{i2}}, \dots, w_{S_{in}}]^T, i = 1, 2, \dots, 4, n_1 = 3, n_2 = 3, n_3 = 4, n_4 = 4$; weight vector of alternative layer: $W_{ij} = [w_{ij}(A_1), w_{ij}(A_2), w_{ij}(A_3)]^T, i = 1, 2, \dots, 4, j = 1, 2, \dots, n_i$

2). Calculate weight $w_G(S_{ij})$ of attribute S_{ij} in criteria level to global (G) layer:

$$w_G(S_{ij}) = w_{Gi} \times w_{S_{ij}}, i = 1, 2, \dots, 4, j = 1, 2, \dots, n_i, \quad (5-7)$$

3). The synthetic weight $w_G(A_m)$ of A_m layer to global (G) layer:

$$w_G(A_m) = \sum_{i=1}^4 \sum_{j=1}^{n_i} w_G(S_{ij}) \times w_{ij}(A_m), m = 1, 2, 3 \quad (5-8), w_G(A_m) \text{ is global weight}$$

of A_m , the bigger the value of $w_G(A_m)$, the better the alternative.

4). Assuming the consistency index of elements ($j = 1, 2, \dots, n$) in sub-criteria layer to criteria layer is CI_j , random index is RI_j , so consistency ratio of criteria layer (C)

$$\text{is : } CR = \frac{\sum_{j=1}^n w_j CI_j}{\sum_{j=1}^n w_j RI_j}, \text{ When } CR \leq 0.1, \text{ the layer has near consistency, otherwise we}$$

need to adjust the judgment matrices of criteria layer (C) and take analysis.

5. Come to a final decision-making based on the results of this process

4.4 Questionnaire

Questionnaire is one of the most commonly used methods for scientific research, and it is especially suitable for those situations such as unavailable or unreliable data and information. It's a method featured as simple, time-saving, and easy for collection.

4.4.1 Scoring Criteria

The author takes Thomas L. Saaty's scale (1-9) as a quantitative grading scale. Respondents fill in the tables with the number 1, 2...9. A relatively bigger number indicates the factor C_i is more important than other factors in certain specific aspect. The marks of questionnaire reflect the understanding and appraisal of the relative importance of various factors based on the objective facts.

4.4.2 Questionnaire Respondents

Whether the survey results are typical or not lies in the choice of respondents. The respondents must be comprehensive and representative. Based on the requirements of research, the following persons are selected as the respondents of the survey.

- 1) Experts in Related Fields. Relevant experts in this field are more familiar with the status quo and the up-to-the-minute development of the research and related professional knowledge and their answers of the related issues are more accurate. SMU and WMU professors are invited to fill questionnaire. Like Professor Zhen Hong, Professor Ma Shuo, Professor Donnor and Professor Ircha etc.
- 2) Professional E-products Enterprise. E-products enterprises can be divided into two categories: one is R & D staffs, who are familiar with the characteristics, structure and value of EOL e-products. The other is logistics staffs, they do RL for EOL e-products, and their views and suggestions are full of representativeness, and they can give the exact scores depending on experience. Technical and logistics staffs in Omron Shanghai Co., Ltd. are asked to fill questionnaires. Omron is a well-known e-products company in the world.

- 3) Logistics Enterprises & EOL E-products Vendors. Staffs that specialized in logistics or transportation, and their views are also very important. Logistics staffs in DHL are asked to fill questionnaires. Second, some small vendors and individual recyclers engaged in recycling EOL e-products are major part.
- 4) General Public. EOL e-products recycling network also depend on the general public, so the public's views and recommendations are very important. More than 10 persons randomly selected to fill in questionnaire.

4.4.3 Main Contents of Questionnaire

According to research objects and purpose, the author designed a questionnaire in table form based on the four major aspects of BSC, and put forward some indicators that include: finance, the service scope and anti-risk ability etc. to each mode.

4.4.4 Questionnaire Investigation

Investigation: Issued 30 questionnaires, 30 questionnaires were returned, of which 25 valid questionnaires.

4.5 Conclusion

For the decision-making on take-back mode in RL, the dissertation will employ above research methods. The combination of BSC, AHP and Questionnaire will deal with the decision-making problem perfectly. All in all, these methods can make an integrated evaluation into the implementation of RL for EOL e-products.

CHAPTER 5 APPLICATION OF EVALUATION INDICATORS SYSTEM IN Z COMPANY

5.1 Evaluation Indicators of Take-back Modes in Reverse Logistics for EOL E-products for Z Company

The evaluation indicators system for take-back modes in RL for EOL e-products is the most important element for decision-making. It should cover all aspects of RL system objectively and completely. Based on the respective strengths and weaknesses of three modes, and combined with BSC, indicators will be analyzed in following paragraphs.

1. Financial Indicator

① Investment. The implementation of RL needs to involve comparative investment in recycling facilities. It mainly includes the construction of reclaim & disposal center, remanufacturing plant, the purchasing of demolition equipments, and investment in fixed assets such as inventory and transportation tools. Under the term of STM, the investment will be undertaken by Z Company. For PTM or TTM, Z Company only needs to undertake part or none of the investment.

② Cost: The cost of RL is an aspect that can not be ignored. Several costs will be

listed below: recycling cost, disposing cost, recirculation cost, and burying/burning cost.

- ③ Profit. For Z Company, the profit is a significant factor that has to be taken into RL. For STM & PTM, profit primarily manifests in the reduction of raw materials costs, and obtain reusable components through demolition. For TTM, profit is mainly reflected in increase of intangible income through provision high quality RL services.

2. Service Indicator

- ① Customer Satisfaction. It means customer's appraisal after experienced RL service. High-quality service, as well as high efficiency can not only lure potential customers, but also increase the reputation of Z Company.
- ② Service Scope. Services scope refers to different kinds of services provided by RL for EOL e-products. It mainly includes recycling, demolition, testing, sorting and disposing. All in all, the more the service scopes expand, the more improvement in the quality of products recycled. The service scope of RL is also an important aspect to evaluate Z Company service quality.
- ③ Convenience. The convenient degree of RL services for EOL e-products provided for the customers. Therefore, Z Company should pay full attention to this point.

3. Flexibility Indicator

- ① Anti-risk Ability. Z Company should carry out the risk assessment in full length before investment. Z Company's anti-risk ability appears more important in modern society. The big investment of RL for EOL e-products combined with its characteristics like dispersion, slowness, uncertainty will cause implementation of

RL face all sorts of risks. It can be said that the anti-risk ability is an important symbol.

- ② Information Feedback Ability. It mainly reflected by the timeliness feedback and accuracy in information. Timeliness means that Z Company can track & trace location and status of products from time to time, and this has direct impact on the operation of RL. Accuracy is the most basic and important requirement, if the information is not accurate, then the timeliness does not has any significance, and will result in some unnecessary losses, then further affect the operation.
- ③ Forecasting Ability. Forecasting accuracy links closely with information feedback accuracy. With the development of Z Company, the increase of investment and research, forecasting accuracy will be gradually enhanced, the higher the accuracy the stronger the forecasting ability.
- ④ Disposing Ability. It can be measured by Z Company's maximum disposal capacity and level. The maximum disposal capacity means the volume of EOL e-products can be disposed at the same time. Disposal level means the level of EOL e- products equipment.

4. Growth Indicator

- ① Environmental Protection Level. Environmental protection level refers to the Z Company's environmental protection ability in disposing hazardous substances. It not only link with the advanced disposal equipment and disposing capacity, but also with Z Company's awareness of environmental protection. Therefore, the consideration of environmental indicator is very important when Z Company selects RL mode.
- ② Staff Overall Quality. For Z Company, professionals and technical staffs are key

factors in RL. It means technical level and business knowledge of the staffs engaged in RL. Z Company must be concerned whether staff can keep up with the RL development and need to be trained or not. Particularly in PTM and TTM, Z Company also needs to strengthen cooperation with partners to maintain good relationship. The coordination of pooled enterprise plays a decisive role in the success or failure of RL for EOL e-products.

- ③ Management Level of RL. It's very important for Z Company to control over RL. For Z Company, whether it has advanced management knowledge of RL, whether it can carry out the effective monitoring the operation of RL, the number of professionals in RL, and the quality of staff will affect the operation of RL. Under STM and PTM, RL management ability directly affects the Z Company's RL business development. However, for TTM, the RL management ability will affect the competitiveness of Z Company directly.
- ④ External Communication Skills. RL is different from forward logistics, its development is driven by the policies and regulations and it is very important to the sensitivity and the execution ability.

5.2 Establishment of Evaluation Indicators System for Take-back Modes in RL for E-products for Z Company

For the complex problem of decision-making on take-back mode in RL for EOL e-products, according to AHP method, the problem was modeled as a hierarchy, and we can see the following figure. Hierarchy: 1.Goal level: decision-making on the most appropriate take-back mode for Z Company; 2.Criteria level: a group of criteria that relate the alternatives to the goal, four perspectives of RL for EOL e-products based on BSC; 3.Sub-criteria level: sub-criteria for criteria, and detailed analysis of all

important indicators has made in last section; 4. Alternative level: alternatives for reaching the goal (STM, PTM and TTM). From the goal to alternatives, one hierarchy is used to integrate large amounts of information.

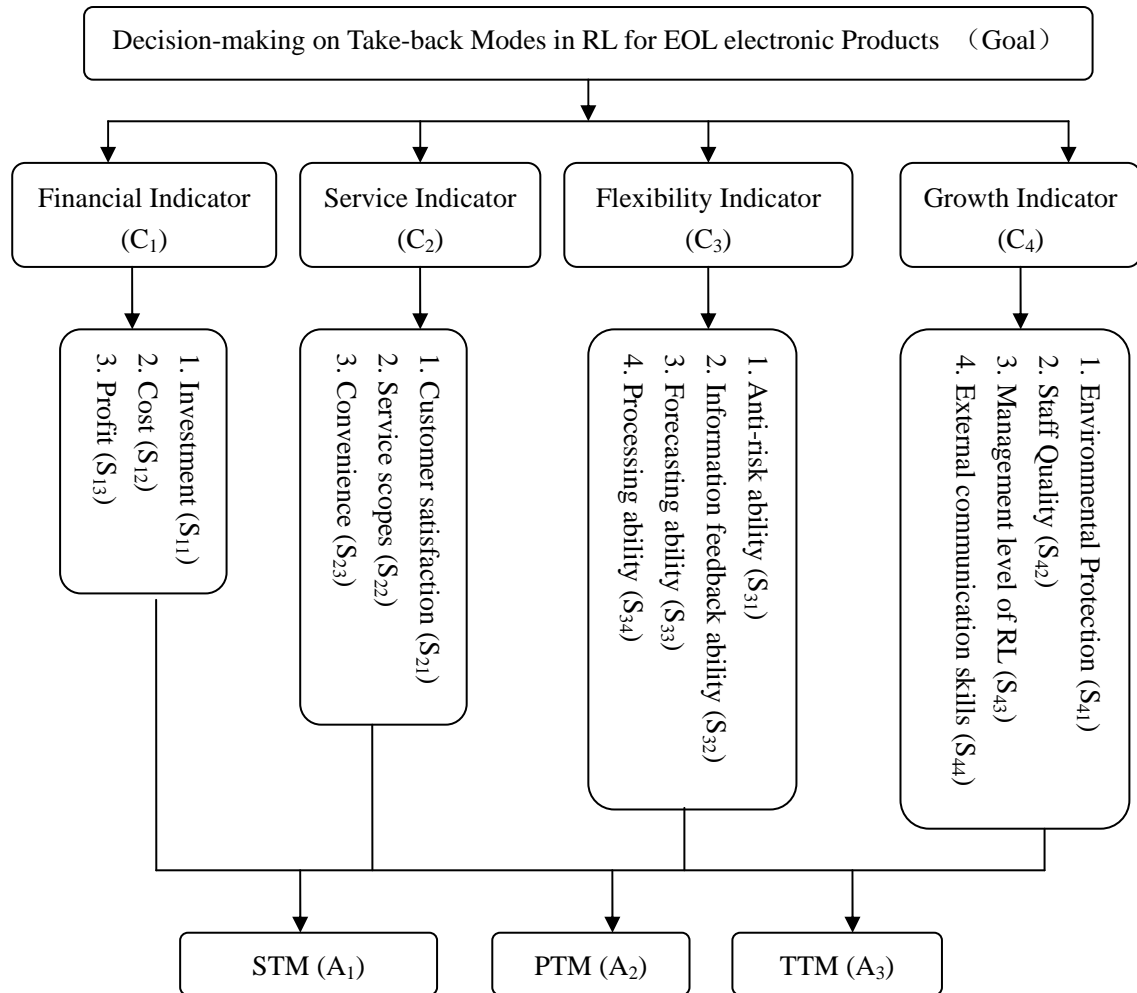


Figure 5-1 Evaluation Indicators System for Take-back Modes in RL for EOL E-products for Z Company

Source: Drawn on my own

5.3 Pairwise Comparison

5.3.1 Pairwise Comparison in Criteria Level

From the questionnaire, for Z Company, the most important one is the financial indicator such as increment of profit, reduction of operating cost. Second one is the increment of service quality and the expansion of service scopes. Third one is the enhancement of RL flexibility. Last one is growth, under such a fierce competitive situation, Z Company also has to provide a good development direction for employees. (C₁: Financial (47%) > C₂: Service (37%) > C₃: Flexibility (11%) > C₄: Growth (5%))

1. Construct G-C Judgment Matrix

$$C = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{matrix} \begin{bmatrix} 1 & 2 & 5 & 7 \\ 1/2 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 2 \\ 1/7 & 1/5 & 1/2 & 1 \end{bmatrix}$$

2. Normalized Pairwise Comparison Matrices C to get C^*

$$C^* = \begin{bmatrix} 0.543 & 0.566 & 0.526 & 0.467 \\ 0.271 & 0.283 & 0.316 & 0.333 \\ 0.109 & 0.094 & 0.105 & 0.133 \\ 0.078 & 0.057 & 0.053 & 0.067 \end{bmatrix}$$

3. Estimate the Weight for Criterion i

$$W_G = [w_{G1}, w_{G2}, w_{G3}, w_{G4}]^T = [0.525 \quad 0.301 \quad 0.110 \quad 0.063]^T$$

4. Checking for Consistency

- Computer CW

$$CW = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{matrix} \begin{bmatrix} 1 & 2 & 5 & 7 \\ 1/2 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 2 \\ 1/7 & 1/5 & 1/2 & 1 \end{bmatrix} * \begin{bmatrix} 0.525 \\ 0.301 \\ 0.110 \\ 0.063 \end{bmatrix} = \begin{bmatrix} 2.122 \\ 1.211 \\ 0.442 \\ 0.254 \end{bmatrix}$$

- Calculate λ_{\max} : $\lambda_{\max} = \sum_{i=1}^n \frac{(CW)_i}{nW_i} = 4.020$

- Compute the Constancy Index (CI): $CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{4.020 - 4}{4 - 1} = 0.007$
- Compute the Constancy Ratio (CR)

$$RI = 0.9 \quad CR = CI/RI = 0.007/0.9 = 0.007 < 0.1$$

5.3.2 Pairwise Comparison in Sub-criteria Level

Use the same method to construct the judgment matrix of criteria level.

1. Finance Indicator C_1

Questionnaire result: Profit or not loss money for Z Company to implement RL for EOL e-products is the most important one, then the lower cost and finally the less investment. (S_{13} : Profit (58%) $>$ S_{12} : Cost (21%) = S_{11} : Investment (21%))

$$\begin{bmatrix} C_1 & S_{11} & S_{12} & S_{13} \\ S_{11} & 1 & 1/3 & 1/5 \\ S_{12} & 3 & 1 & 1/2 \\ S_{13} & 5 & 2 & 1 \end{bmatrix} \quad w_{C1} = [w_{S11}, w_{S12}, w_{S13}]^T = [0.109, 0.309, 0.581]^T$$

$$\lambda_{\max} = 3.004, CI = 0.002, CR = 0.003 < 0.1$$

2. Service Indicator C_2

From questionnaire result: the first rank is customer satisfaction, the higher customer satisfaction the more profit for Z Company. The customer satisfaction is mainly embodied by service convenience, and then through provides more kinds of services to solve more problems of customers. (S_{21} : Customer satisfaction (58%) $>$ S_{23} : Convenience (37%) $>$ S_{22} : Service scope (5%))

$$\begin{bmatrix} C_2 & S_{21} & S_{22} & S_{23} \\ S_{21} & 1 & 7 & 4 \\ S_{22} & 1/7 & 1 & 1/2 \\ S_{23} & 1/4 & 2 & 1 \end{bmatrix}$$

$$w_{C2} = [w_{S21}, w_{S22}, w_{S23}]^T = [0.715, 0.098, 0.187]^T$$

$$\lambda_{\max} = 3.002, CI = 0.001, CR = 0.002 < 0.1$$

3. Flexibility indicator C_3

Based on questionnaire, information feedback ability and disposing ability are of equivalent importance. Z Company should first enhance the information feedback accuracy and strengthen disposing ability. Then, due to these two abilities have been enhanced the forecasting accuracy will be increased, and then it can and further strengthen anti-risk ability. (S_{34} : Disposing ability (36%) > S_{32} : Information feedback ability (32%) > S_{33} : Forecasting ability (21%) > S_{31} : Anti-risk ability (11%))

$$\begin{bmatrix} C_3 & S_{31} & S_{32} & S_{33} & S_{34} \\ S_{31} & 1 & 1/5 & 1/3 & 1/5 \\ S_{32} & 5 & 1 & 2 & 1 \\ S_{33} & 3 & 1/2 & 1 & 1/2 \\ S_{34} & 5 & 1 & 2 & 1 \end{bmatrix} w_{C3} = [w_{S31}, w_{S32}, w_{S33}, w_{S34}]^T = [0.071, 0.368, 0.193, 0.368]^T$$

$$\lambda_{\max} = 4.004, CI = 0.001, CR = 0.002 < 0.1$$

4. Growth Indicator C_4

According to questionnaire, good management level of RL will give Z Company a better development, but all the developments work on the premise of environmental protection. So these two indicators have the same importance. And staff overall quality is more important than external communicate skills, because the higher staff quality, Z Company can make faster adjustments. (S_{41} : Environmental protection

(53%) > S_{43} : Management level of RL (37%) > S_{42} : Staff quality (5%) = S_{44} : External communication skills (5%))

$$\begin{bmatrix} C_4 & S_{41} & S_{42} & S_{43} & S_{44} \\ S_{41} & 1 & 2 & 1 & 5 \\ S_{42} & 1/2 & 1 & 1/2 & 3 \\ S_{43} & 1 & 2 & 1 & 5 \\ S_{44} & 1/5 & 1/3 & 1/5 & 1 \end{bmatrix} w_{C4} = [w_{S41}, w_{S42}, w_{S43}, w_{S44}]^T = [0.368, 0.193, 0.368, 0.071]^T$$

$$\lambda_{\max} = 4.004, CI = 0.001, CR = 0.002 < 0.1$$

Calculate the weights of criteria level to goal level and check the consistency, according to formula (5-7), we can get:

$$w_G(S_{ij}) = w_{G_i} \times w_{S_{ij}}, i = 1, 2, \dots, 4, j = 1, 2, \dots, n_i$$

$$w_G(S_{11}) = 0.057, w_G(S_{12}) = 0.162, w_G(S_{13}) = 0.305$$

$$w_G(S_{21}) = 0.215, w_G(S_{22}) = 0.029, w_G(S_{23}) = 0.056$$

$$w_G(S_{31}) = 0.001, w_G(S_{32}) = 0.040, w_G(S_{33}) = 0.021, w_G(S_{34}) = 0.040$$

$$w_G(S_{41}) = 0.023, w_G(S_{42}) = 0.012, w_G(S_{43}) = 0.023, w_G(S_{44}) = 0.0004$$

$$CR = \frac{\sum_{j=1}^n w_j CI_j}{\sum_{j=1}^n w_j RI_j} = \frac{0.525 \times 0.002 + 0.301 \times 0.001 + 0.110 \times 0.001 + 0.063 \times 0.001}{0.525 \times 0.58 + 0.301 \times 0.58 + 0.110 \times 0.9 + 0.063 \times 0.9} = 0.0002 < 0.1$$

Therefore, it satisfied consistency.

5.3.3 Pairwise Comparison in Alternative Level

Construct 14 judgment matrices in sub criteria level, and get the weights of each indicator to criteria level, and check the consistency. The following are the scoring criteria of judgment matrices by examples:

1. Judgment Matrix $S_{11} - A_m$ (Investment-Alternative)

The scoring criterion is less investment more important the alternative. The questionnaire result actually reflects investment in STM is max, while TTM relatively minimum. For A_1 , Z Company has to invest in construction of facilities, purchasing disposal equipments, recruitment of professionals and so on, so its investment is enormous. For A_2 , Z Company can ally with pooled enterprises to make investment in manpower, materials and construct RL system for EOL e-products together, so its investment is relatively less than A_1 . For A_3 , it's no need for Z Company to put investment in any infrastructure of RL system, only to pay charges for RL service. Therefore, for the indicator S_{11} , A_3 is moderately more important than A_2 , A_2 is moderately more important than A_1 , A_3 is extremely more important than A_1 . (S_{11} : Investment, A_1 : STM (47%) > A_2 : PTM (32%) > A_3 : TTM (21%))

$$\begin{bmatrix} S_{11} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/3 & 1/9 \\ A_2 & 3 & 1 & 1/3 \\ A_3 & 9 & 3 & 1 \end{bmatrix} \begin{matrix} w_{11} = [w_{11}(A_1), w_{11}(A_2), w_{11}(A_3)]^T = [0.077, 0.231, 0.692]^T \\ \lambda_{\max} = 3, CI = 0, CR = 0 < 0.1 \end{matrix}$$

2. Judgment Matrix $S_{12} - A_m$ (Cost-Alternative)

The scoring criterion is less cost more important the alternative. Questionnaire result shows TTM is larger than STM. But to Z Company, for A_1 , all costs borne by Z Company alone, and due to the characteristics such as slowness and uncertainty of EOL e-products, Z Company is difficult to reduce costs during transportation and inventory. For A_2 , Z Company and pooled enterprises shared the recycling and disposing costs and large recycled products volume and variety types can form the

economies of scale. For A_3 , recycling service of third-party provider featured as large-scale and low cost, and Z Company doesn't need to bear the any costs of recycling EOL e-products. Recycling and disposing cost of TTM is the lowest for Z Company. Therefore, for the indicator S_{12} , A_3 is moderately more important than A_2 , A_2 is moderately more important than A_1 , A_3 is very strongly more important than A_1 . (S_{12} : Cost, A_3 : TTM (47%) > A_1 : STM (42%) > A_2 : PTM (11%))

$$\begin{bmatrix} S_{12} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/3 & 1/7 \\ A_2 & 3 & 1 & 1/3 \\ A_3 & 7 & 3 & 1 \end{bmatrix} \begin{matrix} w_{12} = [w_{12}(A_1), w_{12}(A_2), w_{12}(A_3)]^T = [0.088, 0.243, 0.669]^T \\ \lambda_{\max} = 3.007, CI = 0.004, CR = 0.006 < 0.1 \end{matrix}$$

3. Judgment Matrix $S_{22} - A_m$ (Service Scope-Alternative)

The scoring criterion is wider service scopes more important the alternative. Questionnaire result tells STM wider than PTM, but due to Z Company has never run RL business so it need some adjustments when make decision. For A_1 , Z Company recycles and disposes its own products, so service scope is limited. For A_2 , Z Company and pooled enterprises recycle and dispose similar types EOL e-products, so the service scope is wider than A_1 . For A_3 , third-party provider enjoys the widest range of services and it can provide special services to specific enterprise. Therefore, for the indicator S_{22} , A_3 is moderately more important than A_2 , A_2 is strongly more important than A_1 , A_3 is very strongly more important than A_1 . (S_{22} : Service Scopes, A_3 : TTM (79%) > A_1 : STM (16%) > A_2 : PTM (5%))

$$\begin{bmatrix} S_{22} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/4 & 1/7 \\ A_2 & 4 & 1 & 1/3 \\ A_3 & 7 & 3 & 1 \end{bmatrix} \begin{matrix} w_{22} = [w_{22}(A_1), w_{22}(A_2), w_{22}(A_3)]^T = [0.079, 0.265, 0.656]^T \\ \lambda_{\max} = 3.033, CI = 0.016, CR = 0.028 < 0.1 \end{matrix}$$

4. Judgment Matrix $S_{23} - A_m$ (Convenience- Alternative)

The scoring criterion is more convenience more important the alternative. For A_1 , Z Company recycles and disposes its own products, so it means convenience for recycling. For A_2 , Z Company provide recycling and disposing service to partners, the convenience for Z Company under PTM means it should dispose partners' EOL e-products efficiently. For A_3 , third-party provider recycled EOL e-products at customers home and let them feel convenience. Therefore, for the indicator S_{23} , A_3 is moderately more important than A_2 , A_2 is moderately more important than A_1 , A_3 is very strongly more important than A_1 . (S_{23} : Convenience, A_3 : TTM (63%) > A_2 : PTM (21%) > A_1 : STM (16%))

$$\begin{bmatrix} S_{23} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/2 & 1/7 \\ A_2 & 2 & 1 & 1/3 \\ A_3 & 7 & 3 & 1 \end{bmatrix} \begin{matrix} w_{23} = [w_{23}(A_1), w_{23}(A_2), w_{23}(A_3)]^T = [0.103, 0.216, 0.681]^T \\ \lambda_{\max} = 3.003, CI = 0.001, CR = 0.002 < 0.1 \end{matrix}$$

5. Judgment Matrix $S_{32} - A_m$ (Information Feedback Ability-Alternative)

The scoring criterion is more quick and accurate information feedback the more important the alternative. For A_1 , Z Company constructed RL system by itself, it involves only itself and the operation is relatively simple, but due to Z Company has

limited information technology so that the information feedback is moderate. For A_2 , the recycling and disposing of EOL e-products is done by Z Company and partner. The smooth operation needs perfect cooperation. And any misunderstanding among each other will cause the information feedback slow and inaccurate. For A_3 , third-party providers can also feedback the information more quick and accurate. Therefore, for the indicator S_{32} , A_3 is moderately more important than A_1 , A_1 is strongly more important than A_2 , A_3 is very strongly more important than A_2 . (S_{32} : Information Feedback Ability, A_3 : TTM (63%) > A_1 : STM (21%) > A_2 : PTM (16%))

$$\begin{bmatrix} S_{32} & A_1 & A_2 & A_3 \\ A_1 & 1 & 5 & 1/3 \\ A_2 & 1/5 & 1 & 1/7 \\ A_3 & 3 & 7 & 1 \end{bmatrix} \begin{matrix} w_{32} = [w_{32}(A_1), w_{32}(A_2), w_{32}(A_3)]^T = [0.283, 0.074, 0.643]^T \\ \lambda_{\max} = 3.066, CI = 0.033, CR = 0.056 < 0.1 \end{matrix}$$

6. Judgment Matrix $S_{33} - A_m$ (Forecasting Ability- Alternative)

The scoring criterion is more accurate forecasting ability more important the alternative. Questionnaire result reflect STM higher than PTM, but because Z Company has limited information technology and lack of professionals, so it need some adjustments when make decision. For A_1 , Z Company lack of professionals and unfamiliar with this field, so forecasting accuracy is the worst. For A_2 , Z Company can depend on its partners to enhance the forecasting accuracy. For A_3 , third-party provider is just the opposite of A_1 , it has advanced the RL network and equipments and many professionals, so they can make most accurate forecasting. Therefore, for the indicator S_{33} , A_3 is strongly more important than A_2 , A_2 is strongly more important than A_1 , A_3 is extremely more important than A_1 . (S_{33} : Forecasting ability,

$A_3 : \text{TTM (63\%)} > A_1 : \text{STM (32\%)} > A_2 : \text{PTM (5\%)}$

$$\begin{bmatrix} S_{33} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/4 & 1/9 \\ A_2 & 4 & 1 & 1/5 \\ A_3 & 9 & 5 & 1 \end{bmatrix} \begin{matrix} w_{33} = [w_{33}(A_1), w_{33}(A_2), w_{33}(A_3)]^T = [0.065, 0.199, 0.735]^T \\ \lambda_{\max} = 3.072, CI = 0.036, CR = 0.062 < 0.1 \end{matrix}$$

7. Judgment Matrix $S_{34} - A_m$ (Disposing Ability-Alternative)

The scoring criterion is stronger disposing ability the more important the alternative. Questionnaire result tells STM stronger than PTM, but because Z Company lack of professionals and experience, so it need some adjustments when make decision. For A_1 , although Z Company has enough EOL e-products resources, Z Company disposes its own EOL e-products so its volume is still limited. For A_2 , Z Company and partners recycle and dispose their EOL e-products, so its volume is larger than A_1 . For A_3 , third-party provider can recycle and dispose various types of EOL e-products because they enjoy rich experience and advanced equipments, so its volume is the largest. Therefore, for the indicator S_{34} , A_3 is strongly more important than A_2 , A_2 is strongly more important than A_1 , A_3 is extremely more important than A_1 . (S_{34} : Disposing Ability, $A_3 : \text{TTM (53\%)} > A_1 : \text{STM (42\%)} > A_2 : \text{PTM (5\%)}$)

$$\begin{bmatrix} S_{34} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/4 & 1/8 \\ A_2 & 4 & 1 & 1/5 \\ A_3 & 8 & 5 & 1 \end{bmatrix} \begin{matrix} w_{34} = [w_{34}(A_1), w_{34}(A_2), w_{34}(A_3)]^T = [0.070, 0.206, 0.723]^T \\ \lambda_{\max} = 3.096, CI = 0.048, CR = 0.083 < 0.1 \end{matrix}$$

8. Judgment Matrix $S_{41} - A_m$ (Environmental Protection Level-Alternative)

The scoring criterion is more attention paid to environmental protection more important the alternative. Decision-making needs adjustment. For A_1 , although Z Company has strong awareness of environmental protection and can invest large capitals in construction RL system and purchasing advanced equipments, Z Company has no professionals, so it will make the equipments become useless and polluted environmental. For A_2 , Z Company and pooled enterprises will strengthen their attention to environmental pollution. For A_3 , third-party provider is opposite to the A_1 . One more point is TTM pay more attention to environmental protection will enhance the corporate image and attract more potential customers. Therefore, for the indicator S_{41} , A_3 is strongly more important than A_2 , A_2 is moderately more important than A_1 , A_3 is very strongly more important than A_1 . (S_{41} : Environmental Protection Level, A_3 : TTM (57%) > A_1 : STM (32%) > A_2 : PTM (11%))

$$\begin{bmatrix} S_{41} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/3 & 1/6 \\ A_2 & 3 & 1 & 1/4 \\ A_3 & 6 & 4 & 1 \end{bmatrix} \quad \begin{aligned} w_{41} &= [w_{41}(A_1), w_{41}(A_2), w_{41}(A_3)]^T = [0.093, 0.221, 0.685]^T \\ \lambda_{\max} &= 3.054, CI = 0.027, CR = 0.047 < 0.1 \end{aligned}$$

9. Judgment matrix $S_{42} - A_m$ (Staff Overall Quality-Alternative)

The scoring criterion is higher staff overall quality more important the alternative. Questionnaire result tells STM stronger than PTM, but because Z Company lack of professionals and experience, so it need some adjustments when make decision. For A_1 , Z Company has no professionals in RL management and unfamiliar with RL, so Z Company should recruitment new employees. For A_2 , enhancement of staff overall quality Z Company will by professionals in pooled enterprises. For A_3 , one of the advantages of TTM is it has many professionals in different kinds of RL. So its

staff overall quality is the highest. Therefore, for the indicator S_{42} , A_3 is strongly more important than A_2 , A_2 is moderately more important than A_1 , A_3 is extremely more important than A_1 . (S_{42} : Staff quality, A_3 : TTM (58%) > A_1 : STM (37%) > A_2 : PTM (5%)).

$$\begin{bmatrix} S_{42} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/3 & 1/9 \\ A_2 & 3 & 1 & 1/4 \\ A_3 & 9 & 4 & 1 \end{bmatrix} \quad w_{42} = [w_{42}(A_1), w_{42}(A_2), w_{42}(A_3)]^T = [0.074, 0.201, 0.726]^T$$

$$\lambda_{\max} = 3.009, CI = 0.005, CR = 0.008 < 0.1$$

10. Judgment Matrix $S_{43} - A_m$ (Management Level of RL-Alternative)

The scoring criterion is higher RL management level more important the alternative. Questionnaire result reflects STM is higher than PTM, but Z Company is unfamiliar with RL, thus it need some adjustments when make decision. For A_1 , Z Company has to manage RL itself, but Z Company has no experience in RL business, and lack of professions, meanwhile the integration of RL and forward logistics will lay a direct impact on its management level in RL. For A_2 , Z Company and its partners construct pooled recycling center and disposal factory, and hire professionals, but the RL management level will be affected by partners' management level. For A_3 , third-party provider hold comprehensive logistics network, rich experience in RL operations and advanced management system, its RL management is the best. Therefore, for the indicator S_{43} , A_3 is strongly more important than A_2 , A_2 is moderately more important than A_1 , A_3 is extremely more important than A_1 . (S_{43} : Management Level of RL, A_3 : TTM (57%) > A_1 : STM (32%) > A_2 : PTM (11%))

$$\begin{bmatrix} S_{43} & A_1 & A_2 & A_3 \\ A_1 & 1 & 1/3 & 1/9 \\ A_2 & 3 & 1 & 1/4 \\ A_3 & 9 & 4 & 1 \end{bmatrix} w_{43} = [w_{43}(A_1), w_{43}(A_2), w_{43}(A_3)]^T = [0.074, 0.200, 0.726]^T$$

$$\lambda_{\max} = 3.001, CI = 0.005, CR = 0.008 < 0.1$$

In following list will show results of judgment matrices of other indicators, and questionnaire results will be find in appendix 2:

1. Judgment Matrix $S_{13} - A_m$ (Profit-Alternative)

$$w_{13} = [w_{13}(A_1), w_{13}(A_2), w_{13}(A_3)]^T = [0.615, 0.292, 0.093]^T$$

$$\lambda_{\max} = 3.003, CI = 0.001, CR = 0.002 < 0.1$$

2. Judgment Matrix $S_{21} - A_m$ (Customer Satisfaction-Alternative)

$$w_{21} = [w_{21}(A_1), w_{21}(A_2), w_{21}(A_3)]^T = [0.088, 0.243, 0.669]^T$$

$$\lambda_{\max} = 3.007, CI = 0.004, CR = 0.006 < 0.1$$

3. Judgment Matrix $S_{31} - A_m$ (Anti-risk Ability- Alternative)

$$w_{31} = [w_{31}(A_1), w_{31}(A_2), w_{31}(A_3)]^T = [0.071, 0.180, 0.748]^T$$

$$\lambda_{\max} = 3.029, CI = 0.015, CR = 0.025 < 0.1$$

4. Judgment Matrix $S_{44} - A_m$ (External Communication Skills-Alternative)

$$w_{44} = [w_{44}(A_1), w_{44}(A_2), w_{44}(A_3)]^T = [0.206, 0.079, 0.715]^T$$

$$\lambda_{\max} = 3.018, CI = 0.009, CR = 0.0168 < 0.1$$

All above the indicators satisfy the consistency.

Calculate the synthetic weight of Alternative level to Goal level and check the consistency.

	w_i	A_1	A_2	A_3
S_{11}	0 . 057	0 . 077	0 . 231	0 . 692
S_{12}	0 . 162	0 . 088	0 . 243	0 . 669
S_{13}	0 . 305	0 . 615	0 . 292	0 . 093
S_{21}	0 . 215	0 . 088	0 . 243	0 . 669
S_{22}	0 . 029	0 . 079	0 . 265	0 . 656
S_{23}	0 . 056	0 . 103	0 . 216	0 . 681
S_{31}	0 . 008	0 . 071	0 . 180	0 . 748
S_{32}	0 . 040	0 . 283	0 . 074	0 . 643
S_{33}	0 . 021	0 . 065	0 . 199	0 . 735
S_{34}	0 . 040	0 . 070	0 . 206	0 . 723
S_{41}	0 . 023	0 . 093	0 . 221	0 . 685
S_{42}	0 . 012	0 . 074	0 . 200	0 . 726
S_{43}	0 . 023	0 . 206	0 . 079	0 . 715
S_{44}	0 . 004	0 . 206	0 . 079	0 . 715

$$w_G(A_1) = 0.255, w_G(A_2) = 0.243, w_G(A_3) = 0.497, \quad CR = \frac{\sum_{j=1}^n w_j CI_j}{\sum_{j=1}^n w_j RI_j} = 0.013 < 0.1$$

Satisfy the consistency

According to the above matrix, and the result of formula, it can be clarified first is TTM: A_3 (0.497), second is STM: A_1 (0.255), third is PTM: A_2 (0.243). And we can see that TTM is the best choice for Z Company, and it's the most appropriate one.

5.4 Conclusion

Through above calculation, it can be noticed TTM is most suitable for Z Company. TTM is the development trend of take-back modes in RL. While the recycling & disposing business of EOL e-products is left to third-party RL provider, Z Company could focus on production and sales. Thus, Z Company can not only inject more energy into product promotion & sales performances and simultaneously simplify the organization, but also pass the risks brought about by uncertainties of EOL e-products to the third party. TTM enjoys a broad scope of application fields, especially the emerging electronic business. With the development of logistics industry, TTM will take continues improvement and growth, and meanwhile more enterprises will consider outsourcing their RL for EOL e-products.

CHAPTER 6 CONCLUSION & SUGGESTION

With the growing importance of RL and the occurrence of peak period of EOL e-products, it's imperative for enterprises to carry out the RL for EOL e-products. Under such circumstance, how to make a wise decision on an appropriate take-back mode will become a hot point in both theoretical and business field. However, there are only a few researches of decision-making on take-back modes in RL for EOL e-products at home and abroad. This paper is carried out under this background.

This paper is based on relevant literatures related to RL and combine with actuality. The main line of this paper is followed by:

First, in the light of literature review of RL at home and abroad, this paper sum up RL, motivations for RL for EOL e-products, and with a large number of facts and data about RL for EOL e-products in current China, the author points out the importance and urgency of research on take-back modes in RL for EOL e-products.

Second, the introduction of three take-back modes in RL for EOL e-products at full length: STM, PTM and TTM. The author analyzed their strengths and weaknesses respectively. On this basis, analysis of three take-back modes in order to enable Z Company to be available for a clear understanding of three take-back modes before decision-making.

Finally, the application of BSC, Questionnaire and AHP method in decision-making

on take-back modes in RL for EOL e-products, and explains in great details about decision-making methods and steps through Z Company. The analysis of three take-back modes in RL for EOL e-products and the establishment of evaluation indicators system of take-back modes based on BSC, AHP and Questionnaire is what this paper are driving at.

Because RL research in China is still at the initial stage, naturally enterprises that implement RL for EOL e-products are very few, so it's very difficult to do research on this topic. Due to most of the enterprises information is non-public so it's harder to carry out data analysis of specific enterprise. There is more needs to be done for the improvement of this paper, e.g. the evaluation indicators of decision-making on take-back modes should be further improved, and the applicability of decision-making methods has yet to be further examined. And further discussion hope to be taken with specific enterprise in the near future.

During the decision-making process on take-back modes in RL, respective analysis of three take-back modes is beneficial to simplification of the research, while its practical guidance has greatly diminished. Actually, for logistics system in the enterprises, whatever the forward logistics system or the RL system should be involved in enterprise's entire strategic system, enterprises can be an outsourcing or self-running part of RL business or they can integrate RL and forward logistics to carry out the decision-making on take-back modes. Therefore, an organic analysis of different aspects in logistics system will be a vital orientation in logistics field.

Although there is a lot more need to be done in this paper, the author hope that through this research, it may offer some useful methods for enterprises analyzing take-back modes in RL to some degree.

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Website:

China Economic and Social Council web site gives further information on course (<http://www.china-esc.org.cn/news.asp?id=624>)

China Environment Protection web site gives further information on course (<http://www.chinaep.net/index.htm>)

E-waste Comprehensive Utilization Work Committee web site gives further information on course (<http://www.e-waste.org.cn/>)

Reverse Logistics Executive Council web site gives further information on course (<http://www.rlec.org/>)

The Ministry of Industry and Information Technology of the People's Republic of China web site gives further information on courses (<http://www.miit.gov.cn/n11293472/index.html>)

APPENDICES

APPENDIX 1 QUESTIONNAIRE

Dear Ladies/Gentlemen:

Thank you for sparing some time to complete this questionnaire. I am a graduate student of the World Maritime University, conducting Research on Decision-making on Take-back Modes in Reverse Logistics for End-of-Life Electronic Products. The questionnaire doesn't involve any business secrets or personal privacy. All information collected for this research study will be kept confidential. Please use your judgment for filling out the tables based on your analysis and opinions.

The following concepts will assist you in completing this brief questionnaire.

Reverse logistics refers to the process of commodity flow from the consumer back to the manufacturer. It includes returned and waste material logistics. Returned logistics is the flow of rejected goods along with packaging containers from the demand-side to supply-side. Waste material logistics means the flow of EOL products after recycling, sorting, disposing, transportation and inventory being sent to a disposal center.

Reverse logistics for EOL electronic products is a recycling and disposing process when e-products leave the consumer market at their mid and later stage of life cycle. This approach embodies social and economic benefits.

Please complete the following tables:

The evaluation method: Please insert into the appropriate column in each table a value number from 1 through to 9. A bigger number indicates the factor C_i is relatively more important than other factors for a specific aspect. The numerical value is not an absolute evaluation to certain indicator rather it offers a relative comparison.

Table 1

Factors	Goal	Decision-making on Take-back Modes in Reverse Logistics for EOL Electronic Products
Financial Indicator		
Service Indicator		
Flexibility Indicator		
Growth Indicator		

Explanation:

Evaluation Method: The relative importance of four indicators to decision-making on take-back modes (1, 2, 3, ..., 9) (from low to high).

Financial Indicator: The cost, investment and profit of recycling and disposing the EOL electronic products.

Service Indicator: The customer satisfaction, service scopes and convenience for recycling EOL electronic products.

Flexibility Indicator: Emergency-dealing ability of Reverse logistics for EOL electronic products for any changes. Therefore, it's essential to provide forecasting function for prompt and correct adjustments when changes occur. The flexibility indicator includes anti-risk ability, information feedback and forecasting ability.

Growth Indicator: The growth of Reverse Logistics system for EOL electronic products. Such as staff overall quality, external communication skills, management of

Reverse Logistics.

Table 2

Factors	Indicator	Financial Indicator
Investment		
Cost		
Profit		

Explanation:

Investment: The investment in recycling facilities and equipments. It mainly includes the construction of reclaim & disposal center, remanufacturing plant etc.

Cost: The cost of RL is an aspect that can not be ignored. Several operating costs involved like recycling cost, repairing cost, recirculation cost, etc.

Profit: The adoption of Reverse Logistics service can reduce the material costs and increase profits.

Table 3

Factors	Indicator	Service Indicator
Customer Satisfaction		
Service Scopes		
Convenience		

Explanation:

Customer Satisfaction: The customer appraisals after experienced Reverse Logistics service for EOL electronic products.

Service Scopes: Services scope refers to different kinds of services provided by RL for EOL e-products. It mainly includes recycling, demolition, testing, sorting and disposing.

Convenience: The convenient degree of RL service for EOL e-products provided such as recycling, demolition and others for the customers.

Table 4

Factors	Indicator	Flexibility Indicator
Anti-risk Ability		
Information Feedback Ability		
Forecasting Ability		
Disposing Ability		

Explanation:

Anti-risk Ability: The characteristics of Reverse Logistics for EOL electronic products like dispersion, slowness and uncertainty causing the implementation of reverse logistics face various risks. Here, the anti-risk ability means to appraising ability of system to reduce risks.

Information Feedback Ability: The timeliness feedback and accuracy of information.

Forecasting Ability: Forecasting of the uncertainty of demand and period of Reverse Logistics for EOL electronic products.

Disposing ability: It can be measured by maximum disposing capacity and level of Reverse Logistics for EOL electronic products. The maximum disposing capacity means the volume of EOL electronic products can be disposed at the same time. Disposing level means the level of EOL electronic products equipment.

Table 5

Factors	Indicator	Growth Indicator
Environmental Protection Level		
Staff Overall Quality		
Management Level of Reverse Logistics		
External Communication Skills		

Explanation:

Environmental Protection Level: The ability of dealing with hazardous substances and promoting environmental protection. It not only link with the advanced disposal equipment and disposing capacity, but also with awareness of environmental protection.

Staff Overall Quality: It means technical level and business knowledge of the staffs engaged in Reverse Logistics for EOL electronic products.

Management Level of RL: Advanced management knowledge of Reverse Logistics, the effective monitoring of Reverse Logistics operation, the quality of staff, and number of professionals.

External Communication Skills: RL is different from forward logistics, its development is driven by the policies and regulations and it is very important to the sensitivity and the execution ability.

Table 6

Factors	Modes	Self-running Mode	Pooled Mode	Third-party Mode
Investment				
Cost				
Profit				
Customer Satisfaction				
Service Scopes				
Convenience				
Anti-risk Ability				
Information Feedback Ability				
Forecasting Ability				
Disposing Ability				
Environmental Protection Level				
Staff overall quality				
Management Level of Reverse Logistics				
External Communication Skills				

Explanation:

Evaluation method: The relative importance of various factors to three different modes: Self-running Mode, Pooled Mode and Third-party Mode (1, 2, 3, ..., 9) (low to high). For example:

Factor \ Modes	Self-running Mode	Pooled Mode	Third-party Mode
Investment	7	5	2

Self-running Take-back Mode: Each electrical and electronic enterprise establishes an independent Reverse Logistics system to manage and recycle of EOL electronic products business to meet their development needs.

Pooled Take-back Mode: Enterprises producing the similar products cooperate with each other or make joint investment to set up pooled mode in Reverse Logistic for EOL electronic products (including establish pooled recycling center and disposing plant of EOL electronic products). The main function of this system is to provide service to partners.

Third-party Take-back mode: The manufactures consigns all or parts of the EOL electronic products recycle business to a professional Reverse Logistics provider through contractual agreement.

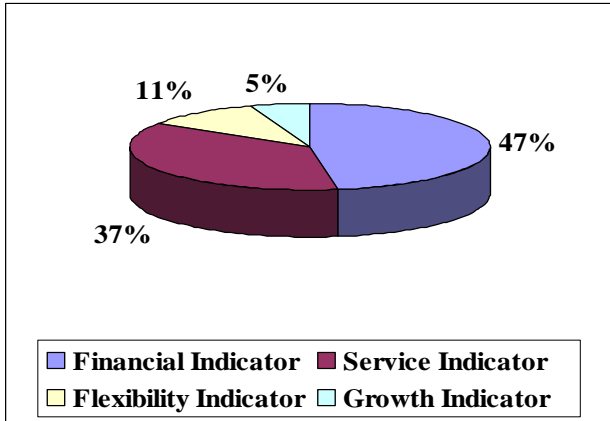
Company: _____

Name: _____

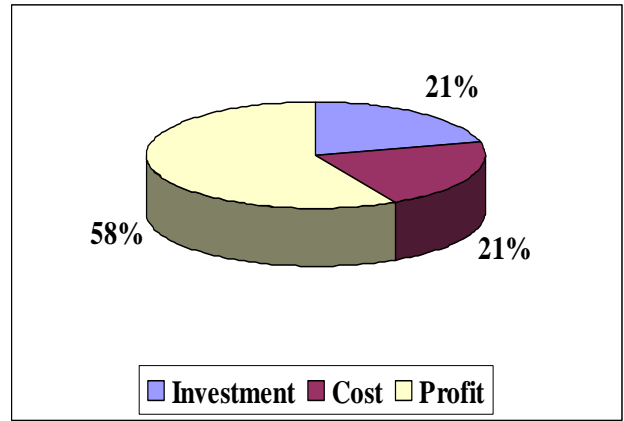
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Thank you sincerely for your support!

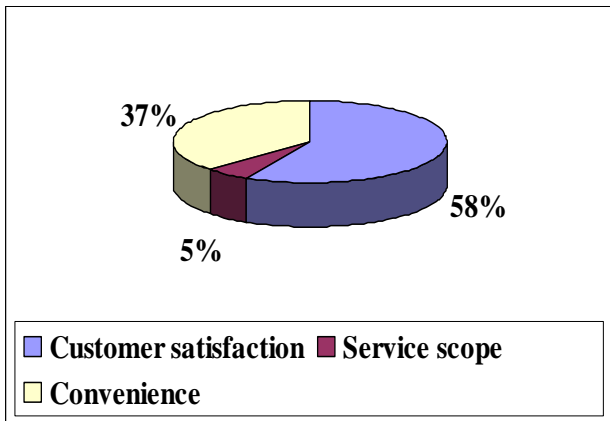
APPENDIX 2 QUESTIONNAIRE RESULT



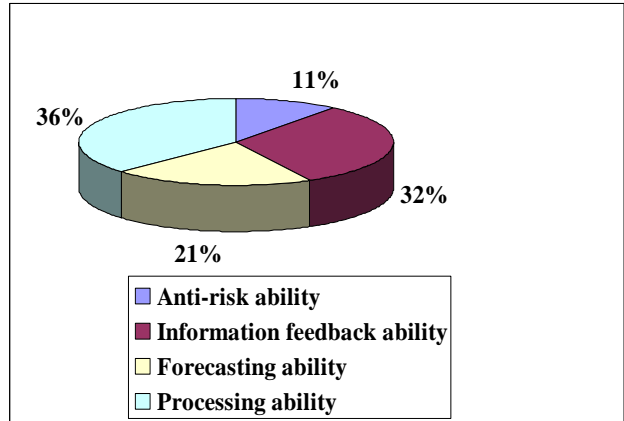
Goal Level



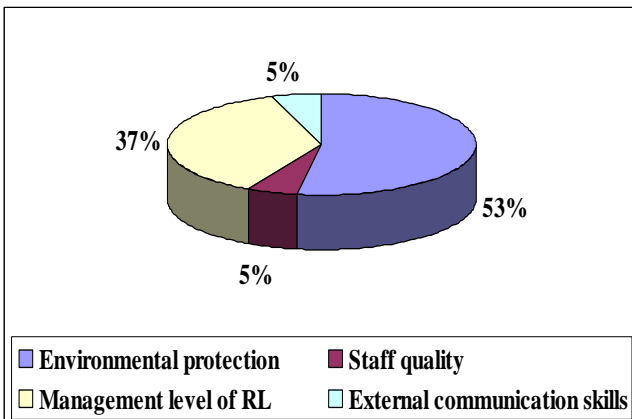
Finance Indicator C_1



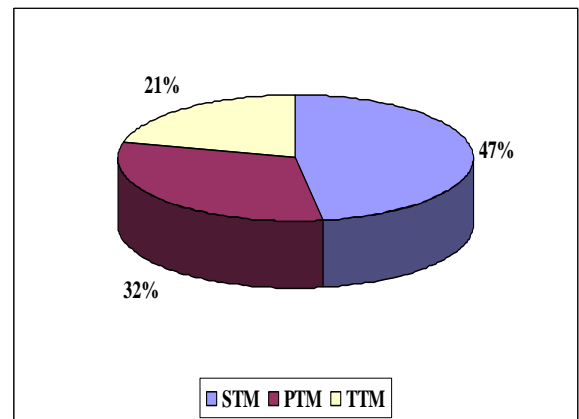
Service Indicator C_2



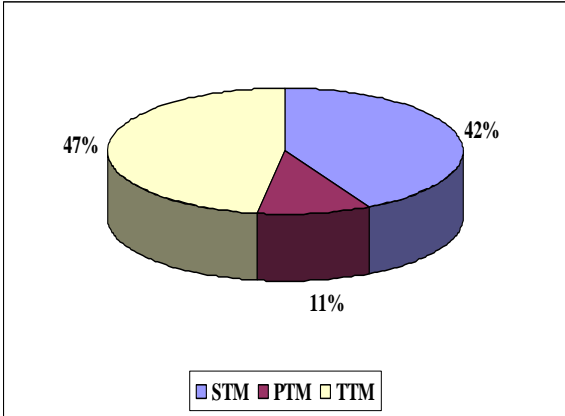
Flexibility Indicator C_3



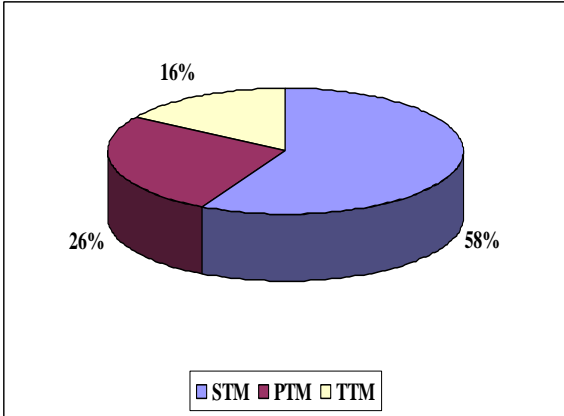
Growth Indicator C_4



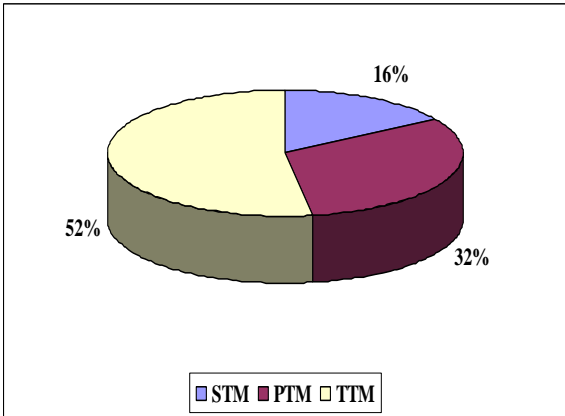
Investment ($S_{11} - A_m$)



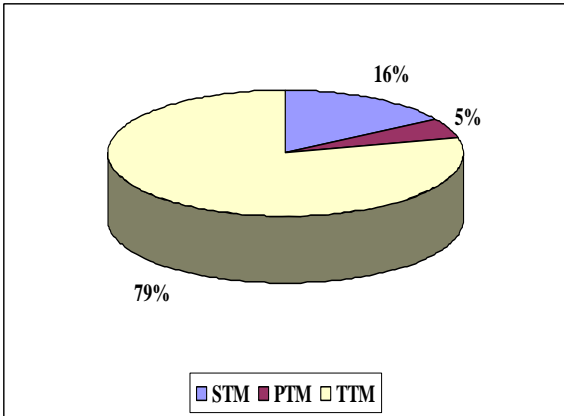
Cost ($S_{12} - A_m$)



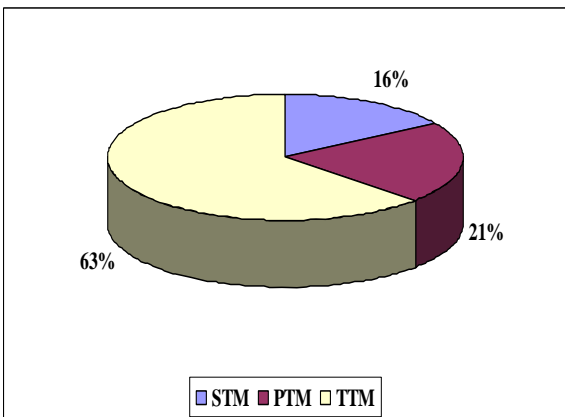
Profit ($S_{13} - A_m$)



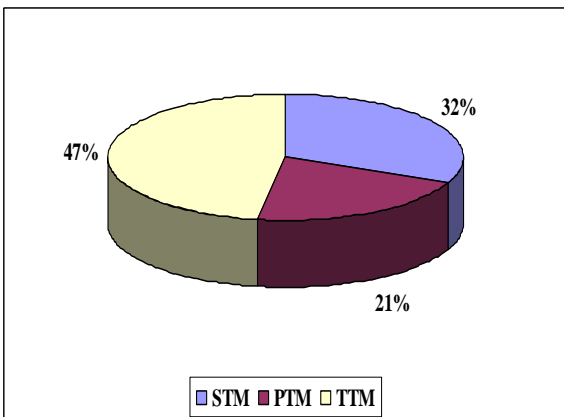
Customer Satisfaction ($S_{21} - A_m$)



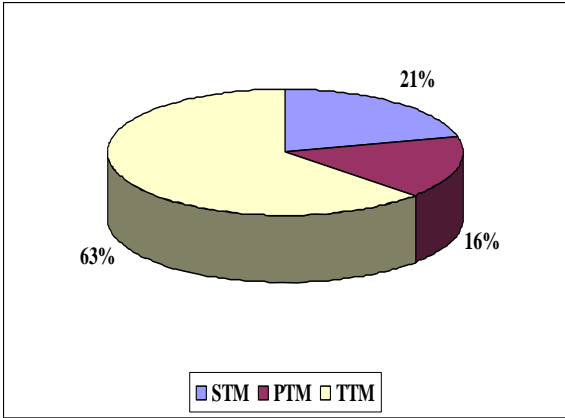
Service Scopes ($S_{22} - A_m$)



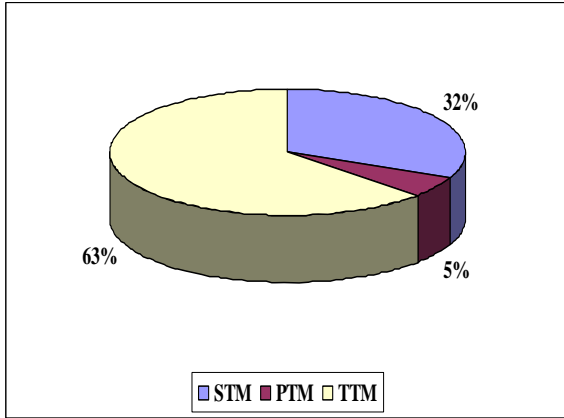
Convenience ($S_{23} - A_m$)



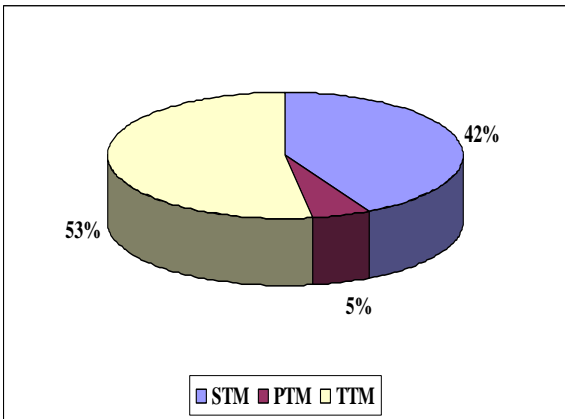
Anti-risk Ability ($S_{31} - A_m$)



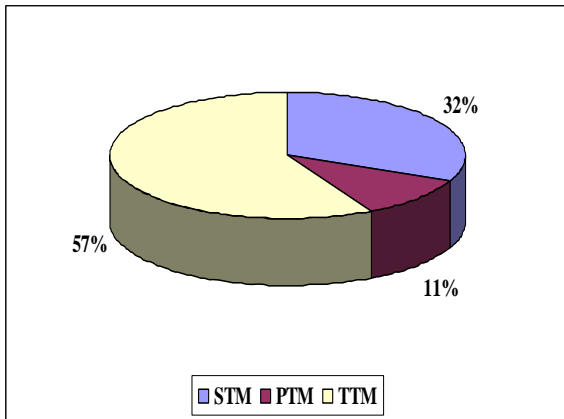
Information Feedback Ability ($S_{32} - A_m$)



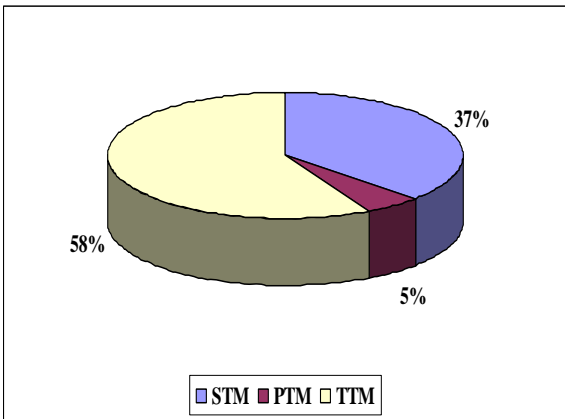
Forecasting Ability ($S_{33} - A_m$)



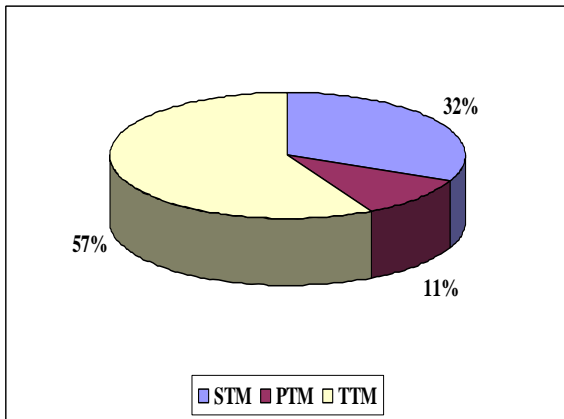
Disposing Ability ($S_{34} - A_m$)



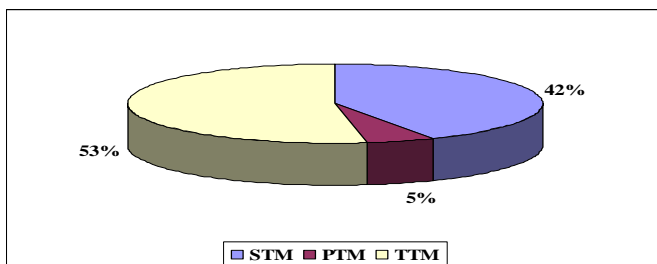
Environmental Protection Level ($S_{41} - A_m$)



Staff Overall Quality ($S_{42} - A_m$)



Management Level of RL ($S_{43} - A_m$)



External Communication Skills
($S_{44} - A_m$)