Abstract number: 015-0605

Abstract title: ANP-based Reverse Logistics Model for e-Waste Management

Author's information:

[1] Hokguan Jo, [2] Seongmin Yang, [3] Taioun Kim, [4] Hongbae Kim*

Department of Industrial & Management Engineering, Kyungsung University
314-79 Daeyeon-3 dong, Nam-gu, Busan, Korea
Telephone: 82-51-663-4720
e-mail; [1] cedric@jeisys.com, [2] smyang@ks.ac.kr, [3] twkim@ks.ac.kr, [4] hbkim@ks.ac.kr

POMS 21st Annual Conference
Vancouver, Canada
May 7 to May 10, 2010

ANP-based Reverse Logistics Model for e-Waste Management

[1] Hokguan Jo, [2] Seongmin Yang, [3] Taioun Kim, [4] Hongbae Kim*

Department of Industrial & Management Engineering, Kyungsung University
314-79 Daeyeon-dong, Namgu, Busan, Korea (608-736)

e-mail; [1] cedric@jeisys.com, [2] smyang@ks.ac.kr, [3] twkim@ks.ac.kr, [4] hbkim@ks.ac.kr

* Corresponding author

Abstract:
The reuse and recycling of products to avoid the disposal of concentrated materials are important issues because environmental problems are inevitable. This activity is highly related with logistics and SCM. With logistics issue, reverse logistics attract a big concern on top of the forward logistics. Reverse logistics deal with all operations related to the reuse of products and materials. Most problems in SCM or logistics area are related to the multiple criteria decision making. In dealing with multiple criteria and multi-attribute problems, Analytic Network Process (ANP) is well suited. It can solve feedback and interdependence relationship which is not possible in Analytic Hierarchy Process (AHP). The purpose of this paper is to analyze the reverse logistic issues regarding the e-waste. E-waste occupies the highest priority in the solid waste area because of short life cycle and frequent model change. A decision making model about reverse logistics for used cellular is constructed and analyzed based on ANP model.

Keywords: ANP, reverse logistics, remanufacturing, used cell phone

1. INTRODUCTION

The concern and management of electronic waste (e-waste) is emerging as a global environmental issue due to the short life cycle from fast model change, increased consumption, and hazardous materials in the product. This happens regardless of developed or developing countries because new technologies emerge and are transferred so fast. Cell phones are typical products with e-waste problem for their frequent displacement and popular in reuse and recycling market.

Annually the cell phone company introduces more than hundreds new products in the market. Each product has new features and functions. For example, in the 3rd generation (3G) era, the user can communicate not only by voice but also can see the live picture. Recent technology enables the 3G phone to connect mobile internet. This kind of cellular is called the Smartphone. These days, Smartphone is in high demand in the market, because it can combine mobile internet, camera, video, micro browser, mp3, touch screen, Digital Multimedia Broadcasting (DMB) and other functions just in a single cell phone.

The fast developing technology and high rate of model upgrade caused e-waste a big issue. In 2006 more than one billion cell phones were shipped worldwide. However, Nokia (the market leader) recycles just 2 percent of the phones it sells (Greenpeace, 2008). This is very low compared to the 9 percent of PC. To address the rising tide of e-waste, all manufactures must offer free and convenient recycling of their products to all their customers. Where companies are unwilling to do this recycling effort, more tough legislation is needed to ensure electronic products are safely recycled.

Decision making issues related to the SCM, e-waste or reverse logistics correspond to the Multiple Criteria Decsion Making (MCDM) problem. AHP has been widely adopted to solve MCDM problem. Decision criteria such as quality, cost, delivery, lead-time, service level are used in the AHP model for the supplier selection. AHP is a clear and simple method for multi-attribute decision making. However, independence is assumed among the decision attributes in the hierarchy. Saaty proposed an ANP (Analytic Network Process) as a more general form of AHP (Saaty, 2001; 2005). An ANP incorporates feedback and interdependent relationships among decision attributes and alternatives. Lee and Oh (2008) proposed a strategic decision making framework for reverse logistics using ANP. They adopted 5 clusters, 23 components, and 2 alternatives for a strategic reverse logistics model.

The purpose of this paper is to analyze e-waste and reverse logistics issues and decision parameters. Multi-criteria decision making problem is constructed and ANP model is applied to solve the problem. Section 2 describes reverse logistics and waste management issues. Section 3 proposes ANP model and supermatrix structure. Section 4 demonstrates ANP steps to implement reverse logistics. As an application domain, used cell phone is adopted because it suits well for the reverse logistics and e-waste issues. Section 5 follows with conclusions.

2. WASTE MANAGEMENT and Cell Phone Life Cycle

2.1 Waste Management

Waste management is the collection, transport, processing, recycling or disposal of waste materials. It is usually related to the materials produced by human activity, and is generally undertaken to reduce their effect on health and the environment. Waste management is also carried out to recover resources from the waste materials. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

Their practices differ between developed and developing countries, between urban and rural areas, and between residential and industrial areas. The types of waste management are landfill, incineration, reuse, recycle, physical reprocessing, and export. They will be discussed in the following.

(1) Landfill

According to the US EPA, more than 4.6 million tonnes of e-waste ended up in US landfills in 2000. Toxic chemicals in electronics products can leach into the land over time or are released into the atmosphere, impacting nearby communities and the environment. In many European countries, regulations have been introduced to prevent electronic waste being dumped in landfills due to its hazardous content. However, the practice still continues in many countries. In Hong Kong for example, it is estimated that 10-20 percent of discarded computers go to landfill.

(2) Incineration

Incineration is a waste treatment technology that involves the combustion of organic materials and/or substances. This releases heavy metals such as lead, cadmium and mercury into the air and ashes. Mercury released into the atmosphere can be bio-accumulated in the food chain, particularly in fish - the major route of exposure for the general public. If the products contain PVC plastic, highly toxic dioxins and furans are also released.

(3) Reuse

Reuse is a good way to increase a product's lifespan. Many old products are exported to developing countries. Although the benefits of reusing electronics in this way are recommendable, this process causes serious problems because the old products are dumped after a short period of use in areas that are unlikely to have hazardous waste facilities.

(4) Recycling

Recyling refers to the reuse or recover of materials that would normally be considered waste. There are a few different methods of recycling such as: physical reprocessing, biological reprocessing, and energy recovery. People are always looking for new ways as well to recycle materials because of the constant issues we are having with waste in our environment.

Although recycling can be a good way to reuse the raw materials in a product, the hazardous chemicals in e-waste can harm workers in the recycling yards, as well as their neighboring communities and environment. In developed countries, electronics recycling takes place in purposely-built recycling plants under controlled conditions. In many EU states, for example, plastics from e-waste are not recycled to avoid brominated furans and dioxins being released into the atmosphere. In developing countries however, there are not such controls. Recycling is done by hand in scrap yards, often by children.

The most common consumer products recycled include aluminum beverage cans, steel food and aerosol cans, HDPE and PET bottles, glass bottles and jars, paperboard cartons, newspaper, magazines, and cardboard.

(5) Export

E-waste is routinely exported from developed countries to developing countries, often in violation of the international law. Inspection results from 18 European seaports in 2005 showed that 47 percent of waste destined for export, including e-waste, was illegal. In the UK alone, at least 23,000 metric tonnes of undeclared or 'grey' market electronic waste was illegally shipped in 2003 to the Far East, India, Africa and China. In the US, it is estimated that 50-80 percent of the waste collected for recycling was exported in this way.

2.2 Life-Cycle of Cell Phone

Similar to other electronics products, making cell phones and its parts use natural resources and energy, which can potentially impact air, land, and water. The life cycle of cell phone consist of several phases.

The first phase of a cell phone life cycle is the material extraction in order to prepare necessary material. A cell phone is composed of many types of materials. In general, the handset consists of 40% metals, 40% plastics, and 20% ceramics and trace materials. The major components of cell phone are consisted of housing, Printed Wiring Board (PWD), Liquid Crystal Display (LCD), rechargeable battery, antenna, keypad, speaker, microphone, and connections between components.

. The disassembled components of a cell phone are shown in Figure 1.

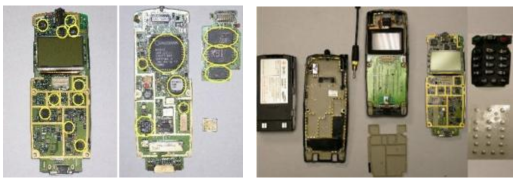


Figure 1. Disassembled components of a cell phone

The second phase is manufacturing process. Products are made in factories and require much energy. Also manufacturing process may produce pollution. In cell phone the plastics and fiberglass are used to make the basic shape of the circuit board, which is then coated with gold plating. The board is also composed of several electronic components, connected with circuits and wires (primarily made of copper) that are soldered to the board and secured with protective glues and coatings. LCD**s** are manufactured by sandwiching liquid crystal between layers of glass or plastic. Batteries consist of two separate parts, called electrodes, made from two different metals. A liquid substance, called electrolytes, touches each electrode.

The third phase is packaging and transportation. Transportations by plane, truck, or rail require the use of fossil fuels for energy, which can contribute to global climate change. Packaging consumes valuable natural resources, such as paper (from trees), plastic (from crude oil in the earth), aluminum (from ore), or other materials. Some packaging, however, can be made from recycled materials.

The fourth phase is the use of cell phone. The life of cell phone can be extended taking care of it, protecting it from damage by storing it in a case, avoiding dropping it, and keeping it out of extreme heat and cold and away from water and other liquids. After the end of life, the cell phone moves into the end of life phase.

The final phase is the end of life cycle. It is divided into three cases, which are reuse, recycling and disposal.

Reuse: For the reuse case, many organizations including recyclers, charities, and electronics manufacturers gather working cell phones and offer them to schools, community organizations, and individuals in need. Reuse gives people, who could not otherwise afford them, free or reduced cost access to new phones and their accessories. Plus, it extends the useful lifetime of a phone. Usually in this reuse alternative, the cell phones from developed country like United Stated or Europe are shipped to the developing countries like China or India, and are resold again there. This reuse phase can extend the life of cell phones longer. The product can restart a useful lifecycle as a new phase.

Recycle: Today, many stores, manufacturers, and recycling centers accept cell phones for recycling. While some electronics recyclers only accept large shipments, communities, schools, or groups can work together to collect used cell phones for shipment to electronics recyclers. Some rechargeable batteries can also be recycled, as several retail stores and some communities have started collecting them. When rechargeable batteries are recycled, the recovered materials can be used to make new batteries and stainless steel products.

Disposal: In the year 2005, the rate at which cell phones are discarded is predicted to exceed 125 million, which resulted in more than 65,000 tons of waste. Cell phones that are thrown in the trash end up in landfills (buried in the ground) or incinerators (burned). Because cell phones contain metals, plastics, chemicals, and other potentially hazardous sub-stances, it is very dangerous for the environment. When the recycle phase brings the cell phone material back to the manufacturing phase, the result can be new cell phone or other product from the recycled material. For example, recycled case from used cell phone which is plastic can be made into a bench in the park. One of the tactics for end users to recycle their old cell phones is called "take-back program." Many cell phone manufacturers and service providers offer the take-back program. The life cycle of cell phone is shown in Figure 2.

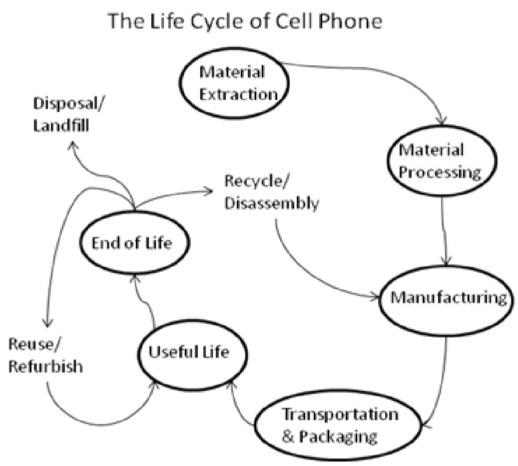


Figure 2. The life cycle of cell phone

2.3 Reverse Logistics

The decision making issues in Supply Chain Management are related with reverse logistics. Reverse logistics stands for all operations related to the reuse of products and materials. It is "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 or proper disposal. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics.

The reverse logistics covers such concepts as green logistics, product returns, repairs, and refurbishment, etc. Reverse logistics operations can be very complicated to manage, since the activities involved tend to be changed frequently. For example, reverse logistics activities need to support repair service activities such as: storage and warehousing; collection and sorting; substitution; transportation and distribution; disposal; repair and remanufacturing; and recertification. In addition, demand is difficult to predict, making product and information flows quite challenging to manage (Amini et al. 2005).

3. ANALYTIC NETWORK PROCESS

The basic assumption of AHP is the condition of functional independence of the upper part, or cluster, of the hierarchy, from all its lower parts, and from the criteria or items in each level. Saaty has suggested the use of AHP to solve the problem of independence among alternatives or criteria, and the use of ANP to solve the problem of dependence among alternatives or criteria. Strategic decisions in supply chain intelligence using ANP was dealt in Raisinghani, and Meade (2005). A comparison of AHP and ANP in the SCM is proposed in Nakagawa and Sekitani (2004). Yuksel and Dagdeviren (2007) adopted ANP in SWOT analysis for a textile firm case. Applying an ANP for the supplier selection in an electronic firm is given in Gencer and Gurpinar (2007).

The structural difference between AHP and ANP is illustrated in Figure 3. A hierarchy has a goal or a source node or cluster. It also has a sink node or cluster representing the alternatives of the decision. Unlike a hierarchy, a network spread out in all directions and its clusters of elements are not arranged in a particular order. Nodes of the network represent components of the system; arcs denote interaction between them, where the directions of arcs signify directional dependence. For example, X ->Y means that the elements of a component Y depends on component X. Interdependency between two clusters, termed outer dependence, is represented by a two-way arrow. Inner dependencies among the elements of a cluster are represented by looped arcs.

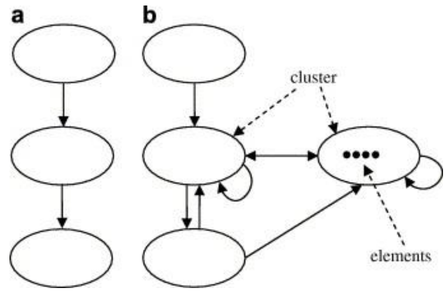


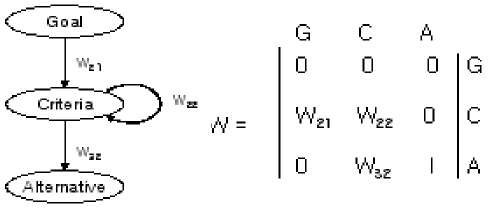
Figure 3. Structural difference between a hierarchy and a network:
(a) a hierarchy; (b) a network

Assume that there is a system of N clusters or components, where the elements in each component interact or have an impact on the other elements. The component h, denoted by C_h, h = 1,….,m, has n_h elements, that are represented by e_{h1}, e_{h2}, …, e_{hmk}. A priority vector derived from paired comparisons in a usual way represents the impacts of a given set of elements in a component on another element in the system. When an element has no influence on another element, its influence priority is assigned as zero. A supermatrix is composed of the priority vectors derived from pairwise comparison matrices. An example of supermatrix is shown in Figure 4. The Components C_i alongside the supermatrix include all the priority vectors derived for nodes that are parent nodes in the C_i cluster.

$$W = \begin{array}{cc} & \begin{array}{ccc} C_1 & C_2 & C_N \\ e_{11}\; e_{12} \cdots e_{1n1} & e_{21}\; e_{22} \cdots e_{2n2} & e_{m1}\; e_{m2} \cdots e_{mnm} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \cdot \\ e_{1n1} \end{array} \\ \cdot & \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \cdot \\ e_{2n2} \end{array} \\ \cdot & \\ C_m & \begin{array}{c} e_{m1} \\ e_{m2} \\ \cdot \\ e_{mnm} \end{array} \end{array} & \left[\begin{array}{ccc} W_{11} & W_{12} & W_{1m} \\ W_{21} & W_{22} & W_{2m} \\ : & : & : \\ W_{m1} & W_{m2} & W_{mm} \end{array} \right] \end{array}$$

Figure 4. Supermatrix of ANP (Source: Saaty, 2005)

Multicriteria decision making problem can be represented as a hierarchical structure composed of goal, criteria, and alternatives. If interdependence among criteria is assumed, it is represented as ANP model. Figure 5(a) shows an ANP model with dependence among criteria. W21 represents influence of goal into criteria. W22 corresponds to the dependence of criteria themselves. W32 means the influence of criteria into alternative. This structure can be represented as Supermatrix as shown in Figure 5(b).



(a) Supermatrix represenatation (b) Network represented in matrix W
Figure 5. Supermatrix formation

4. ANP STEPS FOR REVERSE LOGISTICS

Steps for implementing ANP model are proposed as seven steps. The steps are problem definition and hierarchy analysis, ANP model construction, supermatrix formation, finding eigenvectors from pairwise comparison, fill in supermatrix with unweighted one, find the steady state of the supermatrix, and result analysis. The details in each step are given as the following.

Step 1. Problem definition and hierarchy analysis

The first step is to define the problem and analyze the hierarchy of the problem. In this step, decision criteria are identified and their relationships are analyzed. For the reverse logistics model, three perspectives are assumed for the main decision criteria. They are customer perspective, manufacture perspective and government perspective.

As sub-criteria for customer perspective, customer satisfaction, price/cost and quality are suggested. As sub-criteria for manufacture perspective, green product, life cycle and information technology are adopted. As sub-criteria for government perspective, regulations, waste reduction and product recovery option are assumed. For the performance index, remanu-facture domestic, third-party remanufacture and third-party import are assumed. Figure 6 shows the hierarchy of decision variables for SCM performance

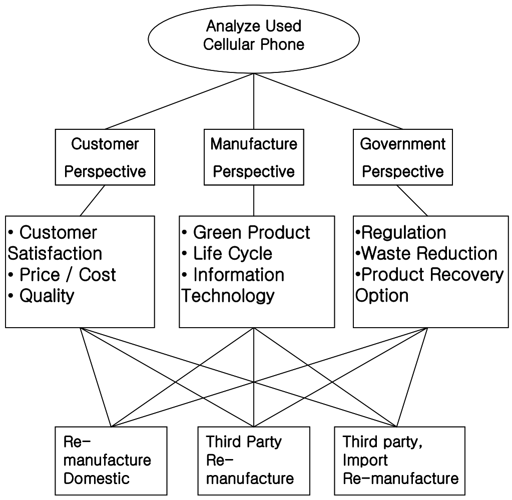


Figure 6. Decision Variables for reverse logistics

Design parameters for the ANP model are assumed as the following:

(1) Customer perspective (CP): This customer is the user of used cell phone.

- Customer satisfaction (CS): from the user of the used cell phone, how high the expectation of the customer satisfaction of the used phone.
- Price/Cost (PC): price consideration of used phone; get the price range from market research.
- Quality (QL): level of the quality of used cell phone.

(2) Manufacturing perspective (MP): from the manufacturing viewpoint, what kind of product will be produced to fulfill the requirements.

- Sustainable Green Product (SG): design a product which is good for environment, can be recycled, remanufactured, reused or refurbished.
- Life Cycle Product (LC): making of a life cycle product. When the life cycle time is due, the user should change the phone.
- Information Technology (IT): How IT is utilized in the manufacturing environment in the SCM, reverse logistics, or waste management.

(3) Government perspective (GP): GP is related to the government or environmental issues to control the electronic waste.

- Regulations (RG): Regulations for phone user. For example, regulation for underage user, regulation for manufacturing restrictions.

- Waste Reduction (WR): The government's project for reducing the electronic waste.
- Product Recovery Option (PR): When a company releases a new model, and a user wants to change with new one, the company takes the old model and sell the new product with discounted price.

This paper suggests three types of reverse logistic alternatives which can be different by the company who does the re-manufacturing.

- Re-Manufacturing (REM): The manufacturer takes the core elements, recycle, recovery, or refurbish by own country and sale again within inside the country.
- Third Party Remanufacturing (TPR): A third party manufacturer collects and remanufactures the used phone in the same country. Product sale may happen domestic or outside of the country.
- Third country Import and Remanufacturing TIR): A company in a third country imports the used phone, and remanufacture and sale in their countries.

Step 2. ANP model construction

In step 2, ANP model is constructed considering the dependency and inter-relationship. In this step, the interactions between and within clusters and elements are determined. The ANP model with its control hierarchy is provided in Figure 7.

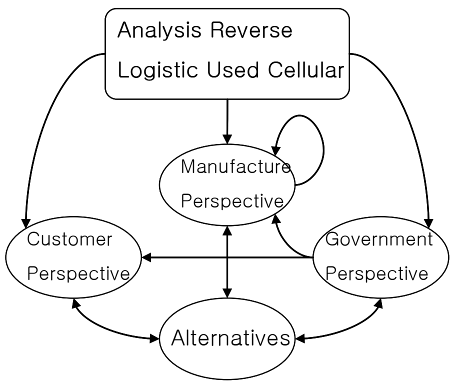


Figure 7. ANP control hierarchy for reverse logistics

Step 3. Supermatrix formation

Supermatrix is constructed according to the ANP model built in step 2. The supermatrix structure which follows the same structure given in Figure 7 is shown as Figure 8. The detail parameter for each cluster of the supermatrix can be referred in Table 3. In the supermatrix, Wij means the sub-matrices in which cluster i depends on cluster j.

$$W = \begin{array}{c} \\ C \\ M \\ G \\ A \end{array} \begin{array}{cccc} C & M & G & A \\ 0 & 0 & W13 & W14 \\ 0 & W22 & W23 & W24 \\ 0 & 0 & 0 & W34 \\ W41 & W42 & W43 & 0 \end{array}$$

Figure 8. Supermatrix for Reverse Logistic Performance

(C: Customer, M: Manufacturer G: Government, A: Alternative)

Step 4. Find eigen vectors from pairwise comparison

For each cluster, eigen vector (e-vector) is calculated from a pairwise comparison. Table 1 represents criteria weights of three alternatives with respect to the customer satisfaction (CS) in customer perspective (CP). For all columns except the zero elements, e-Vector is calculated. The value of e-Vector in Table 1 is found in the first column of alternative rows in Table 2.

Table 1. Criteria (CS in Customer Perspective) weights with respect to three alternatives

CP(CS)	REM	TPR	TIR	e-Vector
REM	1	3	3	0.60
TPR	0.33	1	1	0.20
TIR	0.33	1	1	0.20

Step 5. Fill in supermatrix with unweighted one

Using the eigen vectors from the pairwise comparison for each criteria, the cell of supermatrix is constructed as Table 2. The cells with zero correspond to those clusters which do not have interactions with each other. Each column consists of several clusters. In each cluster, the sum of e-vector sums to 1. Thus, the sum of all values in each column may exceed 1. For each column, normalize the value in the same column that column-sum is 1 (named “column-stochastic”). Table 3 shows the normalized supermatrix

Table 2. Unweighted supermatrix for Reverse Logistic Performance using ANP

		Customer Perspective			Manufacture Perspective			Government Perspective			Alternatives		
		CS	PC	QL	SG	LC	IT	RG	WR	PR	REM	TPR	TIR
Customer Perspective (CP)	CS							0.22	0.12	0.12	0.16	0.14	0.15
	PC		0			0		0.46	0.32	0.20	0.54	0.53	0.30
	QL							0.32	0.56	0.68	0.30	0.33	0.55
Manufacture Perspective (MP)	SG				0.72	0.26	0.36	0.67	0.72	0.62	0.63	0.23	0.26
	LC		0		0.12	0.10	0.44	0.24	0.18	0.25	0.22	0.65	0.64
	IT				0.16	0.64	0.19	0.09	0.10	0.13	0.15	0.12	0.10
Government Perspective (GP)	RG										0.30	0.07	0.12
	WR		0			0			0		0.58	0.28	0.32
	PR										0.12	0.65	0.56
Alternatives	REM	0.60	0.12	0.11	0.64	0.12	0.62	0.20	0.20	0.69			
	TPR	0.20	0.32	0.31	0.10	0.32	0.25	0.40	0.10	0.24		0	
	TIR	0.20	0.56	0.58	0.26	0.56	0.13	0.60	0.70	0.07			

Table 3. Normalized supermatrix for Reverse Logistic Performance using ANP

		Customer Perspective			Manufacture Perspective			Government Perspective			Alternatives		
		CS	PC	QL	SG	LC	IT	RG	WR	PR	REM	TPR	TIR
Customer Perspective (CP)	CS							0.07	0.04	0.04	0.05	0.05	0.05
	PC		0			0		0.15	0.11	0.07	0.18	0.18	0.10
	QL							0.10	0.19	0.23	0.10	0.11	0.18
Manufacture Perspective (MP)	SG				0.36	0.13	0.18	0.22	0.24	0.21	0.21	0.08	0.09
	LC		0		0.06	0.05	0.22	0.08	0.06	0.08	0.07	0.22	0.21
	IT				0.08	0.32	0.10	0.03	0.03	0.04	0.05	0.04	0.03
Government Perspective (GP)	RG										0.10	0.02	0.04
	WR		0			0			0		0.19	0.09	0.11
	PR										0.04	0.22	0.19
Alternatives	REM	0.60	0.12	0.11	0.32	0.06	0.31	0.07	0.07	0.23			
	TPR	0.20	0.32	0.31	0.05	0.16	0.12	0.13	0.03	0.08		0	
	TIR	0.20	0.56	0.58	0.13	0.28	0.07	0.13	0.23	0.02			

Step 6. Find the steady state of the supermatrix

The supermatrix which is constructed in step 5 is an unweighted one. Each column consists of eigenvectors. The element in the supermatrix is a column stochastic which means the sum of a column sums to one. The unweighted supermatrix is multiplied by the priority weights from the clusters, which yields the weighted supermatrix. By multiplying the weighted supermatrix by itself until the supermatrix’s row values converge to the same value for each column of the matrix, the steady state is obtained. Table 4 represents supermatrix in a steady state. All the column values converge to a same value.

Table 4. Supermatrix for Reverse Logistic Performance with a steady state in 32nd iterations

		Customer Perspective			Manufacture Perspective			Government Perspective			Alternatives		
		CS	PC	QL	SG	LC	IT	RG	WR	PR	REM	TPR	TIR
Customer Perspective (CP)	CS	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	PC	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	QL	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Manufacture Perspective (MP)	SG	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	LC	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	IT	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Government Perspective (GP)	RG	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	WR	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	PR	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Alternatives	REM	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	TPR	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	TIR	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Step 7. Result analysis

The result is analyzed and suggestions can be made. From the steady state data of the supermatrix, the alternative with the highest priority can be chosen as the most important alternative for the reverse logistics performance measure. Table 4 represents the steady state of supermatrix after 32nd iterations. Among the alternatives, TIR gives the highest priority, and then REM and TPR order. This corresponds to the priority sequence of third country import and remanufacture, remanufacture by the original company, and third-party remanufacture. This result agrees with our data analysis that used electronic products are exported to third countries and remanufactured over there in many cases. Next important option is to recycle or remanufacture used cell phones after collecting and disassembling them into component pieces by the manufacturer.

5. CONCLUSIONS

In this paper, an ANP model is adopted and applied for analyzing alternatives of used cell phone. As decision criteria, customer perspective, manufacturing perspective, and government perspective are adopted. An ANP-based framework is proposed to analyze reverse logistics and e-waste issues. A supermatrix is constructed using the priority vectors. The priority vectors are the principal eigenvectors of the pairwise comparison matrices. After normalizing the supermatrix, the normalized supermatrix is multiplied by itself until a steady state is reached. The steady state results from the supermatrix correspond to the priority weights among three alternatives. Three alternatives are remanufacturing in the original domestic manufacturer (REM), third-party remanufacturing (TPR), and third-party import and remanufacturing (TIR). The result shows priority weights are 0.12, 0.09 and 0.15 for REM TPR, and TIR.

An important finding from the steady state supermatrix is that the ANP model represents the relationship between the decision criteria and alternatives. It shows how the decision criteria affect the weights of the alternatives and also the alternatives influence the decision criteria vice versa.

The growing number of e-waste from retired product requires environmentally sound recycling processes. Diverse reverse logistics models have to be developed to fit the various recycling patterns according to the product types.

ACKNOWLEDGEMENT

This research was finically supported by the Ministry of Education, Science Technology (MEST) and Korea Institute for Advancement of Technology (KIAT) through the Human Resource Training Project for Regional Innovation.

References

Gencer, C. and Gurpinar, D. (2007), Analytic Network Process in Supplier Selection, *Applied mathematical modeling*, **31**, 2475-2486.

Greenpeace (2008) http://www.greenpeace.org/international/news/e-waste-toxic-not-in-our-backyard210208

Lee, Y. and Oh, H. (2008), Strategic Decision +Making Framework for Reverse Logistics using Analytic Network Process, *Journal of the Korean Society of Supply Chain Management*, **8**(2), 1-16.

Naksgawa, J. and Sekitani, K. (2004), A Use of Analytic Network Process for Supply Chain Management, *Asia Pacific Management Review*, **9**(5), 783-800.

Raisinghani, M. S. and Meade, L. L. (2005), Strategic Decisions in Supply-Chain Intelligence using Knowledge Management: an Analytic-Network-Process Framework, *Supply Chain Management: An International Journal*. **10**(2), 114-121.

Ravi, V., Shankar, R. and Tiwari, M.K. (2005) Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach, *Computer & Industrial Engineering* **48**(2005), 327-356

Saaty, Thomas L., Vargas, Luis G. (2001), *Model, Methods, Concept &Application of Analytic Hierarchy Process*, Kluwer Academic Publishers.

Saaty, , Thomas L. (2005), *Theory and Application of the Analytic Network Process*, RWS publications.

Sanjay, J. and Ravi, S. (2007) Selection of logistics service provider: An analytic network process (ANP) approach, *The International Journal of Management Science*, **35**(2007) 274-289

Yuksel, I. and Dagdeviren, M. (2007), Using ANP in a SWOT analysis – A Case Study for a Textile Firm, *Information Sciences*, 177, 3364-3382.