A Monitoring System Architecture and Calculation of Practical Recycling Rate for End-of-Life Vehicle Recycling in Korea

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End-of-life vehicles (ELVs) are important recycling sources, and there are several recycling stages, including dismantling, shredding, and treatment of the automotive shredder residues (ASR). The legal recycling rate should be at least 95% by 2015. To achieve this, a unified system to monitor the recycling of ELV parts and to calculate practical recycling rates is required. This paper describes a web-based monitoring system equipped with the databases for a standard parts list, dismantling & recycling, and standard recycling rate. The system effectively collects dismantling & recycling data, and it calculates a part's recycling rate based on the collected data. It also facilitates the estimation of a reasonable recycling rate for unreported parts by utilizing a standard recycling rate and respective ratio of treatment. The system is designed and implemented in a Windows® environment, as part of a research project sponsored by the Ministry of Environment of Korea.

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1. Introduction

It is an important issue to properly recycle end-of-life vehicles (ELVs), which are composed of various kinds of materials such as ferrous and non-ferrous metals, plastics, glass, rubber, etc. Roughly 75% of an ELV by weight consists of metallic material, so ELVs should be recycled as much as possible. It was reported that on average, 670,000 waste vehicles per year were dismantled during the period of 2008 to 2010 in Korea.¹

The EU (European Union) Directive 2000/53/EC² as well as Commission Decision 2005/293/EC³ have imposed a basic guideline for ELV recycle monitoring and recycling rate. Regulatory requirements for the ELV recycling based on the 'Act on resources recycling of electric & electronic equipment and vehicles' by Korea's Ministry of Environment will result in law enforcement of reasonable treatment & recycling.⁴ Regulatory requirements will eventually require a 95% recycling rate, including 10% energy recovery by 2015.² The need for a higher recycling rate is growing. Accordingly, many European and Asian countries have investigated and assessed their ELV treatment process to improve material recovery techniques such as

Italy,⁵ the Netherlands,⁶ Germany,⁷ Denmark,⁸ Japan and Taiwan.^{9,10}

Ways to satisfy the requirements of the rather high recycling rate legally as well as technologically include vehicle design for disassembly and dismantling,^{5,12} efficient recycling technologies to yield more material return, and EPR (extended producer responsibility) regulation. As for more material recovery, the treatment of ASR (automobile shredder residue) from which ferrous and non-ferrous metals can be recovered has steadily been studied.^{5,13-16}

In addition, a practical and effective recycle monitoring system should be designed and implemented to check whether the dismantled parts are properly recycled, and to collect recycling data (e.g., recyclers, materials, weight, etc.) for verification of the ELV recycling. As for the recycle of waste electrical and electronic equipment, there is a reporting tool, WF-RepTool,¹⁷ that is used to track all part fractions of WEEE¹⁸ (waste electrical and electronic equipment) until their final use of final disposal, and allows to calculate recycling and recovery rates. But it is rarely found such an integrated and systematic data collecting application for the ELV recycling.

EcoAS is a network network-based official reporting system in Korea,⁶ but it does not encompass all operators, nor does it guarantee

completeness of the input data. In addition, dismantlers and recyclers may report only rough estimates of treatment weight. There are similar reporting systems in Taiwan and Japan,^{9,10} but they seem to have restricted monitoring functionalities. Therefore, a monitoring system that can collect dismantling & recycling data and calculate recycling rates is required.

The practical recycle monitoring system is designed for (1) data maintainability, from dismantling to final treatment; (2) tracing dismantled part usage and weight data throughout the whole recycling process; and (3) practical calculation of the recycling rate of the dismantled ELVs. This research is a part of on-going R&D projects sponsored by the Ministry of Environment, which is developing dismantling facilities and monitoring software.

Section 2 describes the current status of recycle monitoring and the need for an effective monitoring system. The system architecture and data processing are explained in the Section 3, followed by a practical strategy for recycling rate calculation.

2. Current Status and Requirement of ELV Recycling and Monitoring

The dismantling and recycling flow for an ELV can be summarized as follows. A waste vehicle starts the recycling process at a dismantling plant. It is required by law that the dismantler separate designated parts such as refrigerants, fuel, fluid oil, lubricants, tires, airbags, bumper covers, fuel tanks, catalysts, and batteries from the ELV. Then, reusable parts are separated to be sold and reused, and reusable core parts of a component are retreated for use as main parts of new components through remanufacturing. Other detached metallic parts are collected and sent to steel mills (ferrous metal) or smelters (non-ferrous metal) for material recycling. The vehicle shell (hulk) is then shredded, and materials are separated by proper methods, where ASR is further recycled for energy recovery and sent to a landfill. A typical dismantling and recycling process is described in Fig. 1,²⁰ and a sample recycling map after dismantling is illustrated in Fig. 2 based on a field survey in Korea.

The ELV recycling schemes are nearly invariant in countries such as Taiwan, Japan, China, Korea, the USA, and EU countries.^{9,10,21-25} The operators in the scheme include collectors, dismantlers, shredding plants, ASR treatment facilities, recyclers, and dealers of reused and secondary products.⁹ From a monitoring point of view, the ideal

situation involves all operators reporting treatment results (e.g., materials and weight data) regularly and faithfully, but this is difficult to expect due to practical issues. Firstly, it poses a problem of complicated material flow (see Fig. 3) because many operators are involved in the overall recycling process. Secondly, not all operators faithfully report their treatment results, partly because a proper reporting & monitoring system is not available. Therefore, either inexact recycling data would be gathered, or recycling data would be missed.

The Ministry of Environment constructed an official reporting system called EcoAS, which is operated as a regulatory requirement for the dismantlers and recyclers to report their recycled materials and weight data (see Fig. 4). Such reporting systems can be found in other countries like Taiwan.⁹ However, the system does not encompass all recyclers on the ELV recycling routes, and the reported data cannot be confirmed due to incompleteness. For example, the scheme does not include recyclers other than authorized dismantlers, shredders, and ASR operators. This usually leads to a loss of recycling data for the parts collected by unauthorized out-of-network recyclers. Also, information on the separated parts and materials at a dismantling plant may be incorrect or lost, because the data gathering process relies solely on manual

Fig. 1 Typical ELV recycling process

Fig. 2 Sample recycling process

Fig. 3 Complicated recycled material flow

description. Therefore, it is difficult to collect accurate recycling data in the EcoAS, and a new monitoring system is required.

A design is needed for a systematic reporting & monitoring system that can trace the flow of parts and materials from dismantling to final treatment (e.g., part reuse, material recycle, energy recovery), in order to facilitate the accurate calculation of recycling rates for the dismantled ELVs. The purposes of such a system are as follows:

Dismantling data collection at the dismantling plant

Recycling data collection from the secondary recyclers

Calculation and estimation of recycling rate based on the recycled weight data

Generation of reports for the EcoAS system interface

To satisfy the requirements, the following information is necessary:

Waste vehicle part lists with weight and material constituents before dismantling

Part separation data at the dismantling plant

Part transfer data

Part treatment type (e.g., reuse, recycle, disposal) and weight

Considering these specifications, a network-based monitoring system should be designed with data gathering and storage tools to facilitate on-line reporting for the authorized operators. In addition, the system has to properly estimate unauthorized operators' recycling data (e.g., loss of recycling data), for which a practical strategy utilizing standard recycling rate (SRR) data is designed in this research.

Fig. 4 Overview of EcoAS reporting system

Fig. 5 Schematic diagram of the overall monitoring system

3. Monitoring System

3.1 Overall View

The proposed system architecture is a *web-based monitoring system* equipped with a central database for data gathering and storage. A schematic diagram is shown in Fig. 5. The system is composed of a central monitoring system and a dismantler monitoring system. The dismantler monitoring system locally collects and uploads dismantling data to the database of the central monitoring system (see Fig. 6). Also, the part transfer and treatment data are uploaded. The standard part database provides an initial parts list of each vehicle type, which serves as a basis for creating a dismantling worksheet. All authorized operators in the recycling process can access the system and report their recycling results via the network or over the Internet. The recycling rate (RR) for a certain query is calculated based on the collected data. The system operation is described in Section 3.3 in more detail.

The SRR database is designed as a practical methodology for a reasonable estimation of missed recycling data. Section 3.2 describes how to construct and utilize the SRR database.

3.2 SRR Database

The SRR database provides a practical tool to estimate the untraceable part's recycled weight (RW) and recycling rate (RR). Basically, the dismantled parts' recycling result can be obtained through reporting by recyclers. However, the recycling data may not be reported, even when much time has elapsed after dismantling. Presently, there are unauthorized collectors and recyclers who are not obliged to report recycling data. Also, failure to report can even happen with authorized operators (e.g., in the vent that the dismantled parts are not treated yet after some designated time period). To

address this, a '*scenario-based*' RR estimation method is proposed.

The construction and utilization of the SRR database is based on an idea that the RR value per dismantled part depends on recycling methods. In other words, the RR value of a part varies according to how it is treated: reuse (R_a), remanufacture (R_b), material recycle (R_c), energy recovery (R_d), disposal (R_e), etc. (R_f). A plastic bumper, for example, may be reused or remanufactured ($R_a = R_b = 100$), processed and recycled as a resource material for new plastic parts ($R_c = 80$), incinerated for energy recovery ($R_d = 20$), or sent to a landfill ($R_e = 0$). If it is sold for reuse, then its RR is R_a . Note that the numerical values of R_a through R_e for each part of an ELV type are estimated based on the current representative recycling method, and may vary as a result.

It is also considered that the selected treatment method for a dismantled part may vary (i.e. between reuse, recycling, recovery, etc.), which leads to RR variation for a dismantled part. A set of the respective ratio values of treatment methods for a part are adopted to estimate the standard recycling rate: reuse (S_a), remanufacture (S_b), material recycle (S_c), energy recovery (S_d), disposal (S_e), etc. (S_f). An average ratio at which a dismantled part is treated is considered. To determine the ratio values, the treatment ratio values from the input data of authorized recyclers are collected and averaged, starting from certain initial values obtained based on field surveys of representative recyclers (see Fig. 8).

A dismantled part's recycled weight W_r , whose original weight is W_x , can be estimated as follows: $W_r = W_x(S_a R_a + \dots + S_f R_f)$.

3.3 Information Flow and Implementation

3.3.1 Information flow

The overall information flow of the proposed system is depicted in Fig. 9, which is summarized as follows. Fig. 10 shows a schematic of

Fig. 6 Schematic diagram of the dismantler monitoring system

Treatment type	Standard Recycling Rate (%)	Respective ratio of treatment types (%)
Reuse	R_a	S_a
Remanufacturing	R_b	S_b
Recycle	R_c	S_c
Recovery	R_d	S_d
Disposal	R_e	S_e
Etc	R_f	S_f

Fig. 7 Factors for standard recycling rate estimation for a part

Category	Component	Recycler	Used part sales (domestic)	Used part sales (export)	Remanufacture	Recycle	Energy Recovery	Disposal	Etc
Liquid, battery, catalyst	Airbag	-	100					100	explosion
	Fuel	Samsung autos							
	Fluid oil	Sinsung enertech				100			
	Coolant	Sinsung enertech					100		
	Refrigerant	Dongbang tech		10		70	10	100	emanation
Ferrous Metal	Battery	Daesung recycling	10	10	10	70			
	LPG fuel tank	Hando Industry				100			
	Joint, hub, brake	Hando Industry				100			
	Shock absorber, mounting	Hando Industry				100			
	Door, hood, fender, trunklid	Hando Industry				80	10	10	
	wheel(iron)	Hando Industry				100			
	engine assembly	Geumsung recycling				100			
	mission assembly	Geumsung recycling			10	90			
	radiator, condensor	Dongsin recycling				100			
	muffler	Namchun recycling				100			
	other								
	wheel(al)	Andong recycling	10			90			
	alternator	Daesung recycling	10	10	10	70			
	start motor	Daesung recycling	10	10	10	70			
	motor(others)	Ocean recycling			10	90			CIBS
Non-ferrous Metal	cylinder head cover	Geumsung recycling				100			
	bumper back beam	Hando Industry				100			
	wire harness	Munhwa industry				100			
	other								
	fuel tank(pl)					100			CIBS
Plastic	bumper	Hwanhee recycling	20			80			
	dashboard	Hwanhee recycling	20			80			
	lamps	Ocean recycling	20			80			
	interior trims					100			CIBS
	radiator grill					100			CIBS
	Tanks					100			CIBS
	(washer, oil, brake)								
Rubber, Glass, Seat, Electronics, others	tires	Osung recycling		10			80	10	
	other	Ocean recycling				100			CIBS
	glass parts	Ocean recycling				100			CIBS
	seat	Ocean recycling				100			CIBS
	seat foam	Ocean recycling				100			CIBS
	belt, mat					100			CIBS
	audio, ECU, meter set		10			90			CIBS
Body shell	body shell	Ocean recycling				100			Shredder

Fig. 8 Sample field survey: respective ratio of treatment

user interaction, and each number corresponds to those in Fig 9.

[1] Dismantling stage (by dismantler)

A. Dismantling worksheet based on standard part list of the input ELV is created, by which workers follow the separation instructions.

B. Dismantling data (i.e., separation) are stored in the local dismantling database

[2] Upload dismantling data to DR (dismantling & recycling) database.

[3] Report part transfer data (by dismantler).

A. Dismantled parts transfer to a recycler.

B. Report transfer data (date, recycler, parts).

[4] Update transfer data at the DR database.

[5] Take over dismantled parts & confirm (by recycler).

[6] Treatment stage (by recycler)

[7] Report processing result (by recycler)

A. Web-based log-in

Fig. 9 Information flow of the proposed system

Fig. 10 Schematic user interaction diagrams

- B. Retrieve unprocessed parts list from the DS database.
 C. Input treatment type and weight data.
 [8] Update recycling data at the DR database.
 [9] Update respective ratio data at the SRR database.

3.3.2 Implementation and Operational Issues

The proposed system contains three databases: (A) a Standard part database, (B) a Dismantling & recycling database, and (C) an SRR

database. The database design and operation are described as follows.

A vehicle's standard part list for the dismantling process is stored in the standard part database. Each part in the list is a separation unit, and the average number of parts for an ELV is 130. The part list tables for over one hundred vehicle types have been constructed by a Korean automotive recycling company through dismantling operations. Each item of part data of the list includes the part name, weight, MCR (material constituent rate), SRR (standard recycling rate), and RRT

Vehicle Information			Material Constituent									Standard Recycling Rate						Respective Ratio of Treatment					
Vehicle Information (type, weight, etc)			Material Constituent (%)									SRR (%)						RRT (%)					
Part Name	STN	Weight (kg)	F M	N F M	PL	RU	GL	LO	LC	GA	Etc	Ra	Rb	Rc	Rd	Re	Rf	Sa	Sb	Sc	Sd	Se	Sf
fluid (oil)	2							100				90				0	0			50	50		
coolant	2								100			90				0	0			100			
refrigerant	2									100		90				0	0					100	
battery	1	15.46		80	20							100	60	40	10	0	0		50	50			
bumper(F)	1	7.24			100							100	100	80	20	0	0	50		50			
bumper®	1	8.18			100							100	100	80	20	0	0	50		50			
weatherstrip	3	6.20				100						100		60	20	0	0			100			
engine mount	5	9.98	100									100				0	0			100			
fuel tank band	5	1.26	100									100				0	0			100			
body shell		364.00	100									100				0	0			100			

Fig. 11 Example standard part list of an ELV type

Fig. 12 Data processing of dismantling & recycling

(respective ratio of treatment types), as shown in Fig. 11.

The material constituents denote the respective ratios of component materials: ferrous metal (FM), non-ferrous metal (NFM), plastic (PL), rubber (RU), glass (GL), oil (LO), coolant (LC), and refrigerant (GA). This information is used in the estimation of treated material weight for a recycled part. The SRR and RRT data are utilized when estimating the recycling rate of unreported parts, as mentioned earlier.

The dismantling & recycling database (DS DB) data structure and schematic data processing are shown in Fig. 12, where the numbers denote those in Fig. 9. If an ELV is dismantled at a dismantler, a dismantling & recycling (DR) parts table for the ELV is instantiated in the dismantler's local server. In the figure, the DR table contains part index ('Part Idx'), part separation ('Separation'), and other recycling data. 'Part Idx' stores the part index of the corresponding standard part list, and 'Separation' denotes whether the part is separated or not. The ELV parts that are not separated in the DR table are supposed to be compressed in the vehicle shell, which is transferred to a shredder. The dismantler's DR table for an ELV is later uploaded into the central dismantling & recycling database, where the dismantler table stores the loaded DR table index value. The dismantler table contains multiple dismantlers and their own processing ELV data.

When a recycler takes over the separated parts from a dismantler, data fields concerning part transfer are filled: 'Date (transfer),' 'Recycler,' and 'Confirm.' 'Confirm' is set by the accepting recycler's interaction. At the same time, a part index table for each recycler is instantiated, and transferred part indices are stored in the table. When a recycler's part index table already exists, the part data are added to the table.

Finally, the recycling data fields are filled when the recycler finishes treating the transferred parts. The recycler selects one of the treatment types (reuse, remanufacture, recycle, recovery, disposal, etc.) to set 'Result,' and 'Value' is set to 1 (initial value = 0).

4. Calculation of Recycling Rate

4.1 Definition of Recycling Rate

Guidelines have been established for the calculation of the ELV recycling rate (RR). The Directive 2000/53/EC² and Commission Decision 2005/293/EC³ from the EU developed rules for the monitoring of the reuse, recovery, and recycling of ELVs. Also, ISO 22628²⁶ provides a calculation method of ELV recyclability and recoverability. The recycled weight may be specified at each stage (e.g., pre-treatment, dismantling, shredding, ARS treatment). The basic recycling rate for a given time period is calculated as follows:

$$RR = \text{Recycled weight} / \text{Total vehicle weight}. \quad (1)$$

The recycled weight (RW) comes from the sum of weights of automobile parts that are reused, recycled, or subjected to energy recovery.^{3,26} The total vehicle weight is the sum of the individual vehicle weights. Weights are defined at recycling stages as shown in Fig. 13, and the recycled weight can be written as follows:

$$\begin{aligned} \text{Recycled weight} &= SW_{1k} + W_{21} + W_{31} + SW_{4k} + SW_{5k} + W_{501} \quad (k > 0) \\ \text{Total vehicle weight} &= W_0 \end{aligned} \quad (2)$$

The recycled weight at each recycling stage is as follows:

- Weight at reuse stage: SW_{1k}

- Weight at material recycling stage:

$$W_{21} + W_{31} + SW_{4k} + SW_{5k} + SW_{50k} + W_{501}$$

- Weight at energy recovery stage: W_{502}

The material constituent information of each part facilitates acquisition of the recycled weight of distinct material types (e.g., ferrous metal, non-ferrous metal, plastic, etc.).

4.2 Calculation of Recycling Rate

RW (recycled weight) plays an important role in calculating RR, which is acquired from collected data in the central monitoring database. Unless reported, RW is estimated based on the dismantled part's SRR and RRT data as described in Section 3.2. The part's recycled weight W , whose original weight is W_x , is estimated by:

$$W = W_x(Sa_x Ra_x + \dots + Sf_x Rf_x) \quad (3)$$

This estimation method can also be applied to a dismantled part when its treatment is not reported within a designated amount of time. Optionally, the part may be considered to have been discarded. RRT data are continuously updated by recyclers' input, which enhances the fidelity of the calculation. Fig. 14 depicts the RR calculation strategy.

5. Conclusion and Discussion

A web-based ELV recycling monitoring system has been designed, and its architecture was described. The monitoring system features

Fig. 13 Weight definition

Fig. 14 RR calculation strategy

three databases: a standard part database, dismantling & recycling database, and standard recycling rate database. The standard part database provides an ELV part list, which is used to create a dismantling worksheet, as well as for separated part indexing. The dismantling & recycling database collects all necessary data concerning dismantling, part transfer, and recycling. The standard recycling rate database plays a key role in calculating the practical recycling rate, and features SRR (standard recycling rate) and RRT (recycling ratio of treatment) data for each ELV part. This database facilitates estimation of a reasonable recycling rate for the parts that are unreported within a designated amount of time.

The designed system provides a practical and effective tool for purposes of ELV treatment monitoring, for assisting efficient dismantling, tracing dismantled part usage, collecting recycling data, and calculating and estimating the recycling rate. This reporting & monitoring system could be better than the present official system in operation in terms of credibility and practicality. The system is currently being implemented in a Windows® environment, and is scheduled to operate for the authorized operators in Korea.

Finally, the applicability of the proposed system should be addressed from two different aspects: system construction and system operation. The monitoring system can be constructed by implementing the database system which collects dismantling & recycling data, and web-based data input application for the participating authorized treatment actors. The standard part database along with MCR, SRR and RRT data for each ELV could be evaluated by respective dismantling process, field survey and continual update. For a vehicle type for which such data are not existent, the data for a representative vehicle type can be used. The most important problem in operating the proposed system may be fidelity of data gathering, because considerable operators or collectors are involved in from dismantling to ASR treatment stages. It could be overcome by systematic and strategic ways. The legislatively authorized treatment facilities or operators utilize the proposed system, where transfer and receipt of dismantled parts are cross-checked by the system. Also a practical approach to calculation of recycling rate is provided based on SRR and RRT data. It is expected to minimize the discrepancy between calculated and real recycling rate.

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