Fifth International Workshop on Computational Intelligence & Applications
IEEE SMC Hiroshima Chapter, Hiroshima University, Japan, November 10, 11 & 12, 2009

The Development of the Computer Aided Remanufacturing System (CARES) Part I: Software Development (Phase I) and a Simulation Study

Zakri Ghazalli[1] and Murata Atsuo[2],
Department of Intelligent Mechanical System,
Division of Industrial Innovasion Sciences,
Graduate School of Natural Science and Technology,
Okayama University,
3 – 1 – 1, Tsushimanaka Okayama – Shi, 700 – 8530, Japan
Email[1]:zakri@iims.sys.okayama-u.ac.jp
Email[2]:murata@iims.sys.okayama-u.ac.jp

Abstract — **The environment bills that passed by the legislators triggered a new dimension towards the manufacturers to consider producing eco – friendly product. This paper presents the developed software of the remanufacturing evaluation system so-called "Computer – Aided Remanufacturing Evaluation System (CARES)". The software is developed by integrating an analytic hierarchy process (AHP) with case based reasoning (AHP – CBR) approach. The result of the simulation study showed that the maximum similarity between the input case and the retrieve case is 80%. The evaluation system recommended that mirror cover, mirror base and mirror holder should be remanufactured.**

I. INTRODUCTIONS

The environmental impact and ecological issues are always in the priority of many governments worldwide. Public concerns about diminishing natural resources, limited landfill space and hazardous waste disposal has prompted the legislators to place the End – of – Life (EOL) product recovery issues to the manufacturers.

As about 5 million, 12 million and 15 million of vehicles are scrapped in Japan, US and Europe, respectively, each year. The legislation in European Union, Japan, USA, and Australia have passed a bill that requires manufacturers not only to produce the product that has a little impact on the environment but also to take back their products at the end of their life [1]. According to EU Directive, by 2015, vehicles are allowed to reach into the market only if they are reusable and / or recoverable to a minimum of 95% of the total weight [2; 3]. Any manufacturer that does not comply with the directive would be excluded from the global market competition. To survive the competition, the manufacturers have to produce products which are safe and friendly to the environment. One of the aspects of the product development that focus on the recovery resources is the design for remanufacturing (DfRem). Manufacturers that fail to practice DfRem might squander future revenues [4].

Several studies have focused on the selection of EOL strategies selection. Rose [5] developed a system called ELDA (End – of – Life Design Adviser) to determine the EOL strategies. Zhang et al. [6] adopted an analytical hierarchy process (AHP) to find the best recycling strategy. Bras and Hammond [7] proposed remanufacturing indices to define the product remanufacturability. Hula et al [8] dedicated his work on minimizing the environmental impact via genetic algorithm while, Shih et al [9] applied the case base reasoning approach to product recycling. The authors applied a trial and error approach to determine the weights for similarity function. Therefore, there is a need for developing a systematic way to determine the weights for similarity function.

The EOL products need to be delivered to the market as early as possible before competitors do. Hence, it is desirable that the OEM manufacturers and remanufacturers should attempt to develop a system that can integrate the remanufacturing method with the artificial intelligence (AI) tools, and provide and facilitate the decision – making processes at the design and development phase [10].

Most of the previous works consider a rule based approach to evaluate the remanufacturing process. However, the application of AI tools is limited to evaluate the product recycling. Less attention is paid to incorporating any of AI tools into remanufacturing. Therefore, it is important to integrate the remanufacturing process with artificial intelligence tools, and support the decision – making process at the early design stage.

With the aims of improving the effectiveness and the efficiency for the development of remanufacturing evaluation system, a comprehensive computer aided system to support the decision – making process at the design stage is deemed necessary. This paper presents a software development of a computer aided evaluation system using an integrated analytic hierarchy process with case base reasoning (AHP – CBR) approach that focuses on the integrated design for the evaluation system of remanufacturing process to support the automobile product design at the design phase. In this system, CBR provide the past experiences of selection EOL path. The AHP provide the systematic process to determine the weights for similarity function in CBR. An assumption study based on the developed software is also presented in this paper.

II. Simulation Method

A. Outline of the Simulation

The computer aided remanufacturing evaluation system (CARES) was developed by using the object oriented C#. The simulation method of the developed software is illustrated in Figure 1. The Microsoft Access (MS Access) is used as a file (*.mdb) to stored the previous data. This file is integrated into the developed software so that the stored data can be accessed, selected and retrieved.

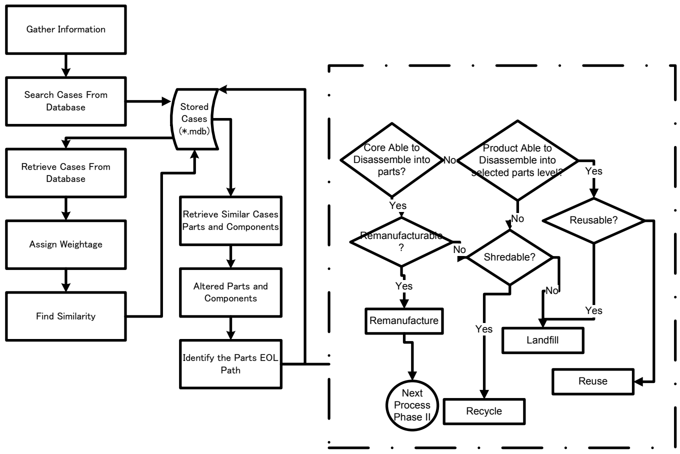

Figure 1. Computer aided remanufacturing evaluation system (CARES) simulation method.

As shown in Figure 1, the evaluation process begins with the gathering of the information of cores. The information consists of the parameters such as core maker, core name, core quantities and core production year that will be use in CARES to search the similar information in the database. In CARES, the information on the classification of the automobiles is gathered. Next, the characteristics of the parts and components are identified. These characteristics are [5]:

1. Wear – out life – The length of time from product purchase until it has no longer meets original functions.
2. Technology cycle – The period during which the product will be on the leading edge of technology before new technology makes the original product obsolete.

3. Level of integration – The interrelation between product modules and product functions.
4. Number of parts – The number of assemblies or cores in the product that is relevant to EOL treatment.
5. Reason for redesign – The reasons companies design or redesign products. It is classified into five categories, namely, original design, evolutionary design with function improvement, evolutionary design with aesthetic improvement, feature change with function improvement, feature change with aesthetic improvement.
6. Design cycle – The cycle with which a design team redesigns the product.

The weights for these characteristics were given based on the Analytic Hierarchy Process (AHP). The structure of AHP is shown in Figure 2.

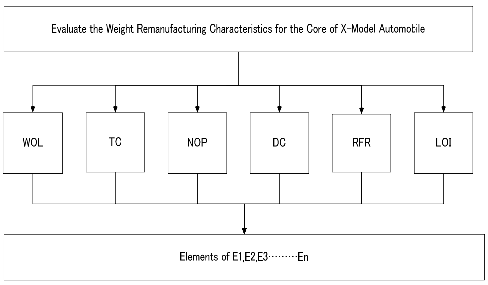

Figure 2. AHP evaluation approach

After that, the Nearest Neighborhood algorithm (NN) is applied to find the smallest difference between the input case (latter known as the subject) and the retrieved cases. NN values and the weights are applied to find the similarity between the input case and retrieved cases. The retrieved case with a maximum percentage of similarity is considered as the closest case to the subject. The next step is to retrieve the parts and component with a maximum percentage of similarity. The retrieved core is then altered according to the input case parts and components for the part level EOL path selection.

B. FEATURES OF DEVELOPED SOFTWARE

The software for aiding the designer in decision making for determining the remanufacturing path was developed. This software consists of sets of tools to input the gathered information of the core, to calculate the similarity and finally to recommend the EOL path of the core parts and core component. The developed software is illustrated in Figures 3 – 8. The developed software consists of several features. These features are:

1. Product Level Information – As illustrated in Figure 3, the product information level consist of the information of the cores at the product information level. The related information includes the core name, quantity, maker, model year. Such information is necessary for retrieving the stored cases in the database.
2. Product Characteristics – As illustrated in Figure 4, the product characteristics consist of the ones defined by Rose [5]. Such information is necessary for finding the similarity after retrieving the stored cases in the database.
3. Retrieve Data button – Its function is to retrieve the data which was specified in the product level information (see Figure3 and 4). Figure 5 shows the retrieved data on the specified core name and core maker after clicking ‘Retrieve Data’ button.
4. Pair – wise comparison for AHP process – This consist of a set of tables to calculate the pair-wise comparison for AHP process. Figure 6 shows an example of the pair – wise comparison table.
5. Similarity table – This table displays the similarity functions between the input case and the retrieved cases. Figure 7 shows an example of the selected data after similarity calculation.
6. Part level EOL path selection – It contains a series of rules that recommends either the part can be reuse or remanufacture, or recycle or landfill. Figure 8 shows an example of the EOL selection at the part level.

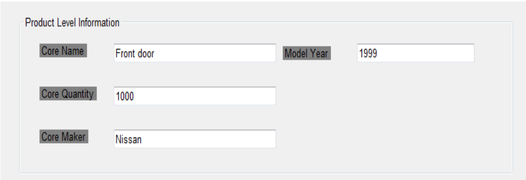

Figure 3. Core Information – Product level information

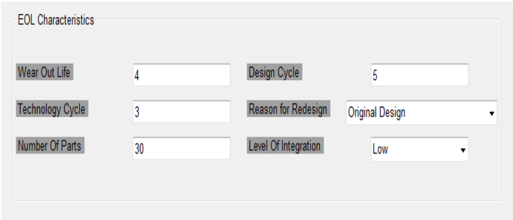

Figure 4. Core Information – Product level information

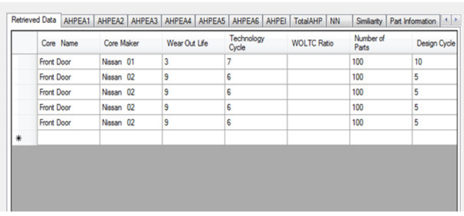

Figure 5. Retreived data after clicking the 'Retrieve Data' button

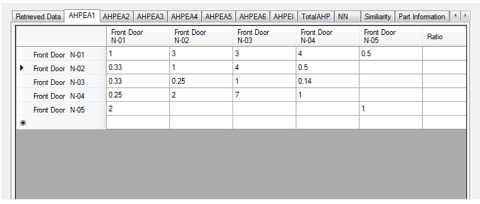

Figure 6. Pair – wise comparison for AHP process

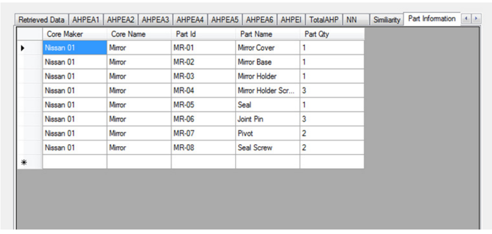

Figure 7. Selected case after similarity calculation

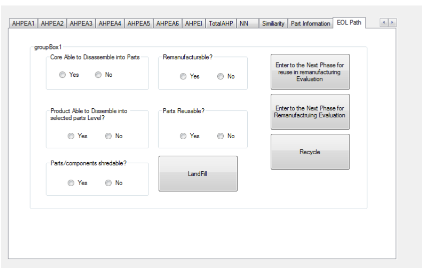

Figure 8.Part level EOL path selection

C. Assumptions of the Simulation Method

The simulation study was implemented on a car door right side mirror. This door mirror is illustrated in Figure 9.

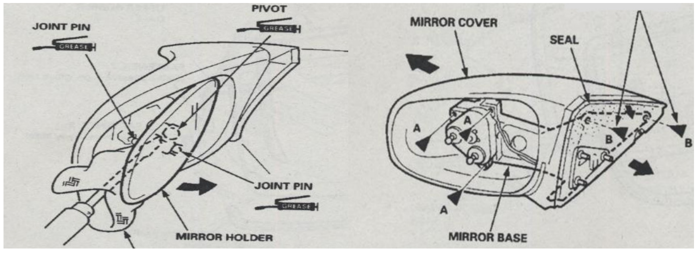

Figure 9. Side mirror that used as a case study

The side mirror consists of mirror cover, mirror base, mirror holder, mirror, mirror holder screw, seal, joint pin and seal screw.

Input Case

The input case is classified as N-I. The parameters of the input case is shown in Table 1.

Table 1. The parameter of the input case

Sample	WOL (yrs)	TC (yrs)	NOP (unit)	DC (yrs)	RFR	LOI
N-I	15	8	16	5	Function Improvement	High

Retrieved Parameters

After the input case (N – I) had defined, the next step is to search for the similar stored data. In this study, it is assumed that, after searching process, only 3 similar cases to the input case had been found. These data were retrieved and will be compared to the input case in order to find the similarity. The retrieved case is shown in Table2. Each of these cases contains different parameters (See Table 2).

Table 2. Retrieve Cases from database

Samples	WOL	TC	NOP	DC	RFR	LOI
N-1	9	6	16	7	Original Design	Medium
N-2	10	5	16	7	Aesthetic Changes	Medium
N-3	7	5	17	5	Feature Changes	High

AHP Evaluation

Table 3 shows the result of AHP evaluation for each samples. The weight in AHP is calculated as follows:

$$GM_i = \left\{ \prod_{j=1}^{M} a_{ij} \right\}^{\frac{1}{M}} \quad (1)$$

The geometric mean GM_i, is used to find out the relative normalized weight (W_j) for retrieve cases. The relative normalized weight can be represented by Equation (2):

$$W_j = \frac{GM_i}{\sum_{i=1}^{M} GM_i} \quad (2)$$

Table 3. Weighted result of the retrieve cases elements

Samples	WOL	TC	NOP	DC	RFR	LOI	Total
N – 1	0.141	0.196	0.041	0.041	0.054	0.024	0.497
N – 2	0.057	0.024	0.035	0.034	0.031	0.021	0.203
N – 3	0.023	0.045	0.029	0.171	0.005	0.027	0.300

Nearest Neighborhood Evaluation

The similarity values can be represented by Equation (3).

$$Total\ Similarity\ (P,Q) = \sqrt{\frac{\sum_{i=1}^{n} W_i \times \frac{|P-Q|}{Range(P,Q)}}{\sum_{i=1}^{n} W_i}} \quad (3)$$

Where, P is the input case and Q is the retrieve cases. For symbolic features or non-numerical value, the following equations for $|P-Q|$ is apply;

$$P-Q = \begin{cases} 0 & if\ P = Q \\ 1 & if\ P \neq Q \end{cases}$$

The $Range(P,Q)$ is a difference between the maximum and minimum of P and Q. However, for the non – numerical value, the $Range(P,Q)$ is equal to 1.

Table 4 shows the result of Nearest Neighborhood evaluation for each sample.

Table 4. Results of Nearest Neighborhood evaluation

Samples	WOL	TC	OP	DC	RFR	LOI	NN
N-1	0.079	0.087	0.000	0.041	0.054	0.024	0.242
N-2	0.022	0.024	0.000	0.034	0.031	0.021	0.189
N-3	0.023	0.045	0.029	0.000	0.005	0.000	0.415

Using the Equation (3), the similarity values were obtained (See Figure 10),

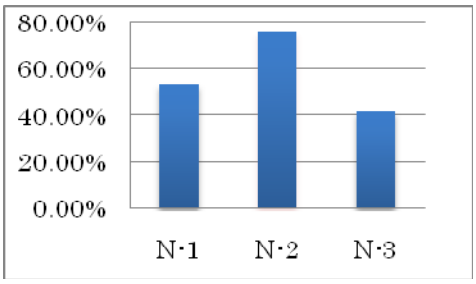

Figure 10. Similarity Case towards input Case

The result of the EOL path at the part level is summarized in Table 5.

Table 5. EOL Path at parts level for the door side mirror

Part Name	Qty	○	●	▲	▼	◆	Path
Mirror Cover	1	Y			Y		❶
Mirror Base	1	Y			Y		❶
Mirror Holder	1	Y			Y		❶
Mirror	1	N			N	Y	❷
Mirror Holder	3	Y			N	N	❹
Seal	1	Y		N	N	N	❹
Joint Pin	3	Y		N	N	N	❹
Pivot	2	Y		N	N	N	❹
Seal Screw	2	Y		N	N	N	❹

Reusable ▲	Remanufacturable ▼	Shreadable ◆

○	Able to Disassemble Into Parts		
●	Able to Disassemble into Selected Parts Level		
❶	Remanufacture	❷	Recycle
❸	Reuse	❹	LandFill

III. Discussion

In AHP evaluation, it shows that the N – 1 has more importance in WOL, TC, NOP and RFR than N – 2 and N – 3. Overall, the N – 1, has more importance than N -2 and N – 3. In Nearest Neighborhood evaluation, it shows that the N – 3 has the highest value than N – 2 and N – 1. Figure 10 show that N – 2 has the highest similarity percentage than N-1 and N – 1. In the other words, the EOL path of the N – I, is similar to N – 2. From Table 5, the mirror cover, mirror base and mirror holder are recommended to be remanufactured. The recommendation is made based on a set of rules which consider the disassemblability level of the parts in the component. It is assumed that these parts can be disassemble into parts and remanufacturable.

IV. Conclusions and Future Work

The paper presented the first phase of the developmental framework that applies the integrated AHP – CBR to aid the remanufacturing decision making process. The application of AHP – CBR to the developmental framework enables the designers to retrieve the stored data. Thus, the stored data can be compared with the input data (new case).

The AHP provide a systematic approach for determining the weights of each product characteristics. The Nearest Neighborhood algorithm used these weights to seek stored cases similar to new case. A set of rules regarding to product disassembly have been developed to determine the EOL path at the part level. A software has been developed to demonstrate the developmental framework. It is aim to aid and guide the designers during decision making process. However, the simulation study is based on the assumption. As a task for the future work, the developmental framework needs to be verified with the traditional model of the CBR. As at the part level, the EOL path is determined by a set of rules, a mechanism to quantify and justify this path need to be developed from environmental impact perspective.

References

[1] Brett, R. What is End of Life Vehicle?, (on – line) 1877 End of Life Vehicles.com, 2006. (Access Date: 2009/06/20), http://1877endoflifevehicles.com/eol.cfm.

[2] 2005/64/EC. The reusing, recycling and recovering of motor vehicles. (on - line) 2005/10/26. (Access Date: 2009/06/05.),http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:310:0010:0027:EN:PDF.

[3] PricewaterhouseCoopersLLP. The European Union end – of – life vehicle directive is a sensitive issue for global automotive industry. (on – line) 2002. http://www.pwc.com/.

[4] Ehud, K. and Thomas, H.A., Quantitative Evaluation of Product Disassembly for Recycling, *Research in Engineering Design*, Vol. 10, pp. 1-14, 1998.

[5] Catherine, M.C., *Design for Environment:A Method for Formulating Product End – of – Life Stratergies*. Department of Mechanical Engineering, Stanford University. PhD Dissertation, 2000.

[6] ZhangY Yu, K Jin, FF Ling, and A. D. Barnes.HC Decision – making model for materials management of end – of – life electronic products, *Journal of Manufacturing System*, Vol. 19, pp.94-107, 2000.

[7] Hammond, R. and Bras, B.A., Design for Remanufacturing Metrics, *Proceedings of 1st International Workshop on Reuse*, Eindhoven, The Netherlands, pp. 5–22, November 11–13, 1996.

[8] Hula, A., Jalal, I. K.; Hamza, K., Skerlos, S.J. and Saitou, K., .Multi-criteria decision – making for optimization of product disassembly under multiple situations, *Journal of Environmental Science and Technology*, Vol. 23, pp. 5303-5313, DOI: 10.1021/es0345423, 2003

[9] Shih, LH., Chang,YS., and Lin, YT., Intelligent evaluation approach for electronic product recycling via case-based reasoning, *Advanced Engineering Informatics* Vol. 20, Issue 2, pp. 137–145, 2006.

[10] B. Bras and M.W. McIntosh, Product, process and organizational design for remanufacture: an overview of research, *Robotics and Computer Integrated Manufacturing,* Vol. 15, pp. 167–178, 1999.