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The application of artificial intelligence in optimisation of automotive components for reuse

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Analysis and modelling

ABSTRACT

Purpose: Automotive component reuse as one of the product recovery strategy is now gaining importance in view of its impact on the environment. Research and development on components design and manufacturing as well as tools and methods to facilitate reuse are under way in many countries. To enable reuse, components have to be assessed and its reliability and life time predicted. This paper presents the development work on an optimisation model for assessing potential automotive components for reuse using artificial intelligence approaches.

Design/methodology/approach: As a part of the study, the paper currently focuses on initial study on ease of disassembly design. The model for predicting reliability and durability of reuse components is then developed using Artificial Neural Networks (ANNs) and further optimised for reliability and life cycle cost using Genetic Algorithm (GA).

Findings: The proposed model will enable the local automotive industry to effectively assess potential components for reuse in support of further design and manufacturing improvements.

Research limitations/implications: This study hopes to contribute to design for reuse by assessing high potential and reliable reuse components at the lowest costs.

Originality/value: Artificial intelligence methods, such as artificial neural networks (ANNs) and genetic algorithm (GA), can be applied to solve problem as they can provide satisfactory and acceptable solutions for many complex problems.

Keywords: Design for reuse; Automotive components; End-of-life vehicle; Artificial intelligence

1. Introduction

Environmental concern as well as government legislations have forced manufacturers in many countries to consider product life cycle issues and deal with product recovery at the end of product life cycle. The automotive industry is one of the leading industry in this environmentally conscious manufacturing and product recovery. In the USA, 95% of cars and trucks that are retired each year go the recycler and for each of those cars, 75% by weight is recovered for reuse [1]. In the European Union countries, the European Union End of Life Vehicle (ELV) Directive has passed laws to the member countries to reuse and recover 85% by weight of the average vehicle by the year 2006 and this percentage increases to 95% by the year 2015 [2].

In Malaysia, the establishment of *Proton* in 1985 and consequently *Perodua* in 1993 acted as a catalyst to the development of the automotive sector in Malaysia including the development of local automotive components manufacturers. Currently, there are 4 passenger and commercial vehicle manufacturers, 9 motor vehicle assemblers and 343 components/parts manufacturers in Malaysia with a total production of 441 678 vehicles in 2007 [3]. The government policy provides support and incentives to promote a competitive and viable automotive sector and to enhance local capabilities in the automotive sector. However, the establishment of local automotive industries that have environmentally consciousness is still one step ahead and need support from government and automotive manufacturers.

Although component reuse is still a new phenomenon in the local automotive industry, efforts toward reuse must be conducted to develop a sustainable local automotive industry. The advantages of reuse in terms of economic benefits as well as environmental safety will direct the local automotive manufacturers to deal with the end of life recovery of their products.

In relation to product reuse, previous research on the optimisation of design for product or component reuse is very minimal. Mazhar et al. [4] developed a study that estimated remaining life of used components of washing machine using artificial intelligence. Kara et al. [5] conducted a study to determine the reuse potential of washing machine component based on estimated operating life time by comparing multi regression analysis and artificial intelligence. A study related to product design for reuse of automotive component was also conducted by Kimura et al. [6]. In this study, the development of product modularisation strategies for car air conditioner based on product functionality, product commonality and life cycle similarity were proposed.

Several studies on product/component reuse are in the area of manufacturing system, economic and supply chain. For example, Takata and Kimura [7] developed life cycle simulation system for life cycle process planning by taking into account the reuse of parts over product generations period. While, Uemeda et al. [8] analysed reusability using marginal reuse rate for single camera, photocopier and automatic teller machine (ATM).

Ko et al. [9] assessed manufacturing system reusability using a case example of a right hand side frame of a car body. Koh et al. [10] developed an optimum inventory system for reusable items such as soft drink bottles. While, Simon et al. [11] developed a model of washing machine life cycle based on life cycle data acquisition (LCDA). This model evaluated the economic benefits of using reuse component obtained from the end of life cycle and reusable components arise from servicing.

The essential goal of reuse strategy is to determine the potential reuse components that optimise economic benefits (by reducing manufacturing and other production costs), reliability and durability of the reuse components at the end of life cycle. Therefore, reliability and life time prediction of potential reuse components assessment will be the basis methodology. Based on this, the study will develop an optimisation model for automotive component reuse in order to deliver highly reliable reuse components at minimum costs.

Artificial intelligence methods, such as artificial neural networks (ANNs) and genetic algorithm (GA) have solved many problems in decision making. A neural network can be defined as a model of reasoning based on human brain [12]. The ability of ANNs to learn and understand the problem and to improve its performance through learning process can be applied to predict life time and reliability of automotive components based on failure data analysis. Therefore, the combination of artificial neural network and genetic algorithm can make evolutionary computation to solve optimisation model for automotive components reuse.

2. Product life cycle and design for reuse

Resources that are recovered will reenter the product life cycle and replace the input of virgin materials through directly reusing the product at the end of useful life, reusing some parts, reusing other parts after appropriate reprocessing (remanufacturing) or by recycling materials (Fig. 1). As a consequences, this leads to a decrease in the consumption of virgin materials, decrease the volumes disposed of as waste and saving consumption of energy for processing [13].

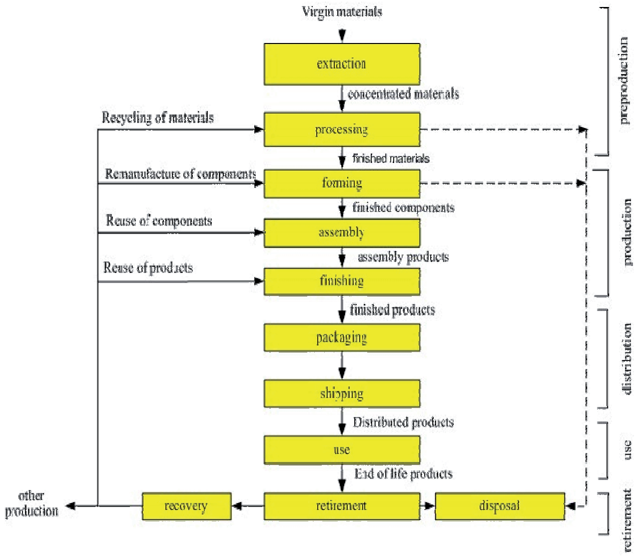


Fig. 1. Physical life cycle of product and flow material resources [13]

According to Fig. 1, strategies for recovery of resources at the end of life cycle can be grouped according to their different recovery levels. They are 3 main recovery levels as follows:

1. Direct reuse – At the end of use, the product can be directly reused, with consequent savings in energy consumption, possible emissions, costs related to the production and assembly and in the volumes of virgin materials.
2. Reuse of parts – Components that have not undergone excessive deterioration can be recovered, possibly after being regenerated through immediate processes, as components for reassembly with savings in energy, possible emissions, costs related to the process of producing the parts and in volumes of virgin materials.
3. Recycling materials – The materials of parts that cannot be reused can be recycled by recovery process or used in external production cycles.

When parts/components are to be reused, in either remanufacture or maintenance, the reliability of the parts/components becomes very important [14]. Reliability is defined as the probability that an item to perform a required function without failure under given environmental and operational conditions and for a stated period of time [15]. If probability density function (f(t)) indicates the failure distribution over the entire range of time, the cumulative distribution function, denoted F(t) is the probability that a product will fail by a specified time. Mathematically, it is defined as :

$$F(t) = \Pr(T \le t) = \int_0^t f(t)dt \tag{1}$$

Therefore, the reliability function or survival function (R(t) is the complement of F(t) and can be written as:

$$R(t) = \Pr(T \ge t) = 1 - F(t) = \int_t^\infty f(t)dt \tag{2}$$

The probability density function (f(t)), cumulative distribution function F(t) and reliability function R(t) as a function of time t can be seen in Fig. 2.

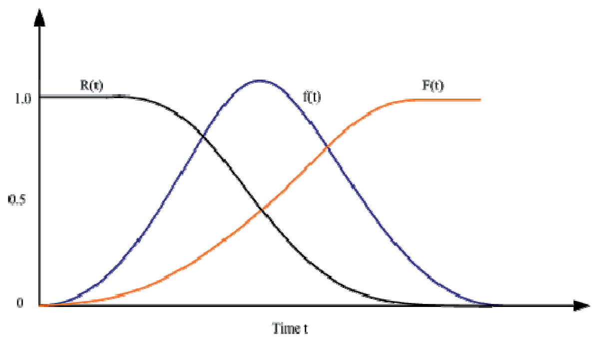


Fig. 2. Probability density, distribution and reliability functions [15]

According to Ogushi and Kandlikar [16], reuse of automotive components/parts can be in form of reintegrating used parts into newly manufactured vehicles or parts reuse for replacement or spares. In practice, no reuse parts/components from end of life vehicles (ELVs) are reintegrated into newly manufactured vehicles exists in Malaysia. As in other countries, parts/components are commonly reused only for parts replacement of used cars either by remanufacture or not.

These are caused by some factors that influence the original equipment manufacturers (OEMs) preference of using reuse parts such as the economic benefit and the quality of reuse components. The economic benefit from reuse in form of reduction of production cost is one of the main concerns. If the cost of producing new vehicles that consist of some reuse parts/components is higher than manufacturing vehicles with all new components, therefore there is no advantage of reuse for the OEMs. Therefore we have to examine whether the OEMs will gain some economic benefit from reuse of automotive components. The other concern is the quality of vehicles as it is driven by customers perception about reuse products that are not as good as new. In this case, prediction of component life time and reliability become very important to ensure the quality of reuse parts/components.

The cost and quality constraints can also be overcome by improvement of automotive design in the very early stage of product development. For example, design for ease disassembly leads to reduction in disassembly time so that can improve cost of recovery. The choice of material and design form can also increase reliability and durability of automotive components.

3. Improving design of car door for reuse

In design for reuse, ease of disassembly is an important criteria and will be one of the focus area of the study. Eventually, an optimisation model of an automotive component for reuse that minimise life cycle cost as well as maximise reliability will be proposed.

As a case example, a Proton Perdana right hand side (RHS) car door is examined (see Fig. 3). The Proton Perdana is manufactured by *Proton*, one of the local automotive manufacturers in Malaysia.

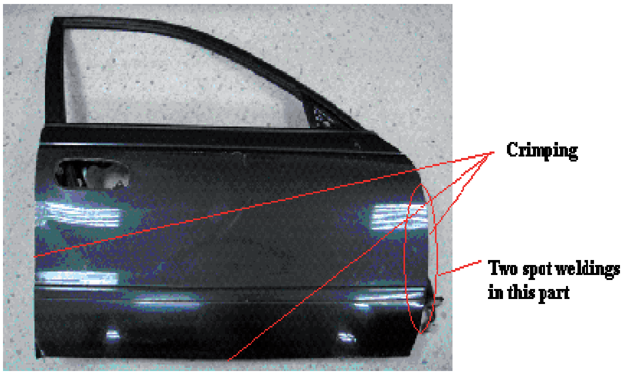
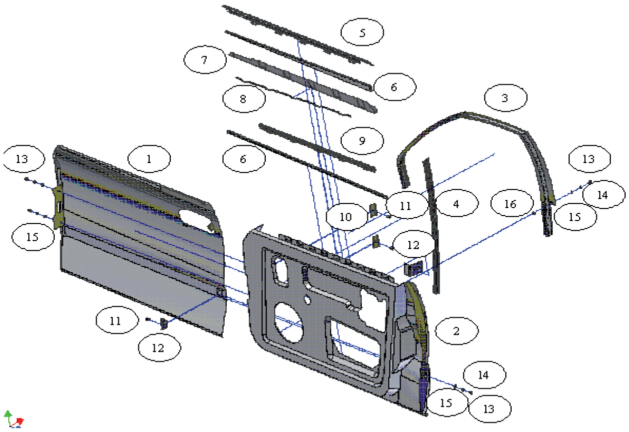


Fig. 3. Right hand side car door of Proton Perdana

The Proton Perdana car door consists of several parts as shown in Fig. 4. In the original design, the Proton Perdana door skin is crimped to the door frame around its sides except the upper side. There are two spot welds on the front side. These crimping and spot welding cause difficulty in removing door skin from the door frame. The disassembly process of this original design may damage the door skin and frame and very time consuming. Besides, the door frame also consists of two parts that are connected by spot welding. Outer window panel uses both snap fit and screw connections and inner window panel uses clip.

Improvements to the car door design is proposed in order to improve car door disassembly. Instead of crimping, the attachment design of door skin to the door frame uses the „tongue and groove" principle. This concept was proposed by Amezquita et al. [17] with some modifications. There are 2 grooves and 2 tongues to guide the door skin direction into the door frame (see Fig. 5). Four bolts (two at each side) will be used to fix the position of door skin to the door frame.



1	Door skin	8	Clip
2	Door frame	9	Inner window panel
3	Door sash	10	Inner nut plate
4	Door sash connection	13	Bolt
5	Outer window panel	14	Sesendal pisah
6	Groove	15	Sesendal rata
7	Groove	16	Nut

Fig. 4. Car door parts

This new design will lead to an easier disassembly of door skin and door frame and prevent damages during disassembly process. This will also lead to reduction in disassembly time and recovery cost. Therefore it will give more opportunity of car door parts such as door frame and door skin to be reused.

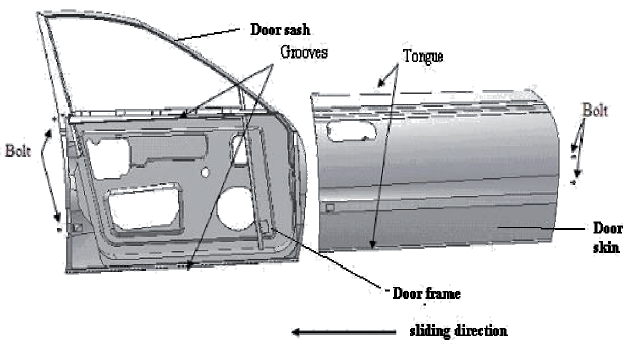


Fig. 5. Tongue and groove principle in new design

It is also suggested that the door frame be constructed in one entity instead of two separate entities connected by spot welds (Fig. 6). This will increase the possibility for reuse because spot welding connection is easy to damage. The outer window panel is designed using snap fit to replace the use of both snap fit and screw. The snap fit was designed for easy removed from the inside, therefore vehicle security is still maintained. It is also proposed that the inner window panel uses snap fit instead of clip. Snap fit is easier to disassembly compared to the clip.

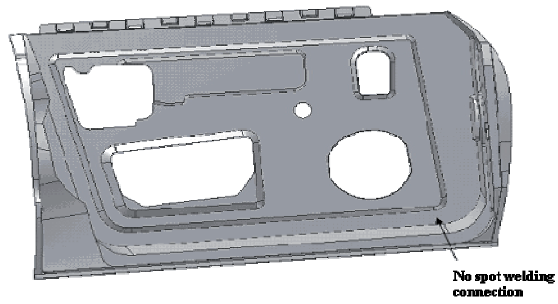


Fig. 6. One entity of door frame

The proposed design changes enable the car door to be disassembled easily and therefore will reduce disassembly time as well as recovery cost. Hence, enhancement to the reusability of the car door.

The proposed design of car door is validated by comparing the maximum stress and displacement of the original and the new design. By assuming that the opening and closing load of the car door is equal to 20 kN, the maximum displacement and stress of the proposed design resulted from finite element analysis are 1.17 mm and 217 mPa (Fig. 7 and Fig. 8). These values are higher than the original design which are 0.789 mm and 162 mPa. However, this new design is acceptable since the stress is still lower the tensile strength of the car door which is 340 mPa.

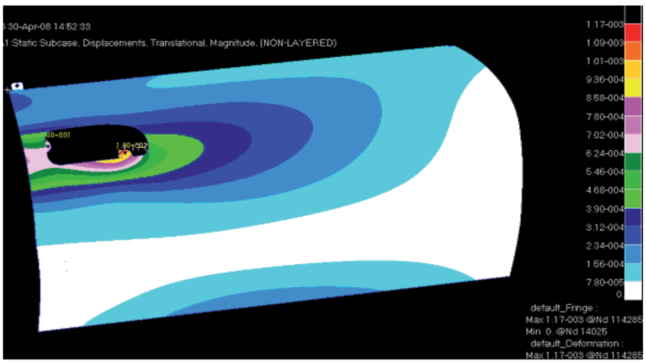


Fig. 7. The maximum displacement of the new car door design

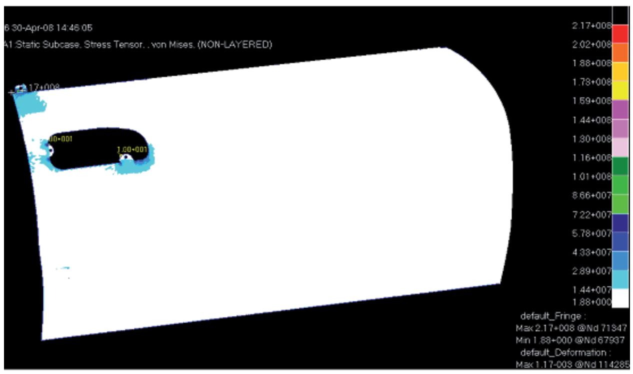


Fig. 8. The maximum stress of the new car door design

In the next section, the model for predicting life time and reliability of automotive component will be proposed. As a case example, the durability and reliability of the proposed design of car door for reuse will be predicted. Next, the optimisation model will determine the potential car door components that maximise durability and reliability as well as minimise life cycle costs.

4. Neural networks model for life time and reliability prediction

Artificial neural networks (ANNs) has been widely used in recent years due to its ability in providing satisfactory and acceptable solution for complex problems in which the conventional mathematical methods are not able to solve. ANNs are inspired by the human brain that consists of a number of interconnected processors, called neurons. The neurons are connected by links and each links has a numerical weight associated with it. A neural network 'learns' through repeated adjustments of these weights.

A multilayer neural networks is a feed forward neural network that consists of one or more hidden layers. Typically, the network consists of an input layer of source neurons, at least one middle or hidden layer of computational neurons and an output layer of computational neurons (Fig. 9).

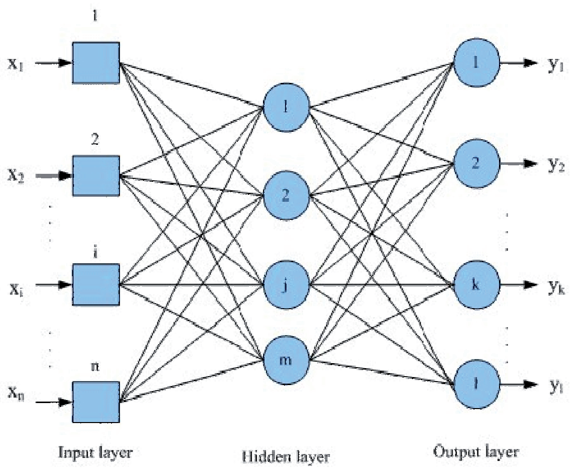


Fig. 9. Three layers neural network [12]

By training the neural network, implicit knowledge can be built into it. A lot of training algorithm are available, however the most popular method is back propagation [12]. In a back propagation neural network, the learning algorithm has two phases. First, a training input pattern is presented to the network input layer. The network then propagates the input pattern from layer to layer until the output pattern is generated by the output layer. If this pattern is different from the desired output, an error is calculated and then propagated backwards through the network from the output layer to the input layer. The weights are modified as error is propagated.

The proposed neural network model is a multilayer feed forward back propagation neural network. The output of neurons in the hidden layer are calculated by:

$$Y_j(p) = f\left[\sum_{i=1}^{n} x_i(p) x w_{ij}(p) - \theta_j\right] \quad (3)$$

where:
f – the transfer function,
n – the number of input neuron *j* in hidden layer,
$x_i(p)$ – the input neuron value at iteration p and $w_{ij}(p)$ is the weight and Θ_j is a threshold applied to the neuron. The actual output of neurons in output layer are calculated by :

$$Y_k(p) = f\left[\sum_{j=1}^{m} x_{jk}(p) x w_{jk}(p) - \theta_k\right] \quad (4)$$

where:
m – the number of input of neuron *k* in the output layer.

Tansig and purelin transfer functions will be used in the proposed model. Both are very common choices for multilayer neural network [18]. Some back propagation learning algorithms such as Levenberg-Marquardt, Resilient Back – p opagation and Scaled Conjugate Gradient will be compared to obtain the best results.

The data requirements for the proposed neural network model will be derived from finite element (FE) analysis using a computer aided engineering software. By simulating loads, the proposed design of car door for reuse will be analysed using FE method so that various stress and cycle to failure could be determined. Based on this, ANNs will predict the durability and the reliability of the car door.

The study on durability and reliability of the proposed design of the car door is currently being carried out. Hence, design improvement of the car door for reuse is not only to increase ease of disassembly but also to increase durability and reliability of the car door components.

Meanwhile, Proton has conducted durability analysis on some of its car door components. Results from the study indicated that the life estimation of a Proton door handle is predicted around 40 000 miles [19]. By improving the design of car door for reuse, it is expected that the durability and reliability of car door components will be improved.

5. The proposed optimisation model of automotive reuse components

Based on the automotive components reliability and durability that resulted from the proposed ANNs model, the proposed optimisation model is developed in order to find the optimum automotive reuse components. The proposed optimisation model describes trade off between life cycle costs and reliability of reuse components.

Life cycle cost of a new product comprises production cost, ie. material (C_w) and manufacturing costs (C_{mft}), and assembly cost (C_{ass}). Compared with the production of new product, reuse components enable a reduction in material and manufacturing costs [13]. However, there is also an additional recovery cost (C_{rec}) that may vary depending on the components to be reused.

On the other side, reuse components may affect reliability of a product or system as a whole. Therefore, in order to determine the optimum components for reuse, the proposed optimisation model optimises the following objectives:

1. To minimise life cycle costs of reuse product.
2. To maximise reliability of reuse product.

The optimisation problem is subject to constraints that indicate the determinant factors limitation such as reliabity, durability and ease of disassembly. The formulation of the optimisation model is as follow:

Objectives:

1. To minimise life cycle cost of reuse product (Z_1):

min: material cost + manufacturing cost + assembly cost + recovery cost

$$Z_1 = \left(\sum_{i=1}^{n}(1-r_i)\,(C_w + C_{mft})\right) + C_{ass} + \sum_{i=1}^{n} r_i\, C_{rec\,i} \quad (5)$$

2. To maximise reliability of reuse product (Z_2):

max : $Z_2 = R_s(t) = E(\phi(X(t)))$ (6)

Subject to:

1. Recovery cost of component -i ($C_{rec\,i}$):

- $C_{rec\,i} = C_{diss\,i} + C_{cl\,i} + C_{sort\,i}$ (7)
- disassemby cost of component -i ($C_{diss\,i}$) is dependent on disassembly time ($t_{diss\,i}$) and labour cost (c_{mh}):

$$C_{dissi} = t_{dissi} \cdot c_{mh} \quad (8)$$

2. Durability (D_i):

- Durability

$$D_i = \mathrm{int}[\frac{PD_i}{T}] \quad (9)$$

- Predicted duration of component -i (PD_i) must be longer than the product working life (T), therefore :

$$D_i \geq 1 \quad (10)$$

- PD_i or mean life time is calculated based on ANNs model.

3. Reliability:

- Reliability of each component ($X_i(t)$) at the end of product life time is predicted from ANNs model.

$$X_i(t) = \begin{cases} 1 & , \text{ if } r_i = 0 \\ X_i(t) & , \text{ if } r_i = 1 \end{cases} \quad (11)$$

r_i is effective reusability of component i.

4. Separability (S_i):

- The reuse component has to be easily separated, therefore :

$$S_i = \begin{cases} 1, \text{ if component -i can be separated} \\ 0, \text{ otherwise where } S_i \text{ is obtained from junction analysis.} \end{cases} \quad (12)$$

5. Effective reusability (r_i):

- $V_i = D_i \cdot S_i$

$$r_i = \begin{cases} 1 & , \text{ if } V_i \geq 1 \\ 0 & , \text{ if } V_i < 1 \end{cases} \quad (13)$$

6. Lower bound constraint:

$$PD_i,\ D_i,\ S_i,\ X_i(t),\ R_s(t),\ V_i,\ r_i \geq 0 \quad (14)$$

This proposed optimisation model will be solved using Genetic Algorithm (GA). Genetic Algorithm is a stochastic search technique based on the mechanism of natural selection and natural genetics. GA deals with a set of solutions, called population, and each individual in the population is called chromosome. During each generation, the chromosomes are generated using 2 main operators, i.e. cross over and mutation, and are evaluated using some measures of fitness [20]. Genetic Algorithm is chosen to solve this optimisation model due to its capability in solving many large and complex optimisation problems compared with other heuristic methods.

6. Conclusions

Reuse of product or component is the highest hierarchy of product recovery at the end of life cycle. Besides the positive impacts of reuse to the environment, it also leads to savings in energy consumption, materials and other production costs. Although there are lots of advantages of reuse for manufacturers, very few research in product or component design for reuse have been conducted especially in automotive industry. This study hopes to contribute to design for reuse by assessing high potential and reliable reuse components at the lowest costs. Artificial intelligence methods, such as artificial neural networks (ANNs) and genetic algorithm (GA), can be applied to solve this problem as they can provide satisfactory and acceptable solutions for many complex problems.

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References

[1] A. Gungor, M. Gupta, Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey, Computers and Industrial Engineering 36 (1999) 811-853.

[2] J. Gerrard, M. Kandlikar, Is Euopean End of Life Vehicle Legislation Living Up to Expectation?, Assessing the Impact of the ELV Directive on 'Green' Innovation and Vehicle Recovery, Journal of Cleaner Production 15 (2007) 17-27.

[3] Malaysian Automotive Association, Summary of Sales and Production Data (http://www.maa.org.my/info_summary.htm).

[4] M.I. Mazhar, S. Kara, H. Kaebernick, Remaining Life Estimation of Used Components in Consumer Product: Life Cycle Data Analysis by Weibull and Artificial Neural Network, Journal of Operation Management 25 (2007) 1184-1193.

[5] S. Kara, M. Mazhar, H. Kaebernick, A. Ahmed, Determining the Reuse Potential Component Based on Life Cycle Data, Annals of CIRP 54/1 (2005) 1-4.

[6] F. Kimura, S. Kato, T. Hata, T. Masuda, Product Modularization for Parts Reuse in Inverse Manufacturing, Annals of the CIRP 50/1 (2001) 89-92.

[7] S. Takata, T. Kimura, Life Cycle Simulation System for Life Cycle Process Planning, Annals of CIRP 52/1 (2003) 37-40.

[8] Y. Uemeda, S. Kondoh, T. Sugino, Analysis of Reusability Using Marginal Reuse Rate, Annals of CIRP 55/1 (2006) 41-44.

[9] J. Ko, S.J. Hu, T. Huang, Reusability Assessment for Manufacturing Systems, Annals of CIRP 54/1 (2005) 113-116.

[10] S.G. Koh, H. Hwang, K.I. Sohn, C.S. Ko, An Optimal Ordering and Recovery Policy for Reusable Items, Computers and Industrial Engineering 43 (2002) 59-73.

[11] M. Simon, G. Bee, P. Moore, J.S. Pu, C. Xie, Modelling of the Life Cycle of Products with Data Acquisition features, Computers in Industry 45 (2001) 112-122.

[12] M. Negnevitsky, Artificial Intelligence: A Guide to Intelligent Systems, Addison Wesley, Harlow, 2002.

[13] F. Giudice, G. La Rosa, A. Risitino, Product Design for the Environment, CRC Press, Boca Raton, 2006.

[14] L.H. Shu, Reliability modeling in design for remanufacture, Proceedings of the 1996 ASME Design Technical Conferences and Computers in Engineering Conference, Irvine CA, 1996, 1-11.

[15] M. Rausand, A. Hoyland, System Reliability Theory: Models, Statistical Methods and Applications, John Wiley & Sons, New Jersey, 2004.

[16] Y. Ogushi, M. Kandlikar, The Impact of End-Of Life Vehicle Recycling Law on Automobile Recovery in Japan, Proceedings of the 4th International Environmentally Conscious Design and Inverse Manufacturing Symposium, Tokyo, 2005, 626-633.

[17] T. Amezquita, R. Hammond, M. Salazar, B. Bras, Characterizing the Remanufacturability of Engineering Systems, Proceedings of the 21st ASME Design Automation Conference, Advances in Design Automation, Boston 1995, 271-278.

[18] S. Lolas, O.A. Olatunbosun, Prediction of Vehicle Reliability Performance using Artificial Neural Networks, Expert System with Applications 34/4 (2008) 2360-2369.

[19] N.H. Ismail, S.Z. Syed Jaafar, FE Analysis of Door Structure in Meeting Customer's Quality Expectation, Proceedings of the CAE Users Conference, Bangalore, 2006 1-12.

[20] M. Gen, R. Cheng, Genetic Algorithms and Engineering Design, John Wiley & Sons, New York, 1997.