

A Design Framework for End-of-Life Vehicles Recovery: Optimization of Disassembly Sequence Using Genetic Algorithms

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Abstract: Problem statement: It is expected that over the next few years type approval legislation and public awareness will force vehicle manufacturers to identify recovery methods during the design process in order to achieve reuse and recycling targets. Current vehicle design in Malaysia does not sufficiently aid the economic recovery of parts and materials to reach these targets. **Approach:** This study aimed to provide a framework for automotive components to be designed for ease of recovery. Disassemblability concept evolved from the life cycle engineering concept in which design for disassembly is one of the strategies in reducing the impact of the product to the environment. **Results:** The proposed methodology that consisted of three distinct elements namely implementing principles and guidelines of design for disassembly into the design, generating optimum disassembly using genetic algorithm approach and evaluating disassemblability of end-of-life products will be discussed. **Conclusion/Recommendations:** There is a need for effective disassembly in order to enhance the recovery of end-of-life product. The proposed methodology was implemented as a computer-based disassemblability evaluation tool that will enhance disassemblability of the product starting from the design stage.

Key words: Recovery, design for disassembly, optimal disassembly sequence, genetic algorithm

INTRODUCTION

In recent years, the growing amount of waste generated at the End-Of-Life (EOL) of products has become a severe problem in many countries (Kongar and Gupta, 2006). Therefore, in the field of conception and development of industrial products, an approach called Life Cycle Design or Life Cycle Engineering (LCE) has spread and received increasing attention (Giudice and Fargione, 2007). According to this novel approach, emphasis should be placed on the environmental features of products (Gungor and Gupta, 1999), such as the amount of resources utilized in their production, the optimization of these resources through the extension of the useful life of the products, the recovery of resources at the end-of-life and the environmental impact correlated to the entire life cycle. Besides that, growing public awareness on sustainability issues is driving many industries to undertake environmentally conscious policies for their product development, manufacturing, distribution, service and end-of-life management. This includes the growing take-back legislations in Europe, Australia and Asia that

motivates the implementation of product EOL options other than landfill and incineration (Kara *et al.*, 2005). In the majority of EOL processing, a certain level of disassembly may be necessary (Kongar and Gupta, 2006; Lambert, 2002; Lambert and Gupta, 2004). The disassemblability concept evolved from the life cycle engineering concept where the design for disassembly is one of the strategies in reducing the impact of the product to the environment (Afrinaldi *et al.*, 2008). Disassembly can be defined as the systematic separation of an assembly into its components, subassemblies or other groupings (Moore *et al.*, 2001; Ilgin and Gupta, 2010).

As the technology keeps improving, automotive has become one of the fastest growing consumer products. Vehicles are also responsible for the considerable quantities of waste, as 8-10 million cars, trucks and vans are disposed of every year in the USA. In Europe the number is around 14 million and growing and the world figure is about 30 million (Bogue, 2007). According to the data from Malaysian Automotive Association (2009), Malaysia is also facing the same problem. Since vehicles affect the environment through

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their entire life cycle, therefore recovery strategies of automotive are becoming important due to energy and environmental issues (Mok *et al.*, 1997). The automotive industry in Malaysia has grown tremendously since the establishment of Proton in 1985, followed by Perodua in 1993 as a part of the National Car Project. The introduction of the National Car Project has given a boost to the development of components and parts manufacturing in Malaysia. Despite fluctuation in the automotive production, vehicle production in Malaysia tends to increase due to the rapid increase in domestic sales. The total vehicle production in 2007 is 441,678 vehicles as compared to 360,105 vehicles in 2000. From January to September 2009, the total number of vehicles production is 356,490 (Table 1). As such, the automotive industry is facing a number of serious challenges due to its impact on the environment throughout their entire life cycle.

The recovery strategies of Reduce, Reuse and Recycle (3R's) are commonly recognized as the essential ways to decrease the excess of abandoned products generated in the modern society (Takeuchi and Saitou, 2005). However, according to the result of a survey in (Amelia *et al.*, 2009), the interest of Malaysian manufacturers in automotive reuse is not common; reuse is only for the aftermarket sales. The main factors that seemed to influence the perception of the local OEMs (original equipment manufacturers) towards reuse are: customer's perception on the quality of reused products, lack of knowledge and technology to develop reuse and lack of research and development program on reuse.

Efficient disassembly of products is of strategic importance because it can improve their life cycle behavior not only at the use phase and facilitating service interventions (maintenance and repairs), but also at the end-of-life stage, favoring the recycling of materials and the recovery and reuse of components (Giudice and Fargione, 2007). Based on review of Design For Disassembly (DFD) principles and guidelines on DFD, the information should be considered during DFD as outlined below:

- End of life destination for each item: Reuse, recycle or landfill disposal with regular or special treatment
- Value or cost attributable to each item as a result of its end of life destination
- Labor cost for the disassembly of each item
- Cost of disposal of the remainder of the product at each step in the disassembly sequence
- "Total profit" at each step in the disassembly sequence
- "Effect" of each step in the disassembly sequence

Table 1: Production of vehicles in Malaysia in the year 2000-2009

| Year | Passenger vehicle | Commercial vehicles | 4×4 vehicles | Total vehicle |
|----------------|-------------------|---------------------|--------------|---------------|
| 2000 | 295,318 | 37,552 | 27,235 | 360,105 |
| 2001 | 355,863 | 40,916 | 31,922 | 428,701 |
| 2002 | 380,050 | 44,045 | 32,727 | 456,822 |
| 2003 | 327,450 | 65,554 | 33,642 | 426,646 |
| 2004 | 364,852 | 75,384 | 31,739 | 471,975 |
| 2005 | 422,225 | 95,662 | 45,623 | 563,510 |
| 2006 | 377,952 | 96,545 | 28,551 | 503,048 |
| 2007 | 403,245 | 38,433 | - | 441,678 |
| 2008 | 484,512 | 46,298 | - | 530,810 |
| YTD Sept. 2009 | 325,644 | 30,846 | - | 356,490 |

According to Gupta and McLean (1996), research in the area of disassembly can be divided into four groups, product design for ease of disassembly (disassemblability), disassembly process planning, design and implementation of disassembly system and operation planning issues in the disassembly environment. In general, improvements to the disassembly process of a product can be achieved at two levels: in the design phase, making choices that favors the ease of disassembly of the constructional system Design For Disassembly (DFD); planning at best and optimizing the disassembly sequence Disassembly Sequence Planning (DSP).

In this study the first two groups are explored. Disassembly analysis serves as a basis for identifying an efficient product design for reuse. The analysis when performed on a virtual prototype can be used to evaluate sequence and disassembly parameter, ease of disassembly and design decision as well as design rating and optimal design selection. In general, the sequence of disassembly of a product is assumed to be the reverse of the sequence of assembly. However, this assumption is not always true. It is therefore necessary to develop a tool capable of performing evaluation on the disassemblability of a product.

Related study: Several researchers have studied disassembly as it is one of the primary elements for parts and product recovery. In other words, at the EOL of a product, there can be several options for its processing including reuse, remanufacturing, recycling and disposed. In almost all cases, a certain level of disassembly may be necessary. Thus, it is crucial to find an optimal (or near optimal) disassembly sequence in order to increase the efficiency of the process. In recent years, Genetic Algorithm (GA) has gained popularity as a technique for determining the optimum disassembly sequence.

Design for disassembly: Design For Disassembly (DFD) is a class of design method and guidelines to

enhance ease of disassembly for product maintenance or EOL treatments. Research in the area of DFD has increased dramatically since the mid-1980s, when pioneers in design for recycling, such as the German auto manufacturer BMW, first began funding pilot projects to study disassembly (Kroll and Hanft, 1998). Many researchers proposed the general DFD guidelines from the viewpoint of practical disassembly processes. Scheuring *et al.* (1994) discussed the DFD guidelines and their effect on assembly. Dowie-Bhamra (2000) developed guidelines on disassembly for recycling and addition of extra guidelines on disassembly for re-manufacture and reuse. Lee *et al.* (2001) proposed design guidelines for end-of-life disassembly of a product. Bogue (2007) represented the DFD design rules that are achieved by adhering to three key DFE principles: the selection and use of materials; the design of components and the product architecture and the selection and use of joints, connectors and fasteners.

Disassemblability: According to Mok *et al.* (1997), disassemblability is defined as the degree of ease of disassembly. Moreover, Seo *et al.* (2001) defined disassemblability as the ability to optimize the disassembly process for removal of specific parts or materials in such a manner that considers economic and environmental aspects. In the area of design for ease of disassembly, researchers focused their study on the development of disassemblability evaluation system. McGlothlin and Kroll (1995) proposed a spread sheet-like chart to measure ease of disassembly of a product. Kroll and Hanft (1998) extended the McGlothlin and Kroll (1995) study in which they analysed the disassembly task by using a time measurement system called Maynard Operation Sequence Technique (MOST) (Kroll and Hanft, 1998).

Disassembly sequence: In order to find the optimal disassembly sequences, several methods can be used. Gungor and Gupta (1997) proposed a disassembly sequence heuristic which gives a near optimum disassembly sequence for a product (Gungor and Gupta, 1997). The determination of optimum disassembly sequences in electronic product can be found in (Lambert, 2002). Seo *et al.* (2001) presented a genetic algorithm-based approach for an optimal disassembly sequence in term of considering the economic and environmental aspects. Similar study also can be found in (Kongar and Gupta, 2006). Galantucci *et al.* (2004) propose the implementation of hybrid Fuzzy Logic-Genetic Algorithm (FL-GA) methodology to plan the automatic assembly and disassembly sequence of products. Another application of genetic algorithm in disassembly sequencing can be found in (Giudice and

Fargione, 2007). Other metaheuristic methods have also been used in the area of disassembly sequencing, a neural network-based approach to find optimal disassembly sequence in (Huang *et al.*, 2008). Takeuchi and Saitou (2005) presented a computational method for designing assemblies embedded with disassembly sequences that uses a multi-objective Genetic Algorithm (GA) to search for Pareto-optimal designs in terms of the unique realization of the given disassembly sequence, satisfaction of distance specifications among components and the efficient use of locators on components.

Overview of DFD: While Design For Environment (DFE) aims at reducing the environmental impact of products throughout their life cycle, Design For Disassembly (DFD) focuses on the disassembly of products for reuse and recycling at the end of product life (Takeuchi and Saitou, 2005). There are three important factors that must be considered by the designer when designing products with disassembly in mind (Dowie-Bhamra, 2000): The selection and use of materials, the design of components and product architecture and the selection and use of fasteners. Besides that, the design guidelines proposed by Bogue (2007) was achieved by adhering to three key DFE principles: Reducing the material content and energy required in the manufacturing process; increasing the number of recycled parts and increasing the number of parts that are reused in the product.

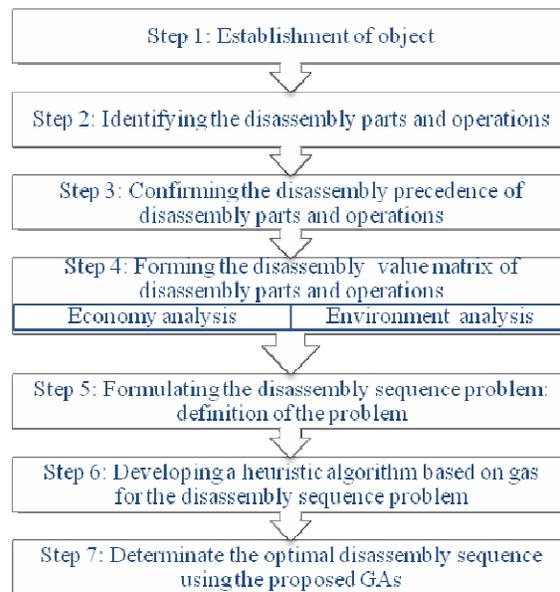


Fig. 1: The flow of the optimal disassembly sequence (Seo *et al.*, 2001)

Overview of DSP: In almost all cases of reuse, remanufacturing, recycling and disposing, a certain level of disassembly may be necessary. Thus, finding an optimal (or near optimal) disassembly sequence is crucial so as to increase the efficiency of the process (Kongar and Gupta, 2006). By definition, a DSP is a sequence of disassembly tasks that begins with a product to be disassembled and terminates in a state where all the parts of the product are disconnected (Gungor and Gupta, 1997). Identifying DSP is not an easy task because DSP generation is described as a Nondeterministic Polynomial-time complete (NP-complete) problem. The number of alternative DSPs increases exponentially with the number of parts in the product being disassembled. Seo *et al.* (2001) proposed a flow chart of the optimal disassembly sequence (Fig. 1). The process starts with the establishment of a product to be disassembled followed by the formulation of the problem and equation with consideration on economic and environmental aspects (Seo *et al.*, 2001). The optimal disassembly sequence is then determined using the proposed GAs.

MATERIALS AND METHODS

The evaluate objectives of the disassembly tool for analyzing product which design for reuse via disassembly are as following:

- The product ease to disassembly for reuse (design assessment)
- Optimal disassembly sequence of the components to be removed for reuse
- Design rate and selection of an optimal design
- Estimated time and cost involved in disassembling the product and
- Decision about the end-of-life option

The proposed method consists of 7 phases. There are:

- Phase 1: Product Data Base and CAD model
- Phase 2: Product Design
- Phase 3: Virtual Prototype
- Phase 4: Product Analysis
- Phase 5: Disassemblability Analysis
- Phase 6: Disassembly Sequence Generation
- Phase 7: Design Rate

The current study in this research is a survey that investigates the implementation for reuse in the automotive or automotive components manufacturers in Malaysia with emphasis on design for reuse via disassembly. From the survey, the locally manufactured automotive components which have potential for reuse

will be identified. The case study will be based on these automotive components.

RESULTS

The proposed framework: From the study, a framework is proposed as shown as Fig. 2. The framework serves as a decision tool for determining suitability of product for reuse. As mentioned earlier, a survey to investigate the implementation of disassembly for reuse in the automotive industry will be conducted. From the survey, the problem statements of the study can be defined clearly. There are 3 main phases in the design process: Conceptual design, configuration design and detail design. DFD shall be implemented at the early stage of product design stage. Besides that, EOL options for the components of product have to be defined at the design stage. Computer aided tools must be deployed for developing product geometry, determining reliability and durability though material selection and engineering analysis. In system modeling, the related mathematical equations are generated. The final stage is evaluation on the optimal disassembly sequence via calculation of disassembly time and end-of-life value. Genetic Algorithms (GA), as a powerful and broadly applicable stool for stochastic search and optimization, are used to generate the optimal disassembly sequence. Hence, the optimal disassembly sequence will be defined.

The ultimate aim of the study is to develop an optimization model for disassembly sequence of components that have potential for reuse. Automotive components that have potential for reuse include clutches, brake shoes, engine block, starters, alternators, water pumps and carburetors (Amelia *et al.*, 2009). The model will be developed based on the Genetic Algorithms (GA) approach.

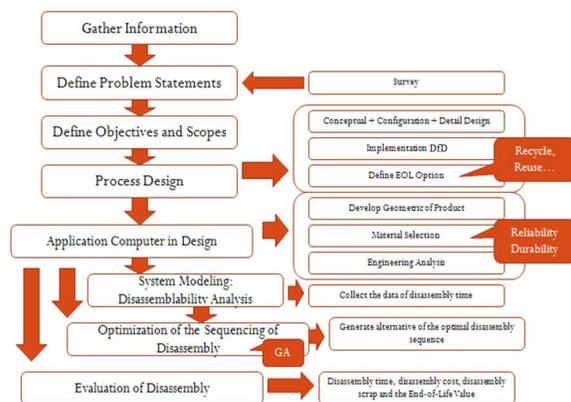


Fig. 2: The proposed framework

MATLAB (Matrix Laboratory) has a wide variety of functions useful to the genetic algorithm practitioner and those wishing to experiment with the genetic algorithm for the first time. Five components of GA as summarized by Gen and Cheng (1999) are a genetic representation of solutions to the problem, a way to create an initial population of solutions, an evaluation function rating solutions in term of their fitness, genetic operator that alter the genetic composition of children during reproduction and values for the parameters of GA. In this study, MATLAB is used for GA implementation to obtain the optimum disassembly sequence for an EOL product. The implementation step includes development of the coding for fitness function, initialization of population, selection of elite chromosomes, GA operators (crossover and mutation) and reproduction (new population) and stopping criteria for the study.

DISCUSSION

The DFD framework (Fig. 3) identifies the abstract design modules that need to be developed in order to build a geometric virtual disassembly tool. The modules are software programs that are executed as part of various design steps. The design steps are: (1) product analysis, (2) disassemblability analysis, (3) optimal disassembly sequence generation and (4) design rating.

Figure 4 represents the abstract design modules for building a virtual disassembly tool in a product design environment. These modules perform the following tasks: virtual prototyping, metric formulation and disassembly analysis.

Virtual prototyping: A virtual prototype is built from the CAD model and a pre-existing database of the product, so that the design step (1) in Fig. 3 can be executed. The virtual prototype is defined to contain the following: Component geometry, topology of components and domain detail (component requiring grouping, the specific hierarchy of the components and joint or fastener information).

Metric formulation: In this stage, the alternate designs that generate and determine the optimal disassembly sequence will be compared (design Step 2 and 3). Genetic algorithms will be used in generated the optimum disassembly sequence.

Disassembly analysis: The disassembly analysis module generates an optimal disassembly sequence for recovery, followed by the evaluation of disassembly parameters such as disassembly time, disassembly cost, disassembly scrap and the End-of-Life Value (Lee *et al.*, 2001) that result from disassembling (design Step 4).

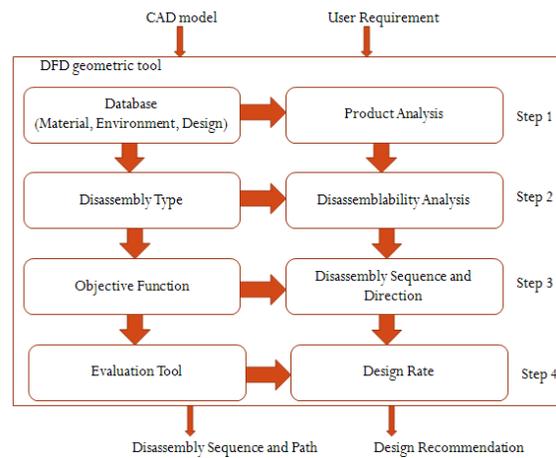


Fig. 3: DFD framework (Srinivasan *et al.*, 1997)

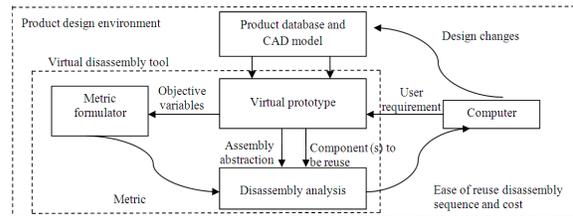


Fig. 4: Virtual disassembly tool to assess for ease of reuse (Gadh *et al.*, 1998)

GA is attractive because it can handle problem constraints by simply embedding them into this chromosome coding and it is a very easy-to-understand technique with very few (or even none) mathematics involved. The procedures GA perhaps will fulfill the follow steps:

- Step 1: Start with a population of 10 chromosomes which are generated randomly and then the fitness of each chromosome is calculated
- Step 2: The chromosomes are sorted in the ascending order according to their fitness values
- Step 3: If the current population is not the initial population, chromosomes which consists the fitness values less than the expectation value are selected as the parents in the crossover operation or chromosomes for the next population
- Step 4: Randomly calculate the crossover probability. If the probability holds, perform one-point crossover operation in which, children will be generated from the selected parents; otherwise, parents are defined as children

- Step 5: Then the fitness of each child is calculated. The children are sorted in the ascending order according to their fitness values. The 10 best chromosomes from parents and children are selected and placed into the new population
- Step 6: If there is less than 10 chromosomes are selected, the less chromosomes will be generated randomly so that the new generation will constantly contain 10 chromosomes. If there is more than 10 chromosomes are selected, the 10 chromosomes which consist the best 10 values of fitness are selected
- Step 7: Randomly calculate the mutation probability. If the probability holds perform mutation operation, sequences of unit 1 and unit 2 will be exchanged with each other; otherwise, the current population is defined as the new population
- Step 8: The execution of GA will stop if the termination condition is satisfied, else return to Step 1 with replace the initial population to new population

CONCLUSION

This study proposes a model for implementing the principles and guidelines of DFD into design using the genetic algorithm approach and evaluating disassemblability of end-of-life products. Currently the study is at the development stage in which the methodology is implemented as a computer-based disassemblability evaluation tool. The genetic algorithm model was presented in order to determine the optimal disassembly sequence of a given part of automotive component. The model provides a quick and reliable input to the disassembly scheduling environment. For the example considered, the algorithm provided optimal disassembly sequence in a short execution time. The algorithm is practical, as it is easy to use, considers the precedence relationships and additional constraints in the product structure and is easily applicable to problems with multiple objectives.

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REFERENCES

Afrinaldi, F., M.Z. Mat Saman and A.M. Shaharoun, 2008. The evaluation methods of disassemblability for automotive components-a review and agenda for future research. *J. Mekanikal*, 26: 49-62.

Amelia, L., D.A. Wahab, C.H. Che Haron, N. Muhamad and C.H. Azhari, 2009. Initiating automotive component reuse in Malaysia. *J. Cleaner Prod.*, 17: 1572-1579. DOI: 10.1016/j.jclepro.2009.06.011

Bogue, R., 2007. Design for disassembly: A critical twenty-first century discipline. *Assembly Automat.*, 27: 285-289. DOI: 10.1108/01445150710827069

Dowie-Bhamra, T., 2000. Design for disassembly. University of Manchester. <http://www.co-design.co.uk/design.htm>

Gadh, R., H. Srinivasan, S. Nugehalli and R. Figueroa, 1998. Virtual disassembly-a software tool for developing product dismantling and maintenance systems. Proceedings of the Annual Reliability and Maintainability Symposium, Jan. 19-22, IEEE Xplore Press, Anaheim, CA., USA., pp: 120-125. DOI: 10.1109/RAMS.1998.653676

Galantucci, L.M., G. Percoco and R. Spina, 2004. Assembly and disassembly by using fuzzy logic and genetic algorithms. *Int. J. Adv. Robot. Syst.*, 1: 67-74.

Gen, M. and R. Cheng, 1999. Genetic Algorithms and Engineering Optimization. 1st Edn., Wiley-interscience, New York, ISBN: 10: 0471315311, pp: 512.

Giudice, F. and G. Fargione, 2007. Disassembly planning of mechanical systems for service and recovery: A genetic algorithm based approach. *J. Intel. Manuf.*, 18: 313-329. DOI: 10.1007/s10845-007-0025-9

Gungor, A. and S.M. Gupta, 1997. An evaluation methodology for disassembly processes. *Comput. Ind. Eng.*, 33: 329-332.

Gungor, A. and S.M. Gupta, 1999. Issues in environmentally conscious manufacturing and product recovery: A survey. *Comput. Ind. Eng.*, 36: 811-853.

Gupta, S.M. and C.R. McLean, 1996. Disassembly of products. *Comput. Ind. Eng.*, 31: 225-228.

Huang, H.H., M.H. Wang and M.R. Johnson, 2008. Disassembly sequence generation using a neural network approach. *J. Manuf. Syst.*, 19: 73-82. DOI: 10.1016/S0278-6125(00)80001-1

Ilgin, A.M. and S.M. Gupta, 2010. Environmentally Conscious Manufacturing and Product Recovery (ECMPRO): A review of the state of the art. *J. Environ. Manage.*, 91: 563-591. DOI: 10.1016/j.jenvman.2009.09.037

Kara, S., M. Mazhar, H. Kaebnick and A. Ahmed, 2005. Determining the reuse potential of components based on life cycle data. *CIRP Ann.-Manuf. Technol.*, 54: 1-4. DOI: 10.1016/S0007-8506(07)60036-5

- Kongar, E. and S.M. Gupta, 2006. Disassembly sequencing using genetic algorithm. *Int. J. Adv. Manuf. Technol.*, 30: 497-506. DOI: 10.1007/s00170-005-0041-x
- Kroll, E. and T.A. Hanft, 1998. Quantitative evaluation of product disassembly for recycling. *Res. Eng. Des.*, 10: 1-14. DOI: 10.1007/BF01580266
- Lambert, A.J.D. and S.M. Gupta, 2004. *Disassembly for Modeling for Assembly, Maintenance, Reuse and Recycling*. 1st Edn., CPC Press, New York, ISBN: 10: 1574443348, pp: 448.
- Lambert, A.J.D., 2002. Determining optimum disassembly sequences in electronic equipment. *Comput. Ind. Eng.*, 43: 553-575.
- Lee, S.G., S.W. Lye and M.K. Khoo, 2001. A multi-objective methodology for evaluating product end-of-life options and disassembly. *Int. J. Adv. Manuf. Technol.*, 18: 148-156. DOI: 10.1007/s001700170086
- Malaysian Automotive Association, 2009. Summary of sales and production data. Malaysia Automotive Association. http://www.maa.org.my/info_summary.htm
- McGlothlin, S. and E. Kroll, 1995. Systematic estimation of disassembly difficulties: Application to computer monitors. *Proceeding of the IEEE International Symposium on Electronics and the Environment*, May 1-3, IEEE Xplore Press, Orlando, FL., USA., pp: 83-88. DOI: 10.1109/ISEE.1995.514955
- Mok, H.S., H.J. Kim and K.S. Moon, 1997. Disassemblability of mechanical parts in automobile for recycling. *Comput. Ind. Eng.*, 33: 621-624.
- Moore, K.E., A. Gungor and S.M. Gupta, 2001. Petri net approach to disassembly process planning for products with complex AND/OR precedence relationships. *Eur. J. Oper. Res.*, 135: 428-449. DOI: 10.1016/S0377-2217(00)00321-0
- Scheuring, J.F., B. Bras and K.M. Lee, 1994. Effects of design for disassembly on integrated disassembly and assembly processes. *Proceeding of the 4th International Conference on Computer Integrated Manufacturing and Automation Technology*, Oct. 10-12, IEEE Xplore Press, Troy, NY., USA., pp: 53-59. DOI: 10.1109/CIMAT.1994.389094
- Seo, K.K., J.H. Park and D. H. Jang, 2001. Optimal disassembly sequence using genetic algorithms considering economic and environmental aspects. *Int. J. Adv. Manuf. Technol.*, 18: 371-380. DOI: 10.1007/s001700170061
- Srinivasan, H., N. Shyamsundar and R. Gadh, 1997. Virtual disassembly tool to support environmentally conscious product design. *Proceedings of the 5th IEEE International Symposium on Electronics and the Environment*, May 5-7, IEEE Xplore Press, San Francisco, CA., USA., pp: 7-12. DOI: 10.1109/ISEE.1997.605198
- Takeuchi, S. and K. Saitou, 2005. Design for product embedded disassembly sequence. *Proceedings of the 6th IEEE International Symposium on Assembly and Task Planning*, July 19-21, IEEE Xplore Press, Montreal, Que., pp: 41-46. DOI: 10.1109/ISATP.2005.1511448