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Genetically optimised disassembly sequence for automotive component reuse

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ABSTRACT

Environmental sustainability through end-of-life recovery has become the main items of contest in the automotive industries. Component reuse as one of the product recovery strategy is now gaining importance in view of its impact on the environment. Disassembly as one of the determinant factors for reuse is a very important and difficult process in life cycle engineering. To enable reuse, a certain level of disassembly of each component is necessary so that parts of the products that have arrived at their end-of life can be easily taken apart. Improvements to the disassembly process of products can be achieved at two levels: in the design phase, making choices that favours the ease of disassembly of the constructional system (design for disassembly) and planning at best and optimising the disassembly sequence (disassembly sequence planning). Hence, finding an optimal disassembly sequence is important to increase the reusability of the product. This paper presents the development work on an optimisation model for disassembly sequence using the genetic algorithms (GA) approach. GA is chosen to solve this optimisation model due to its capability in solving many large and complex optimisation problems compared with other heuristic methods. The fitness function of the GA in this study is dependent on the increment in disassembly time. Comparison of results using different combinatorial operators and tests with different probability factors are shown. This paper will present and discuss the disassembly sequence of an engine block, as a case example which achieves the minimum disassembly time.

1. Introduction

The growing amount of waste generated at the end-of-life (EOL) of vehicle is an issue of great concern in many countries. Environmental awareness and recycling regulations have been putting pressure on many manufacturers and consumers, forcing them to produce and dispose products in an environmentally responsible manner (Ilgin & Gupta, 2010). Thus, during conception and development of products, design for environment (DFE) is focused and the application of life cycle design or life cycle engineering (LCE) has been wide-spread and receiving attention (Giudice & Fargione, 2007;Kongar & Gupta, 2006). DFE and LCE have emphasised on the environmental features of products such as the amount of resources utilized in their production, the optimisation 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 (Giudice & Fargione, 2007). In addition, Taghaboni-Dutta, Trappey, and Trappey (2010) describe the environmental factors to be considered when designing green products that include material, production methods, packaging and transportation, usage, waste, and recovery.

Mathieux, Froelich, and Moszkowicz (2008) defined recoverability of a product as its ability to be recovered, i.e., the ability of the product, its components and the constitutive materials either to be reused, or to be recycled, or to be recovered as energy. Fig. 1 represents the theoretical recovery hierarchy from Gerrard and Kandlikar (2007). Reuse of product or component is the highest hierarchy of product recovery at the end of its life cycle (Amelia, Wahab, Che Haron, Muhamad, & Azhari, 2009; Gerrard & Kandlikar, 2007; Wahab, Amelia, Hooi, Che Haron, & Azhari, 2008).

Reuse is defined as the discarded items that are used again for their original purpose. This enables the highest level of material reuse and has a significantly better impact on the environment than recycling (Océ, 2010). The object does not need to be produced using virgin materials which presents an environmental saving in terms of extracting the materials and also the processing or transporting of the object (Océ, 2010). Reuse can also save money. This is because a new order for a new object will not be required at all, which saves money and time as well. This all results in quicker delivery back to the market. Reuse is important to sustainability for the following reasons: reduces the need for landfilling and incineration, prevents pollution caused by the manufacturing of products from virgin materials, saves energy, decreases emissions of greenhouse gases that contribute to global climate change, conserves natural resources such as timber, water, and minerals, protects and expands manufacturing jobs and increases competitiveness of the

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Fig. 1. Theoretical recovery hierarchy. *Source*: Gerrard and Kandlikar (2007).

manufacturers and finally helps sustain the environment for future generations (Sustainable Jersey, 2010).

In order to improve the recovery of products at the end of their life, two strategies can be implemented by car or car components manufacturers: either curative action or preventive action (Mathieux et al., 2008). Curative actions may include promoting technical and economic development and improvement in recovery processes to be applied to products at the end of their life, while preventive actions are improving, through better design, the product's recoverability which are called design for recycling or design for environment.

Reuse has many advantages especially to manufacturers; however, very few researches in product or component design for reuse have been conducted especially in the automotive industry. There is a large body of scientific literature devoted to discussing the different feasible strategies and tools for eco-design and product life cycle design. An observation is that, among all the documented studies, design for recycling and design for disassembly appear to be the least commonly addressed (Cerdan, Gazulla, Raugei, Martinez, & Fullana-i-Palmer, 2009). Therefore, movement toward design for re-use and remanufacturing seems limited. Increasing the level of re-use and remanufacturing will be a key part of moving toward sustainable vehicle production. In the other words, determining the best strategy for recovery of a product has led several researchers to use cost estimation and Life Cycle Assessment (LCA) techniques. Except for landfill and incineration, components of economic value destined for reuse, remanufacture, or recycling have first to be extracted from the product (Lee, Lye, & Khoo, 2001). It is therefore necessary to determine the optimal stage of disassembly, when all economically valuable components are retrieved.

Disassembly is a very important and difficult process in green remanufacturing engineering (Yan, Jiang, & Li, 2006) and the efficient disassembly of product is important in order to enhance the life cycle behavior, as a certain level of disassembly is necessary in the majority of EOL processing (Kongar & Gupta, 2001, 2006) Additionally, disassembly is an important process in material and product recovery since it allows for the selective separation of desired parts and materials (Ilgin & Gupta, 2010). The premise of recycling and reusing of worn-out products is that the parts of products that have arrived at their lifecycle and need recycling can be easily taken down. According to Afrinaldi and Mat Saman (2008), the environmental impacts of products can be minimized only if the products can be disassembled easily and the cost effectiveness of recycling will be increased if disassembly is made easier. As such, prior to product disassembly, the process should be optimised and programmed properly with the aims to address the economics of disassembling, coordination with the environment and feasibility of technique. Only then, an optimal disassembly sequences can be obtained (Yan et al., 2006).

Therefore, finding an optimal disassembly sequence is important in order to increase the reusability of the product. In this paper, the disassembly of an engine to obtain the engine block is implemented as the case study. Due to the importance of the engine block in the functioning of the car, it is recommended that drivers or automobile owners perform regular maintenance on their vehicles. This is to prevent damage to the internal parts which can be caused by overheating, insufficient oil, and other easily preventable situations which in turn help in extending the life time of engine block. Furthermore, according to Driesch, Oyen, and Flapper (2005), Mercedes-Benz (MB) offers the owners of an MB car, van, or truck the option of replacing their present engine with a remanufactured engine, of the same or different type, with the same quality as a new engine, but for a price 20–30% lower than the price of a similar new engine. Therefore, engine block is a potential reusable end-of-life (EOL) product.

This paper is organized as follows: Section 2 presents the literature review of previous work in reuse/recovery and Section 3 focuses on the case example used for the study and the method to optimise the disassembly sequence of reuse using GA. In Section 4 the results are discussed, followed by the concluding remarks in Section 5.

2. Literature review

It is important to maximize the usage percentage of resources and minimize the damage to the environment in the early product design stage (Tseng, Chang, & Li, 2008). The trend of traditional product development in design is with respect to cost, functionality and manufacturability (Ilgin & Gupta, 2010). However, DFE and LCE forces product designers to consider certain environmental criteria in the design process. Design for X (DFX) is one of the methodologies that have been developed to help product designers make environmentally friendly design choices. DFX involves different design specialties such as Design for disassembly (DFD) and design for recycle (DFR), design for manufacture, design for quality, etc. (Ilgin & Gupta, 2010). Design for environment (DFE) is the design of products in a way that the potential environmental impact throughout the life cycle is minimized (Giudice, La Rosa, & Risitano, 2006; Ilgin & Gupta, 2010). Design for Disassembly (DFD) can be defined as the consideration of the ease of disassembly in design process. Design for Recycling (DFR) focuses on the design attributes which support the cost-effective recycle and disaggregation of the materials embodied in the product. This paper's focuses on disassembly and will therefore consider product recovery related DFD and Disassembly Sequence Planning (DSP).

DFD can be defined as the consideration of the ease of disassembly in design process (Veerakamolmal & Gupta, 2000; Desai & Mital, 2005). DFD addresses maintainability and recyclability, such that flawed components can be easily accessed and replaced in product maintenance, and valuable resources can be efficiently retrieved at the end of the product life cycle (Yu & Li, 2006). According to Afrinaldi and Mat Saman (2008), earlier disassemblability methodologies used spread sheet-like chart to measure disassemblability. McGlothlin and Kroll (1995) designed the spread sheet-like chart to measure ease of disassembly of a product. Kroll and Hanft (1998) extended the Mcglothin and Kroll work in 1998 by added a catalog of task difficulty scores in disassemblability evaluation. The scores are determined based on the work-measurement analyses of standard disassembly tasks. Veerakamolmal and Gupta (1999) introduce Design for Disassembly Index (DfDI) to measure the design efficiency. DfDI is calculated by using a disassembly tree which allows the identification of precedence relationships that define the structural constraints in terms of the order in which components can be retrieved. Kroll and Carver (1999) made an attempt to develop time-based DFD metrics to be used for comparing alternative designs of the same product. Desai and Mital (2003) and Mital and Desai (2007) developed a methodology to enhance the disassemblability of products. They defined disassemblability