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Integrating environmental consciousness in product/process development based on life-cycle thinking

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Abstract

This paper describes a general methodology in Design for Environment (DFE), and a part of our research with a specific application using entropy minimisation. The entropy evaluation brings about the generation of a disassembly sequence in which the disassembly efficiency, the material value and the specific value are big and the liability is small, as a gold ship's chronometer. Fuzzy logic and feature modelling are used during the DFE evaluation for parts, assembly and operations analysis. Increasing and extensive environmental concerns lead to the establishment of general metrics and operational guideline. A case study shows the methodology; only the disassembly analysis is detailed.

Keywords: Design for environment; Entropy evaluation; Fuzzy logic; Features; Disassembly

1. Introduction

Product design is a critical determinant of a manufacturer's competitiveness. It has been claimed that as much as 80% of the costs of product development, manufacture and use are determined during the initial design stages. The earlier in the product design life cycle, that a design team considers environmental factors, the greater the potential for environmental benefit and cost reduction. The needs in incorporating environmental consciousness into the design for a product or production process lead to the emerging of design for environment (DFE). DFE is the systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle. The main environmental implication that a designer seeks to control in a product will dictate what strategy of DFE to pursue. These are Design For Recyclability (DFR), Design For Remanufacturability (DFRM), Design For Reusability (DFRU), Design For Disassembly (DFD), Design For Maintainability/Serviceability (DFMS), and Design For Energy Savings (DFES) in the use phase. Reuse implies that the component, part, or material can be utilised again as it, without modification or upgrade other than cleanup. Remanufacturing involves performing manufacturing operations onto the disposed item so that it can utilise again. Recently, recycling

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became an emphasis in most industrial countries due to the fact that the quantity of used products being discarded is increasing dramatically. It has been recognised that disassembly of used product is necessary in order to make recycling economically viable in the current state-of-the-art reprocessing technology. Three objectives that should be considered during design evaluation: maximisation of profit (benefit–costs) over a product's life span, maximisation of the number of parts reused, and minimisation of the amount (weight) of landfill waste. Due to their wide spread utilisation DFD and DFES have been reported to be the focus of greater research effort (Santochi et al., 2002; Mascle and Balasoiu, 2003; Subramani and Dewhurst, 1991). Some obstacles that made disassembly difficult or today's manufactured products: difficult to gain all the information necessary to plan the disassembly, many consumer products are not designed for ease of disassembly. Two engineering problems associated with DFR are dismantling techniques and recycling costs. The remanufacturing industry faces two issues: (1) components that fail, types of failure, and the distributions of times to failure are often unknown and/or present a large variance, and (2) lack of an incentive to customers to buy remanufactured products, as well as perception that they are ''second'' hand, hence have low quality. Both problems ultimately affect remanufacturing planning. In addition to that, another big issue is the technological barriers to remanufacturing that stem from product differentiation. As for recycling, perhaps the greatest problems that this industry faces are the lack of sufficient collection infrastructure, identification, sorting and compaction of materials, and economic ineffectiveness (Bhander et al., 2003).

2. Related works

A particularly problematic aspect of any DFE method is to find techniques to measure and compare the environmental impact of a design choice. Usually, a product's life cycle can be divided into five stages. The first stage is the material extraction phase in which raw materials are gathered and picked to the manufacturing site. Next, is the material processing stage. Third, in the manufacturing stage, the raw materials are put together to form a finished good. The fourth stage is the usage phase in which the product is actually used and exhausted by the consumer. Finally, the product must be retired when the consumer no longer wants it. In each of these stages, there are many complex interactions with the environment. To understand a product's environmental effect, it is necessary to investigate all the consequences of the product over its entire life cycle. Essentially, all the environmental effects can be said to be dependent on the product's function and on its total design. Nevertheless, it is a very complicated question to infer environmental results from a product design. A number of methods for the comparison and evaluation of an inventory's dissimilar pollution loads and resource demands have been proposed, but no satisfactory solution has yet been identified.

Among them, six methods, representatives of quantitative methods used for Life-Cycle Assessment (LCA) and DFE, were developed. (1) Health Hazard Scoring (HHS) uses the Analytical Hierarchy Process (AHP) to weight workplace toxic effects and accident risks (Srinivasan et al., 1995); (2) The Material Input Per Service (MIPS) aggregates the mass of all the material input required to produce a product or service (Bringezu et al., 1994). (3) The Swiss Eco-Point (SEP) method scores pollutant loading based on a source's contribution to an acceptable total pollution load and an environmental scarcity factor (BUWAL, 1998). (4) The Sustainable Process Index (SPI) determines the area that would be required to operate a process sustainable, based on renewable resource generation and toxic degradation; an extension of the dilution volume approach (Krotscheck and Narodoslawsky, 1994). (5) The Society of Environmental Toxicology And Chemistry's Life-Cycle impact Assessment (SETAC LCA) method aggregates pollutants with similar impacts to equivalency potentials (measured in kg CO_2 equivalent, kg benzene equivalent, etc.) and uses decision analysis to assign weights to different adverse impacts (Consoli, 1999; Hanssen, 1996, 1999; SETAC, 1999). (6) The Environmental Priority System (EPS) characterizes the environmental damage caused by equivalency potentials and expresses it in monetary terms, derived form environmental economics. The impact assessment methods described here span a wide spectrum from simple, limited in scope, and narrow in focus, to sophisticated, inclusive of many impacts, and explicit in valuation. The complexity of the methods and hence the expenses associated with their application increases roughly along this continuum (www.epa.gouv). In Table 1, we present a