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Evaluation of connection types in design for disassembly (DFD) using analytic network process ☆

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Abstract

Design for disassembly (DFD) is an important design concept to make products more friendly for maintenance and remanufacturing practices. One of the important issues in DFD guidelines is related with the selection of the connectors used in the product. This paper evaluates the alternative connection types using the powerful analytic network process (ANP). The paper generates a complete ANP model, which includes all important aspects of connector selection. The model presented evaluates alternative connectors by including the three main concerns: (1) making product disassembly friendly; (2) making product assembly efficient; and (3) increasing the product performance when it is in-use. The results obtained from the model can benefit designers in making better decisions on selecting connectors to be used in the product. Benefits of the approach is detailed through illustrative example.

Keywords: Design for disassembly; Disassembly; Connectors; ANP; Environment

1. Introduction

Disassembly is a systematic method for separating a product into its constituent parts, components, subassemblies, or other groupings for several reasons (Lambert & Gupta, 2005). One of the reasons for disassembly is to carry out maintenance-related activities. Either a simple product or a complicated machine may be disassembled partially for the purpose of repair or periodic maintenance. Until a decade ago, many people believed that this is the only purpose of disassembly. However, with the realization of environmental problems including the alarming rate of diminishing resources, the concept of product recovery has captured the attention of a lot of governments, companies, researchers as well as the general public (Gungor & Gupta, 1999). Product recovery (PR) aims to minimize the amount of waste sent to landfills by recovering components and materials from old or outdated products via remanufacturing and recycling (including reuse of parts and products).

Recycling aims to recover the material content of retired products by performing the necessary disassembly, sorting, and chemical operations. On the other hand, remanufacturing preserves the product's (or the part's) identity and performs the required disassembly, sorting, refurbishing and assembly operations in order to bring the product to a desired level of quality. Disassembly has proven its role in PR by allowing selective separation of desired parts and

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materials. Disassembly may be partial (some subassemblies are not fully disassembled) or complete (the product is fully disassembled) depending on the objectives of the disassembly processes (Gungor & Gupta, 2002). Although complete disassembly has not yet been commonly practiced, the current tendency towards the PR will increase its use (Lambert & Gupta, 2005).

Disassembly operations both in PR and maintenance are affected by the design stage of the product. The number of parts, the fastener elements used to create the product generates a huge impact on the efficiency of disassembly processes. Thus, designing for disassembly (DFD) is important and, therefore, it has been given a special attention (Fischetti, 1992; Inoue, 1994; Li, Zhang, Wang, & Awoniyi, 1995; Lowe & Niku, 1995; Shyamsundar, Ashai, & Gadh, 1998; Simon, 1991; Subramanian, 2004; Villalba, Segarra, Chimenos, & Espiell, 2004; Wittenburg, 1992). DFD initiatives lead to the correct identification of design specifications to minimize the complexity of the structure of the product by minimizing the number of parts, increasing the use of common materials and choosing the fastener and joint types which are easily removable.

Connectors play a key role in determining the disassemblability of the product. A connector or a fastener is a component, which is utilized to hold the mated parts together in a product. The type of fastening method employed determines whether the product is to be disassembled using a destructive or a non-destructive disassembly approach. Therefore, the selection of fasteners become an important question in DFD. Although, destructive approaches such as cutting, breaking and tearing are popular disassembly applications, non-destructive approaches are favorable due to their ability in retrieving parts and materials at higher level of quality. In fact, if one wants to re-use a part from an old product it must be recovered unharmed; thus, non-destructive disassembly remains as a single option. Without any debate, non-destructive method is chosen to disassemble a product for the purpose of repair and maintenance.

Non-destructive disassembly requires the use of connectors that are 'easy' to unfasten. This paper evaluates alternative connection types in design for disassembly (DFD) using an analytic approach. The approach employed is the analytic network process (ANP). ANP is used in many fields including environmentally related practices (Pochampally & Gupta, 2005; Ravi, Shankar, & Tiwari, 2005). The evaluation of connection types deals with quantitative and qualitative measures. This is why the current work uses ANP, which is a strong analytical decision tool capable of including quantitative and qualitative criteria and their interdependencies into the evaluation process.

2. Effects of connectors on DFD

2.1. Design for disassembly (DFD)

Design for disassembly (DFD) is a design concept designers utilize to make products easily disassemblable (Boothroyd & Alting, 1992). DFD is a concept in the general design concept of 'Design for X' (DFX) (Gatenby & Foo, 1990; Kuo, Huang, & Zhang, 2001). DFD has been around for years because of repair and maintenance operations. However, its popularity has increased due to product recovery, which requires some degree of disassembly for selective separation of components and materials from the used products. Disassembly is done destructively or non-destructively depending on the goal. If a certain component is to be retrieved undamaged, the non-destructive disassembly is applied whereas destructive disassembly takes place if there is no concern on damaging the desired component or materials. Destructive disassembly is used for the purpose of material recovery and preferred when non-destructive disassembly is impossible or too costly. Non-destructive disassembly is more challenging due to its objectives. Design for disassembly (DFD) is mostly aimed at making non-destructive disassembly operations more effective. In the literature, DFD related work is limited (Desai & Mital, 2003a,b). Some relevant work is presented here.

DFD is often carried out using software due to the complexity of the problem. Hesselbach and Kuhn (1998) present a computer-based method that supports the design of a product in terms of disassemblability. In order to identify the disassemblability of the product, the authors propose an assessment method. The proposed method covers the calculation of the process parameters level, time, costs and sequence of disassembly and the assessment of product properties. The evaluation method is converted into computerized tool. Kroll, Beardsley and Parulian (1996) propose a rating scheme that allows the designers to translate properties of a design into quantitative scores and thus provide a means of identifying weaknesses in the design and comparing alternatives. Kroll and Carver (1999) study the problem of assessing product ease of disassembly for recycling in light of the broader issue of manufacturability evaluation. They use an electric drill to demonstrate the proposed approach. They also developed some disassembly metric to estimate the disassembly time. Kuo (2000) analyzes the disassembly sequence and cost for the electromechanical