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Evaluation of products at design phase for an efficient disassembly at end-of-life

Mahdi Sabaghi [a,*], Christian Mascle [a], Pierre Baptiste [b]

[a] Department of Mechanical Engineering, École Polytechnique de Montréal, C.P.6079 Succ. Centre-Ville, Montréal, Québec, Canada H3C3A7

[b] Department of Mathematics and Industrial Engineering, École polytechnique de Montréal, C.P.6079 Succ. Centre-Ville, Montréal, Québec, Canada H3C3A

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ABSTRACT

Despite aerospace industries are moving toward circular economy and reutilization of materials and components, every year hundreds of aircrafts end up in landfills without an appropriate treatment. This is mainly due to the lack of a proper design for end-of-life. New innovative approaches should be considered at the design phase with remarkable attention to disassembly aspect at the time of retirement. Considering disassembly as a multi-criteria decision-making problem, several parameters may influence the performance of a disassembly-task. Taking the experience accumulated during the disassembly work on a Bombardier Regional Jet aircraft, five parameters were considered in this study. A hybrid design of experiment (DOE) and TOPSIS method was proposed in order to obtain a unique discriminant disassembly model to calculate the disassemblability index for each two given components. The results from ANOVA showed that the derived disassembly model has a 94.30% of reliability. The application of the proposed model at the design phase could facilitate the evaluation of disassembly operation at the end-of-life.

1. Introduction

As a result of shortened product life-cycle and increasing awareness about the environment, legislation communities come up with more and more strict regulations for product manufacturers. In Europe since 2006 end-of-life policy for vehicles was set to: minimum 80% of the vehicle's material should be reusable and recyclable; and this ratio is supposed to increase to 95% by 2015 (Blume and Walther, 2013; Millet et al., 2012). In aerospace industry, according to Airbus (2008)'s report "Process for Advanced Management of End-of-Life of Aircraft (PAMELA)", around 85% of the weight of a civil aircraft can be potentially recovered (15% for direct reuse, and 70% through valorization). However, a recent study performed in aircraft manufacturing facilities in Wichita, showed that only 20% of the potential recoverable materials from 1765 aircrafts was actually recovered (Asmatulu et al., 2013b).

Many efforts have been done to increase the actual recoverability rate of aircrafts (Asmatulu et al., 2013a; Das and Kaufman, 2008; Feldhusen et al., 2011; Latremouille-Viau et al., 2010; Mascle et al., 2015). The researches have been focused on two main branches: **improvement of end-of-life treatment methods** and **amelioration of product design at the development phase**.

Looking at the efforts to improve end-of-life treatment techniques, in earlier attempts within the framework of the project "*Process for advanced management and technologies of aircraft end-of-life*" (CRIAQ-ENV412), different disassembly/dismantling strategies were implemented on a Bombardier Regional Jet aircraft with the aim to select the best strategy in terms of sustainability. The results showed that disassembly-based strategies can provide more environmental contributions (Sabaghi et al., 2015a). However, due to complexity in structure of the carcass, a complete disassembly is not economically viable (Sabaghi et al., in press). Somehow, this is due to the fact that current aircrafts are being conceived neglecting an efficient design for end-of-life.

Amelioration of product design at the development phase stands as a very promising approach to increase the product recoverability rate (Duflou et al., 2008; Giudice and Kassem, 2009). Several design methodologies have been proposed to be applied for end-of-life suitability such as: design for modularity, design for recycling, design for environment, design for disassembly, design for rebirth, etc. (Åkermark, 1997; Collado-Ruiz and

* Corresponding author. Tel.: +1 514 340 5121x4271; fax: +1 514 340 5867.
E-mail addresses: mahdi.sabaghi@polymtl.ca (M. Sabaghi), christian.mascle@polymtl.ca (C. Mascle), pierre.baptiste@polymtl.ca (P. Baptiste).

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Nomenclature

ANOVA	analysis of variance
DOE	design of experiment
MCDM	multi-criteria decision-making
TOPSIS	technique for order preference by similarity to ideal solution
P1	accessibility
P2	mating face
P3	tools type
P4	connection type
P5	quantity and variety of connections
CR	consistency ratio for comparison-matrices
D	decision-matrix in TOPSIS
n	number of disassemblability parameters in decision-matrix D
m	number of disassembly-tasks (alternatives) in decision-matrix D
P_j	parameter j in decision-matrix D
A_i	disassembly-task (alternative) i in decision-matrix D
d_{ij}	input value of parameter j for disassembly-task i in matrix D
R	normalized decision-matrix
r_{ij}	normalized value of parameter j for disassembly-task i in matrix R
V	weighted-normalized decision-matrix
v_{ij}	weighted-normalized value of parameter j for disassembly-task i in matrix V
W_j	relative importance weight of parameter j
v_j^+	the best value for parameter j among the alternatives in matrix V
v_j^-	the worst value for parameter j among the alternatives in matrix V
PIS	positive ideal solution
NIS	negative ideal solution
d_i^+	Euclidean distance of disassembly-task i to PIS
d_i^-	Euclidean distance of disassembly-task i to NIS
RC_i	disassemblability index of disassembly-task i
Y	response-vector of disassemblability indices in DOE–TOPSIS model
X	coded decision-matrix in DOE–TOPSIS
β	coefficient-vector
β_0	Y-Intercept coefficient
β_j	effect coefficient of parameter j
ε	error-vector
$\hat{Y}$	predicted value of disassemblability index
X_j	coded input value for parameter j
p_j	un-coded input value for parameter j
$p_j\ (min)$	minimum possible input value (un-coded) for parameter j
$p_j\ (max)$	maximum possible input value (un-coded) for parameter j

Capuz-Rizo, 2010; Huang et al., 2012; Mascle, 2013; McCluskey et al., 2009; Qian and Zhang, 2009; Rose et al., 2000; Tseng et al., 2008). The productivity associated with all these design methods depends on a proper disassembly which leads to a higher rebirth rate for components and modules. Disassembly appears as an inevitable activity for products not only at the end-of-life but also during the products life-time and maintenance (Das et al., 2000; McCluskey et al., 2009). Moreover, disassembly job cannot be seen as a static process since the disassemblability of the components may vary through the process depending on the "disassembly state". Several works emphasized the importance of this aspect in evaluation of the components disassemblability for product redesign and disassembly sequencing (Das et al., 2000; Giudice, 2010; Lambert, 1997; Suga et al., 1996; Viswanathan and Allada, 2001).

Currently, there is a lack of a dynamic model that allows designers to efficiently assess the relationships among the components/modules in terms of disassembly at the development phase. In this work, disassembly was considered as a multi-criteria decision-making (MCDM) problem. Different disassembly parameters and their interactions were taken into account. A novel disassembly scoring model using a hybrid technique that combines Design of Experiments and Technique for Order Preference by Similarity to Ideal Solution (DOE–TOPSIS) was developed. The model allows to independently determine the difficulty index for every disassembly-task involved in the product disassembly. The model was developed under the project CRIAQ-ENV412 based on the accumulated experience in disassembly during the work on the carcass of a Bombardier Regional Jet aircraft.

Including this introduction, Section 2 presents the disassemblability parameters; in Section 3, are provided the preliminaries and the proposed methodology; the application of DOE–TOPSIS is presented in Section 4; validation of the model is given in Section 5; and finally, Section 6 presents the conclusion.

2. Disassemblability parameters

Disassembly-task is specifically defined as the act of separation. Separation is achieved when the mechanical connections such as fasteners, jo-bolts, rivets, i-locks, adhesive bonding, etc. for two components are clearly removed. Products are composed of different components assembled via different type of joints in an organized structure. Therefore, to disassemble a product, several disassembly-tasks might be required. These tasks would vary in terms of difficulty related to each one. The level of difficulty associated to a disassembly-task is referred as disassemblability.

Different qualitative/quantitative parameters can influence the disassemblability of the components. These parameters may differ from one product to another. Based on the established parameters, a model can be developed at the design phase to evaluate the disassemblability index for components in the product. Therefore, identifying the appropriate disassemblability parameters, provides more reliability to the model and is the most important and time consuming step.

After group meeting with the partners and decision-makers in the project CRIAQ-ENV412, a list of different disassemblability parameters was obtained. This process of knowledge extraction from the experts was performed using pseudo Delphi.[1] Having presented the problem and the importance to have a universal disassembly

[1] "Delphi is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. The experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. Generally, the range of answers decreases and the group converges towards the "correct" answer. The process is stopped after a pre-defined stop criterion (e.g. number of rounds, achievement of consensus, and stability of results) and the mean scores of the final rounds determine the results".