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Sustainability assessment using fuzzy-inference technique (SAFT): A methodology toward green products

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ABSTRACT

Green products are increasingly becoming the center of attention for policy and decision makers worldwide not only because of environmental and eco-systems crisis but also to satisfy the current competitiveness in the markets. With this aim, it is highly attractive to count with mathematical tools that allow assessing the sustainability of the products. In this regard, fuzzy techniques have been broadly used in different studies due to uncertainty and vagueness associated with sustainability problems. However, these studies are mostly based on fuzzy rules generation which is time consuming and also can lead to redundancy and inaccuracy. In this study, we introduced a fuzzy-inference system to evaluate product/process sustainability (SAFT). The proposed method does not require generation of rules which simplifies the procedure and makes it more precise. Furthermore, fuzzy analytic hierarchy process accompanied by Shannon's entropy formula was employed to determine the relative importance of each element in the hierarchy. The methodology SAFT was compared with fuzzy rule-base technique and impressively pretty the same results were obtained. The method introduced in this paper was built as a user interface platform which can be used as a fuzzy expert system to facilitate the sustainability assessment of products/processes in different manufacturing industries.

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1. Introduction

Over the past decades, sustainability and sustainable development are more and more becoming the hot topics among the managers of every organization, not only because of environmental and eco-systems crisis but also to keep in touch with the competitiveness in the markets. There are obvious evidences showing current product/process development is unsustainable: Ozone depletion, global warming, extinction of species, poverty, economic crisis, social and political unrest, violence, etc.

Sustainable development is a pathway toward sustainability which introduced a new paradigm for product/service/process development. This concept has triggered a wide variety of definitions and interpretations for sustainable development. In the literature, various researchers/organizations have published their own definitions about sustainable development which shows how they put sustainability in action, depending on their goals (Table 1).

A survey done by European Design Council 2001 showed that around 87% of the companies in Europe believe in sustainable development as a great opportunity, and not a cost burden (Curtis & Walker, 2001). The advantages associated with sustainable development include: satisfaction of customer needs, expand marketing with new possibilities, increase economic success chances, augmentation of creativity and innovation in product/design development, alleviation of environmental issues, etc.

With this current increasing attention about sustainability and sustainable development, it is not surprising that a quantifiable sustainability rating would one day be required for all the manufactured products via some obligatory regulations (like energy efficiency labeling for electronic appliances). Quantifying sustainability refers to the use of mathematical techniques to analyze the impact of products on environment, social, and economy. Thus, the sustainable effect of products upon life-cycle will be translated into numbers that are intelligible for the designers, manufacturers, managers, etc. To count with such a rating system, it will not only add value to the products, but also widen the perspective of the designers toward more sustainable products. For example the use of nanotechnology potentially will bring a lot of benefits to improve human's life quality, but still there are numerous challenges facing the assessment of a sustainable nanotechnology (Meyer & Upadhyayula, 2014).

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Table 1
Definitions of sustainable development.

Goal	Definition
Ecological preservation	"Development that is likely to achieve lasting satisfaction of human needs and improvement of the quality of human life" (Allen, 1980)
Biodiversity conservation	Sustainable development is about: "Maintenance of essential ecological processes and life support systems", "Preservation of genetic diversity", and "Sustainable utilization of species and ecosystems" (IUCN, 1980)
Intergeneration equity	"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987)
Environment regulatory consensus	"Sustainable development argues for: (1) development subject to a set of constraints which set resource harvest rates at levels not higher than managed natural regeneration rate, and (2) use of the environment as a "waste sink" on the basis that waste disposal rates should exceed rates of managed or natural assimilative capacity of the ecosystem" (Pearce, 1988)
Eco-business vision	"Sustainable development recognizes economic growth and environmental protection as are inextricably linked, and that the quality of present and future life rests on meeting basic human needs without destroying the environment upon which all life depends" (Schmidheiny, 1992)
Political consensus	"Sustainable development involves a process of deep and profound change in the political, social, economic, institutional and technological order including redefinition of relations between developing and more developed countries" (Strong, 1992)
Business interest	"Sustainable development means basing developmental and environmental policies on a comparison of costs and benefits and on careful economic analysis that will strengthen environmental protection and lead to rising and sustainable levels of welfare" (WorldBank, 1992)
Marketing perspective	"Balancing social, ethical and environmental issues alongside economic factors within the product or service development process to ensure that the needs of both the business customer and society are met while protecting the ecosystem" (Curtis & Walker, 2001)
Technology innovation	"Sustainable development relates to economical, ecological and social developments. Possibilities to co-optimize these developments depend strongly on the availability of technologies, innovation strategies, and the institutional conditions that are set by government policies" (Vollenbroek, 2002)

The present work aims to develop a suitable methodology for product sustainability evaluation considering the environmental, economic, and social risks/impacts of the products upon life-cycle. To deal with uncertainty and fuzziness associated with sustainability problems, fuzzy techniques were applied. The methodology sustainability assessment using fuzzy-inference technique (SAFT) was successfully validated and compared with the results from the literature that used fuzzy rule-base technique.

Including this introduction, Section 2 provides a critical review of the state of the art; in Section 3, the sustainability hierarchy, theory of fuzzy sets and definitions are presented; the proposed methodology and the practical implementation are described in Section 4; the results from the comparison with fuzzy rule-base method and the developed user interface platform for the tool are discussed in Section 5; finally the conclusion is given in Section 6.

2. Literature review

One of the important steps for achieving sustainability in the scope of product manufacturing is to control the environmental, economic, and social impacts of the products (Hu & Bidanda, 2009; Lin, Madu, Kuei, Tsai, & Wang, 2015; Vinodh & Rathod, 2010; Zhang et al., 2012). To this aim, there are plenty of databases, methodologies, and tools that have been developed to help designers to evaluate the impact of processes or manufactured products during their life-cycle. These tools are generally known as life-cycle assessment (LCA): methodological frameworks which are usually generalized and mostly concentrated on environmental aspect only. In addition, in conducting an LCA, usually the design and development phase of the product is excluded (Lee, O'Callaghan, & Allen, 1995; Rebitzer et al., 2004); while the decisions in this phase can significantly influence the impacts of the product in subsequent life-cycle phases. Moreover, LCA techniques are data intensive and require considerable resources (time, labor, cost, etc.), which may not be justifiable in some cases (Hur, Lee, Ryu, & Kwon, 2005; Khan, Sadiq, & Veitch, 2004).

In terms of design and development, Hallstedt (2016) presented an approach to identify proper sustainability criteria and categorize them into different life-cycle phases. eco-design techniques are another way that designers can use to reduce the environmental impact of their new products at the early stage of design (Bovea & Pérez-Belis, 2012; Knight & Jenkins, 2009). Eco-design techniques include guidelines, checklists, and MET (Material, Energy, and Toxicity) matrix. However, these techniques are not widely adopted by industries since they are not generic and require specific forms of customization prior to use. Hur et al. (2005) proposed a simplified LCA method integrated with eco-design techniques for a rapid sustainability assessment of Electrical and Electronic Equipment at the early stage of design. Although the method is faster than a detailed LCA, the application of the method for different product categories is compromised. Furthermore, the method solely focuses on environmental aspect.

However, focusing on environmental requirements only, causes more design constraints and consequently increase of costs (Kaebernick, Anityasari, & Kara, 2002; Liu, 2009). Yet, the ultimate objective of sustainable development is the fully integration of environment, economic, and social aspects into an equilibrium (Santoyo-Castelazo & Azapagic, 2014; Vinodh & Joy, 2012; Vollenbroek, 2002). This requires a paradigm transition in current traditional design methodologies, manufacturing practices, and even educational curriculum in order to be more effective for applications built for sustainable futures (Jawahir, Rouch, Dillon, Holloway, & Hall, 2007).

Product sustainability index (PSI) was developed by Ford of Europe as a management tool in order to translate the sustainability aspects of products to the organization of vehicle product development (Schmidt & Butt, 2006). Although it is mentioned that the three environmental, social, and economic aspects have been covered, the study is more concentrated on environmental and economic zones. Besides, there is a lack of proper data normalization and weight allocation that can influence the final results. Ungureanu, Das, and Jawahir (2007) used a scoring system, to evaluate the level of sustainability of manufactured products by taking into account some contributing sustainability elements. Later, Zhang et al. (2012) performed a hierarchical structure to establish product sustainability index (ProdSI) based on Ungureanu et al. (2007) study. Using a hierarchical structure, ProdSI was divided into the main sustainability aspects (environment, economy, social), and each aspect subdivided into its sub-elements. Sub-elements are then measured via the generated metrics for each individual. Afterward, a simple 0 to 10 data-scaling method have been used accompanied by equal relative weightings to elements and sub-elements. Finally an aggregation was done to obtain the final sustainability index. Similarly, Mayyas, Qattawi, Mayyas, and Omar (2013) proposed a sustainability scoring model with eco-material selection approach in an automotive case study. Yu, Zhixian, and Zhiguo (2007) used a decision-making algorithm based on analytical hierarchy process (AHP) and integrated assessment of environmental and economic performance of chemical products. The results of the study provided some initial guidelines for basic judgment about feasibility of using a certain product.

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