Journal of Cleaner Production xxx (2014) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Adapting the Robust Design Methodology to support sustainable product development

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ARTICLE INFO

Article history:
Received 24 January 2014
Received in revised form
8 May 2014
Accepted 8 May 2014
Available online xxx

Keywords:
Sustainable product development
Quality Management
Robust Design Methodology
Sustainability

ABSTRACT

Research on product development has pointed to a challenge in integrating sustainability considerations into existing engineering practices rather than adding additional sets of practices and tools. The question is what practices are suitable for consideration? One set of practices and tools, deemed suitable due to its focus on long-term impacts and customer focus, is Quality Management. Within this area, the Robust Design Methodology has a historic connection to sustainability vis-à-vis quality loss caused by a product not only to an individual customer, but to society at large. Hence, there appears to be a neglected connection to the sustainability area. This paper explores how efforts based on the Robust Design Methodology may better contribute to sustainability and, more specifically, to sustainable product development. This paper reviews earlier Robust Design Methodology case studies that reveal how it supports sustainability. However, the reviews also reveal that efforts so far have focused only on the manufacturing and use phases of a product's lifecycle. Hence, adaptations of the methodology are needed, such as more conceptual and qualitative tools and explicit inclusion of eco-design indicators as a response variable in, for example, Design of Experiments. Adapting the Robust Design Methodology enables meeting the key aspects of an eco-design tool: addressing early integration of environmental aspects in development processes, having a lifecycle approach, and being a multi-criteria approach.

1. Introduction

Many authors have argued that it is necessary to integrate sustainability considerations throughout product development processes (Masui et al., 2003; Maxwell and Van der Vorst, 2003; Luttropp and Lagerstedt, 2006). One such integration involves elaborating and adapting existing engineering practices and techniques to overcome the perception of eco-design tools as "tools for experts" (Knight and Jenkins, 2009) (p. 550). For example, Quality Management (QM) can benefit such an integration due to its emphasis on the customer and continuous improvement (Dean Jr and Bowen, 1994). As stated by Lopes Silva et al. (2013, p. 175), QM is useful as it is, "well known, corroborated and integrated into most organizations' management processes, familiar to most managers and also very easy to adapt to an environmental program". Sustainability research within QM has addressed a variety of areas such as integrated environmental management systems (Tarí and Molina-Azorín, 2010), adaptations of tools, such as Quality Function Deployment (QFD), in contributing toward the Design for Remanufacture (Hatcher et al., 2011), and the role of QM for the success of environmental management practices (Wiengarten and Pagell, 2012).

QM is defined as, "a philosophy or an approach to management that can be characterized by its principles, practices, and techniques. Its three principles are customer focus, continuous improvement, and teamwork" (Dean Jr and Bowen, 1994). An early description of quality by Shewhart (1931) (p. 53) reads as follows: "One of these [aspects of quality] has to do with the consideration of the quality of a thing as an objective reality independent of man. The other has to do with what we think, feel, or sense as a result of the objective reality. In other words, there is a subjective side of quality". The subjective aspect of quality in QM has generally been interpreted as individual customers' needs and wants.

One QM methodology is the Robust Design Methodology (RDM), which is defined as "systematic efforts to achieve insensitivity to

Abbreviations: DfE, Design for Environment; NF, noise factors; P-diagram, parameter diagram; QFD, Quality Function Deployment; QM, Quality Management; RDM, Robust Design Methodology; SPD, sustainable product development; TIPS, Theory of Inventive Problem Solving.

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http://dx.doi.org/10.1016/j.jclepro.2014.05.018
0959-6526/

noise factors. These efforts are founded on an awareness of variation and can be applied in all stages of product design" (Arvidsson and Gremyr, 2008) (p. 31). Taguchi, an early proponent of the RDM, defined quality in a way that profoundly differs from other early proponents. Taguchi (1986), p. 1) considered quality loss as "the loss a product causes to society after being shipped, other than any losses caused by its intrinsic functions". In this definition, the customer, as the final arbiter of quality, has not been replaced, but rather significantly expanded to society at large. Taguchi does not elaborate on this role, but states that, "what functions society should allow products to have is a cultural and legal problem, not an engineering problem" (Taguchi, 1986) (p. 3).

However, negative impacts to society in terms of, for example, environmental damage, have today reached levels that make sustainability a challenge to all disciplines, including engineering. In the development and production of goods, there are opportunities to make changes that support sustainability. Sustainability studies are not extensive in the RDM literature. One notable example is Ben-Gal et al. (2008) who proposed using the Taguchi method for the eco-design of a factory smokestack. Other examples are Fratila and Caizar (2011) and Hanafi et al. (2012), who described power reduction applications in machining processes.

The examples of applying the RDM have shown that it might be useful in supporting sustainability. However, still lacking is the answer to necessary adaptations of the RDM in early product development phases. The purpose of this paper is to explore how efforts based on the RDM may better contribute to sustainability and, more specifically, to sustainable product development (SPD). Section 2 reviews the RDM and SPD literature. Section 3 describes the method used for the study. An analysis of the interrelationships between the RDM and SPD is carried out in Section 4 using a selection of published case studies. The analysis is followed by discussions in Section 5 and finally conclusions in Section 6.

2. Literature review

The two following subsections will review main ideas underlying the RDM and SPD areas. Further, to identify needed RDM sustainability adaptations, each sub-section will end by pointing to future research.

2.1. The Robust Design Methodology

Over time, a number of authors have argued that variation among units of the same product would lead to dissatisfied customers (Shewhart, 1931; Phadke, 1989). Taking into account that uncontrollable noise factors (NFs) may cause a product characteristic to deviate from its specified target, a tolerance interval is assigned to a target. In Taguchi's 1993 terminology, these deviations cause quality losses. Quality loss is further elaborated by Taguchi (1993) (p. 4) as "the amount of functional variation of products plus all possible negative effects, such as environmental damages and operational costs". As discussed by Kackar (1985), a traditional view of quality loss inside the tolerance interval is zero. An alternative view is the quadratic loss function (Taguchi and Wu, 1979; Taguchi, 1986). Quality loss implies that a customer is most satisfied when the performance characteristic is on target, but becomes gradually dissatisfied when the value approaches tolerance limits.

One way to conceptually analyze NFs and their influence on a product or process is by using a P-diagram (see Fig. 1), which relates an input into a system (signal factor) to a desired output (response variable) while at the same time considering control factors (Phadke, 1989). Later versions of the P-diagram also add various error states as outputs, that is, undesired outputs (Davis, 2006).

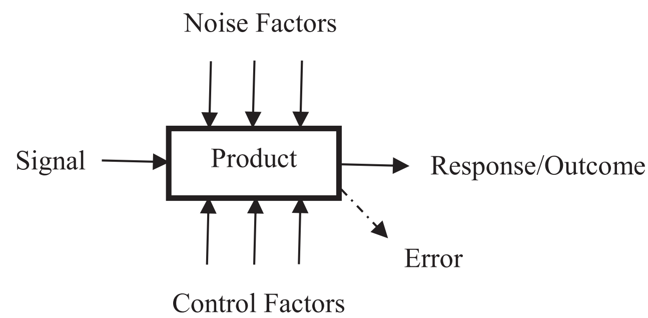

Fig. 1. P-diagram.

The prevalent and well-known NF categorization by Taguchi and Wu (1979) allowed for not limiting outer disturbances to actions taken by a customer or product user. Thus, it is consistent in defining quality loss as losses to society. However, later NF categorizations have become narrower in scope (see Table 1). The broad label of "outer disturbances" has been interpreted, or rephrased, into "variations in condition of use" (Clausing, 1994) or "customer duty cycles" (Davis, 2006). These examples show a change of interpretation from society at large to a single customer or user, although society at large can also affect the product, for example, through legislations and regulations.

Efforts to create NF insensitivity are often divided into two categories based on the application point in a product life-cycle (Taguchi, 1986). On-line efforts are applied during manufacturing and off-line efforts in both designing products and manufacturing processes (Kackar, 1989). In summary, the chances of reducing NF influence increase if the efforts are applied off-line (see Table 2).

Many authors, such as Kackar (1985), Taguchi and Phadke (1989), Taguchi and Clausing (1990), and Box et al. (1988), emphasized applying the RDM proactively when designing products and processes. Despite this emphasis, Thornton et al. (2000) discovered in their study that fewer than half the companies used the RDM proactively. With reference to Table 2, this excludes the possibility of designing a product being robust to variations in conditions of use and deterioration.

One reason for the shortfall in applying the RDM proactively might be found in previous research, which often focused on tools such as Design of Experiments, while neglecting the practices and the question of when to apply the tools (Arvidsson and Gremyr, 2008; Hasenkamp et al., 2009). Addressing these areas has been argued as critical for the RDM's application (Gremyr et al., 2003; Gremyr and Hasenkamp, 2011). Another area in need of future development is practices and tools that can be used in early product development phases when quantitative data is not available (Ford, 1996; Andersson, 1997). In addition, parallel development of the tools, such as research on multiple responses in designed experiments (Jeyapaul et al., 2005; Murphy et al., 2005), is still beneficial.

2.2. Sustainable product development

Since the early 1990s, the sustainable development boom has prompted discussion of environmental concerns in relation to product development and manufacturing (Baumann et al., 2002). On the subject of eco-design, much focus has been aimed at the inclusion of environmental considerations in existing engineering tools, such as the Kano model, Quality Function Deployment (QFD) and the Theory of Inventive Problem Solving (TIPS) (Bovea and Pérez-Belis, 2012). Enhancement is seen as a viable approach to addressing the gap between the demand for existing tools and emerging theories, such as eco-design (Sakao, 2007, 2009).

Please cite this article in press as: Gremyr, I., et al., Adapting the Robust Design Methodology to support sustainable product development, Journal of Cleaner Production (2014), http://dx.doi.org/10.1016/j.jclepro.2014.05.018