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Assessing sustainability and value of manufacturing processes: a case in the aerospace industry

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ABSTRACT

In spite of the growing awareness and significance of accounting for sustainability aspects in product development, design decision support is still immature in this end compared to other decision support areas, such as product performance and manufacturability. This paper proposes a novel decision support method that combines qualitative sustainability assessment techniques with a quantitative analysis, without losing transparency and still covering a full sustainability perspective. The aim is to contribute to an understanding for how to enable value assessment of sustainability issues already in early product development situations. The method, named Sustainability Assessment and Value Evaluation, combines two qualitative sustainability assessment techniques with a quantitative Net Present Value analysis based on alternative future scenarios. A case study, related to the development of a new high-temperature aero-engine component, illustrates both how the sustainability assessment identifies hot-spots and clarifies potential sustainability consequences for a new product technology, and how Net Present Value is used to assess alternative solution strategies based on the hotspot, to facilitate early stage decision-making in design. The paper argues that the method serves two main purposes: i) to make sustainability consequences more concrete and understandable during design concept selection activities, rather than to have an exact measurement, and ii) to simplify and prioritize, systematically asking what is important in the sustainability analysis, rather than to reduce the sustainability problem. The method allows undertaking the sustainability assessment in a more structured way than what happens today in preliminary design, through scenario building based on socio-ecological assessments, including back-casting to cover the longer time perspective. In addition, the Sustainability Assessment and Value Evaluation-method provided the design team of a means for displaying sustainability consequences on an equal basis with other decision support tool results.

1. Introduction

The implementation of decision support for sustainability in product development and manufacturing is a matter of considering socio-ecological aspects in a systematic way, rather than picking ad hoc measures or focusing on one aspect in a reductionist way (Hallstedt et al., 2013b). Sustainability aspects need to be considered in a life cycle perspective (raw material extraction, production, distribution, usage & maintenance, end-of life) (Thompson et al., 2012) and in relation with other aspects, such as functionality and manufacturability. Examples of sustainability issues in the product development process are: What are the sustainability implications of the materials and chemicals currently used in the forthcoming products and production processes? What are the sustainability implications of the manufacturing processes used? How can the manufacturing platform develop to generate a better working environment? How can the product be designed to reduce the energy usage? How can the product be designed to be recycled and to keep materials in closed-loops within the value-chain?

Product development and manufacturing processes have been developed stressing the ability of obtaining high-quality products at minimum costs, to promote the competitiveness of the company. This suggests that efforts to meet environmental regulations should be kept to the barely minimum, as going behind this will increase cost (O'Brien, 1999). Nowadays this attitude is likely to change, because awareness on environmental problems and the impacts of

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products on society is growing (Tukker et al., 2008; EEA, 2014). Sustainability matters are increasingly receiving attention among consumers, who want to make the right choices when buying products and services. To remain competitive, manufacturers need at least to understand consequences of sustainability aspects (risk perspective), and may even actively use insights in these trends as a driver for new products (innovation perspective).

Already today some companies recognize sustainability issues as business opportunities rather than undesirable pressing situations (Bonini and Görner, 2012). Although in the short term improved environmental efficiency may increase costs, in the long term it is expected to show a positive impact on financial performances (O'Brien, 1999) and competitive advantage (Yang et al., 2010). This is because, as far as material, energy and waste disposal costs rise, the cost of inactivation may be higher than making the improvements themselves. This is particular true for companies dealing with product that are produced during a long period of time (i.e. more than 20 years) and that need to be supported for much longer after production has ended. In such cases, the selection of technologies and product/process solutions is driven by considerations grounded long into the future (Hallstedt et al., 2013b).

One of such industries is aerospace, which features the introduction of advanced technologies with long life cycles. Sustainability has therefore become one of the main drivers for technology development in this domain. The Strategic Research Agenda published by the Advisory Council for Aeronautics Research in Europe (ACARE, 2011) identifies sustainability as one of the most significant drivers that will influence current and future solutions for new airframes and aero-engines. Commercial aerospace has experienced a rapid growth in terms of passengers: air traffic has doubled every 15 years in the past, and is expected to double again in the next 15 (Airbus, 2013). The "Ultra green air transport system" defined as a major high-level target for research in aviation (ACARE, 2011), pointing towards reducing the environmental impact of aircrafts and associated systems during their life cycle: from manufacturing to operation, maintenance and disposal phase (Witik et al., 2012).

In parallel to the evolution of strategic initiatives, the design activity needs also to shift focus, and this highlights gaps in established means for decision support. What criteria and indicators shall, for example, be used to assess alternative solutions from a sustainability point of view? While literature emphasizes the impact sustainability has on a company's costs as revenues, empirical observations show that designers tasked with the early-stage selection of a product/technology concept find it difficult to realize the opportunity for value creation generated by a sustainability-friendly choice (e.g. Hallstedt and Isaksson, 2013). A better understanding could be reached by aligning sustainability metrics and product metrics when approaching critical design decisions. In this spirit, the ambition of the design team is often to cover sustainability with quantitative indicators expressing the economic impact of sustainability choices.

Recent attempts to integrate sustainability with a value-based view remains at an organizational strategy level, and do not dive into a design situation (Willard, 2012). To spotlight the value creation opportunity of a sustainable choice, a step change is required to integrate sustainability considerations into the preliminary stages of design (Bey et al., 2013). Identified sustainability criteria need to be taken into consideration with the same importance as any other system requirement in a product-planning phase (Waage, 2007; Hallstedt et al., 2013a). A fundamental problem here is the mix of qualitative methods that can provide a good overview, with quantitative methods typically needed in e.g. economic value situations.

2. Purpose and objectives

The purpose of this work is to strengthen the decision support for design teams that need to value aspects influencing sustainability behavior of products and processes. The objective is to bridge the gap between qualitative assessment models that account for sustainability consequences with more quantitative tools able to express the value consequences of design decision alternatives. The work focuses on the earliest phases of the design process, where the impact on the entire product life cycle is high and the information available is immature.

The paper is organized as the following. The result from a literature review is presented in section 3, followed by a description of the research method in section 4 and findings from empirical studies in section 5. The novel method proposed, named Sustainability Assessment and Value Evaluation (SAVE), which is intended to inform early stage decision makers about the value-related consequences of their sustainable design options, is described in section 6. Section 7 presents the application of the SAVE-method for the development of an aero-engine component technology. The case has been used as main reference to discuss and verify SAVE with designers and process owners in co-located industrial workshops, as described in sections 8. Further discussions and conclusions from this research are elaborated on in sections 9 and 10.

3. Literature review

The literature review covers the field of environmental impact assessment, life cycle assessment, and other tools and methods for sustainable design and sustainable manufacturing. The section ends with a short review of value-driven design in relation to sustainability.

3.1. Environmental Impact Assessment and life cycle assessment

Environmental Impact Assessment is a procedure to support decision making with regards to environmental aspects of activities. The purpose of the assessment is to ensure that decision makers consider environmental impacts when deciding whether or not to proceed with a project (EU, 2011). In product development, EIA identifies significant environmental impacts generated by the product's life cycle from the resource extraction phase to the end of life. From this, it proposes measures to adjust impacts to acceptable levels or to investigate new technological solution. It is often regarded as a local, point-source oriented evaluation, which takes into account time-related aspects, the specific local geographic situation, and the existing background pressure on the environment (Tukker, 2000). EIA is criticized for excessively limiting its scope in space and time, and to focus on short-term, direct and immediate effects on sustainability (Lenzen et al., 2003). Also the ability of EIA to influence decisions is believed to be rather limited, mainly because it is intended to be a decision-aiding tool rather than decision-making tool (Jay et al., 2007).

Life Cycle Assessment (LCA) (ISO, 2006) has been proposed (Manuilova and Suebsiri, 2009) as a natural way to complement EIA with quantifiable information, and hence support the decision-making process in a more structured way (Lozano, 2012). Even branch-specific LCA-tools with common databases have been developed with the aim to enhance eco-design activities, e.g. for the aerospace industry the simplified LCA tools ENDAMI and LEAF have been developed within the EU funded research program called Clean Sky (see: http://cordis.europa.eu/result/rcn/147382_en.html). LCA offers a holistic tool encompassing all environmental exchanges (i.e., resources, energy, emissions, and wastes) occurring over the product/service life cycle (Carvalho et al., 2014). Stand-alone LCAs have