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ScienceDirect
Procedia CIRP 26 (2015) 70 – 75
www.elsevier.com/locate/procedia

12th Global Conference on Sustainable Manufacturing

# Multi-criteria decision making as a tool for sustainable product development – Benefits and obstacles

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**Abstract**

For developing sustainable products design engineers need to foresee diverse interrelations between a product's characteristics and its economic, social and environmental impacts. In order to support this complex task a wide range of design methods has been developed. Retrospective analytical methods like Life Cycle Sustainability Assessment (LCSA) require a large amount of information and are thus utilized when important design decisions are already made. Prospective methods are rather generic (e.g. checklists) and too broad to be helpful in concrete design decisions. In this paper, the integration of discrete decision trees with LCSA is proposed for shifting multi-criterial quantitative analysis to earlier development. On the basis of sustainability indicators Pareto-optimal decision-paths for given material- and process alternatives along the product lifecycle can be compared up-front. Resulting benefits and obstacles are illustrated by evaluating value creation options of a bicycle frame.


Peer-review under responsibility of Assembly Technology and Factory Management/Technische Universität Berlin.

*Keywords:*Decision support;Life Cycle Sustainability Assessment; Multi-criteria decision making; Sustainable Product Development

## 1. Introduction

The principles of sustainable development, as they were defined by the Brundtland commission in 1987 [1], are widely seen as one of the major pillars for future human development. Producing companies can contribute to sustainability targets by offering products with minimal negative economic, environmental and social impacts.
The process on how decisions regarding sustainability issues are made is based on multiple factors mentioning solely the following examples:

- Humans (e.g. competencies, team behavior),
- Quality and availability of sustainability information and
- Company capabilities (e.g. resources, funds).

Within value creation conceptual design has the most significant influence on the product's impact on surrounding systems, since a large extent of the product's-properties are defined in this phase [2]. In terms of the environmental dimension, energy and resource consumption as well as the emission of pollutants are influenced. The social dimension is reflected by working conditions or further implication of usage (e.g. through an increase in safety). Economic effects are for example caused by the product price or customer experience.

By the definition of products characteristics (like materials or geometry) design engineers determine product properties like weight or durability to a large extent [3]. For example the selection of a component-material limits possible processes for production and end of life treatment automatically. The product structure determines whether a product can be disassembled and therefore influences maintenance and remanufacturability [4]. Hence, it would be beneficial if the product lifecycle could be optimized in early design phases.


Peer-review under responsibility of Assembly Technology and Factory Management/Technische Universität Berlin.
doi:10.1016/j.procir.2014.07.110

## 2. Problem Statement

The integration of sustainability aspects into product design requires continuous quantitative assessment of the product along its creation process [5]. Current assessment approaches like Life Cycle Sustainability Assessment (LCSA) demand detailed information about the product which is usually not available in early design phases [6]. Therefore, quantitative-oriented methods are currently used retrospectively when design activities are nearly finished. Approaches like Simplified Life Cycle Assessment (LCA) try to deal with this problem by offering more lean decision support, but only covering the environmental dimension of sustainability [7]. However, they also do not provide a real prospective support. An up-front simulation model for different configurations of value creation networks may enable "planning" of sustainable products.

Furthermore, the various interrelations between lifecycle and product related factors are very complex and a wide variety of criteria is used [8-9]. This includes the functions a product has to fulfill (according to customer wishes and needs) and the product's lifecycle behavior on environmental, social and economic issues.

Research for solving these kinds of problems has been performed in several scientific fields including operational research, environmental science and engineering design research (e.g. [10-11]).

Therefore, it is seen as vital to develop a coherent approach between the following three subjects:

- Engineering design methodology (1),
- Lifecycle evaluation (2) and
- Multi-criteria assessment (3).

(1) The engineering design methodology provides the approach on how to perform a design project; basically a systematic approach for developing sustainable products (e.g. which design decisions have to be made, what are the crucial product properties and characteristics).

(2) The lifecycle evaluation provides the methodology on how to perform a lifecycle assessment considering the three sustainability dimensions (e.g. which assessment methods have to be considered, which sustainability information is available).

(3) The multi-criteria assessment provides a methodology on how to find the most promising lifecycle decision amongst the solution space (e.g. which design decision is more sustainable considering its manufacturing processes, what are the different local optima in the supply chain).

Nowadays, a combined approach is missing. Nonetheless, it is essential for the development of genuine sustainable products.

## 3. State of the art

### *3.1. Sustainable Product Development*

The principle of sustainable development inspired a whole generation of scholars and lead to a multitude of publications in design research from various fields like environmental sciences and mechanical or electrical engineering. As a result different frameworks emerged, which are broad concepts representing certain design ideologies (e.g. Ecodesign, Design for Sustainability, etc.) [11]. The different approaches likewise focus on broadening the scope from a cost-centric perspective to a more integrated view and are sometimes used interchangeably [12]. Sustainable Product Development is a framework which aims at the integration of economic, environmental and social considerations into product development [13]. One of the major challenges on this field of research is the holistic analysis and improvement of products regarding their impact on surrounding systems. For a valid assessment the product needs to be analyzed along its complete lifecycle [14]. Furthermore, the principle of sustainable development requires the consideration of multiple design targets at the same time (e.g. reduction of hazardous waste against higher material cost). In this context conflicting requirements can lead to an over constrained design space where trade-off decisions are necessary [7]. The resulting complexity challenges traditional design approaches and leads to the development of a wide range of design methods with varying simplicity, required application-time and quality [8,15]. Baumann et al. categorize the available approaches into six groups from checklists and guidelines to quantitative assessment methods [11].

In previous research projects more than 50 design methods were analyzed and systematized according to different criteria (e.g. point of application in the product development process or addressed type of users of the method). One key finding was the strong focus on environmental sustainability of existing approaches [16]. Ness et al. are coming to similar results [17]. A further objection regarding currently available forms of design methods is the unsatisfying support of multi-criterial decision situations. Byggeth & Hochschorner state that six of their 15 evaluated methods did not address trade-off decisions. The remaining approaches were missing forms of evaluation. The authors therefore recommend including all three sustainability dimensions from a lifecycle perspective as a basis for evaluation [7].

### *3.2. Life Cycle Sustainability Assessment*

Addressing the three dimensions of sustainability the LCSA method has been suggested. It aims at the integration of Life Cycle Assessment (LCA) [18-20], Life Cycle Costing (LCC) [21-22] and Social Life Cycle Assessment (SLCA) [23].

LCSA can be formally expressed in the symbolic equation [14]:

$$LCSA = LCA + LCC + SLCA \qquad (1)$$

The measurement of impacts concerning the environmental dimension of sustainability is the most advanced methodology within the LCSA framework. The life cycle approach avoids