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Product classification to support approximate life-cycle assessment of design concepts

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Abstract

Many companies are beginning to change the way they develop products due to increasing awareness of sustainable development. Designers, who play a key role in product development, are being asked to incorporate environmental criteria into the design process. The need for analytically based conceptual design methods for integrated life-cycle assessment (LCA) has motivated the development of an approximate life-cycle assessment concept based upon learning algorithms. Although preliminary tests on general approximate models showed promise, it was observed that grouping products to create specialized learning surrogate LCA models for different classes of products might further improve results. This paper presents work to develop an automated classification system to support the specialization of surrogate LCA models for different groups of products. Hierarchical clustering is used to guide a systematic identification of product groups based upon environmental categories. These groupings are then used to create automated classification schemes using the C4.5 decision tree algorithm. Although further data are needed to induce good generalization performance, resulting product classification systems are considered to be a viable approach to support specialized learning surrogate LCA models for different classes of products.

Keywords: Product classification; Hierarchical clustering; Life-cycle assessment; Conceptual design; Learning surrogate LCA models

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1. Introduction

The trend towards sustainable development is driving many companies to consider environmental assessment during product development. Product designers are challenged with questions of what environmental issues are most relevant and how to consider them in relation to the products they are developing. In particular, it is quite relevant to understand how design changes can affect the environmental performance of product concepts early in the design process.

The conceptual design phase typically incorporates decisions on a product's basic physical configuration and product specifications [1]. Decisions that emerge from the conceptual phase are then often frozen due to the large amount of resources–time, manpower, and money–needed to change path as product launch deadlines approach. Early phases of the design process are also widely believed to have the most influence in defining environmental aspects of products [2–4]. Environmental impacts of a product's life cycle should be taken into account in the evaluation of concept feasibility together with the other traditional design criteria (e.g., operational performance and cost) to prevent environmental mistakes (that may not be corrected or mitigated later) from occurring in the first place. This requires the design team must be able to evaluate the environmental performance of many alternative concepts early in the design process.

Conceptual design creates particular challenges for environmental assessment. Competing product concepts are numerous and have dramatic differences, detailed information is scarce, and multi-attribute trade-off and decisions must be made quickly. Previous work [5] illustrated how the capabilities of parametric life-cycle assessment (LCA) models developed by environmental experts could be integrated with traditional design models and made available on demand, using an Internet-based framework called DOME (Distributed Object-based Modeling Environment). However, the use of detailed parametric models is still of limited value for early conceptual design because of the amount of time and information needed to develop the parametric LCA models.

As a consequence, many tool developers are now focusing on the early design stages [6]. Several methods, qualitative and/or quantitative, have been proposed to simplify and significantly reduce the amount of resources required for LCA modeling. They range from checklists [7,3], qualitative matrices [8], abridged LCA [9], and LCA streamlining [10,11], to a variety of other forms of approximate LCA. Although these existing methods are all useful, they are not ideally fitted for early conceptual design in an integrated modeling context. Qualitative information is difficult to use in highly dimensional, fast-paced trade-off analyses, and the streamlined analytical techniques are still somewhat prohibitive from a modeling effort viewpoint.

The lack of analytically based methods for integrated early conceptual design motivated the development of a learning surrogate LCA concept to apply on preliminary life-cycle assessments, within the DOME integrated modeling environment [12]. Preliminary proof-of-concept tests showed that artificial neural network (ANN)-based learning surrogate LCA models were able to: match the detailed LCA results within the accuracy of typical LCA studies; predict relative differences of distinct products; and correctly predict and generalize trends [12]. However, insight gained about the effect of product groupings suggested it might be necessary to specialize surrogate LCA models for different classes of products.

This paper focuses on further research needed to classify products into general categories that can lead to more specific relationships between product attributes and the environmental performance of product concepts. The background section provides an overview on the learning surrogate LCA concept. In