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ScienceDirect
Procedia CIRP 57 (2016) 669 – 673
www.elsevier.com/locate/procedia
49th CIRP Conference on Manufacturing Systems (CIRP-CMS 2016)

Resource optimized product design – Assessment of a product's life cycle resource efficiency by combining LCA and PLM in the product development

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Abstract

Decisions in the product design phase have a significant influence on the resource demand of a product over its entire life cycle. However, relationships between decisions made in the design phase and the life cycle are difficult to evaluate and express. Hence, resource efficiency is typically only assessed after the product has already been designed and gone into production. If the impacts of decisions made in the design phase are neglected a considerable potential for saving resources is ignored.
The aim of the presented work is to make use of this potential. Therefore the determination of the connections between design decisions and resource demand in the manufacturing, use and end of life phase is essential. Mapping these connections and the use of LCA methods allows for the expression of the overall resource demand as a function of the product's design. With this information at hand a design engineer is able to evaluate a design early enough i.e. before going into production.
The provided approach results in an integration of an LCA tool into the engineering workplace consisting of a PLM and a CAD system. It aims for significantly more resource efficient products by partially automated creation and evaluation of alternative product designs. Therefore, design engineers are enabled to develop products with an enhanced resource efficiency over the entire product lifecycle.

Peer-review under responsibility of the scientific committee of the 49th CIRP Conference on Manufacturing Systems

Keywords: Resource efficiency; Product design; Life Cycle Assessment (LCA); Product Life cycle Management (PLM); CAD

1. Introduction

The resource efficiency of a product is significantly influenced by decisions made in the design phase. There are different methods and solutions on the market such as G.EN.ESI [1] or Dassault Solidworks [2] which help product designers to integrate information on environmental performance and resource efficiency of the product in the design phase. At this stage within the product development the integration is very useful as key parameters are still adjustable.

This paper introduces the Fraunhofer I2-Method. The I2-Method is an once-through methodology which assesses the resource efficiency of many design alternatives of a product at once. The five steps of the method are introduced and then applied on a demonstrator part, an injection mould. A conclusion and outlook are given to address remaining issues within the I2-Method.

The nomenclature used within this paper is specified below.

Nomenclature

CAD	computer-aided design
LCA	life cycle assessment
LCI	life cycle inventory

Peer-review under responsibility of the scientific committee of the 49th CIRP Conference on Manufacturing Systems
doi:10.1016/j.procir.2016.11.116

LCIA	life cycle impact assessment
LMD	Laser Metal Deposition
M	material
mBOM	manufacturing bill of materials
PDM	product data management
PLM	product life cycle management
PP	production process

2. Fraunhofer I2-Method

The Fraunhofer I2-Method is a method that supports product designers in their decision for the most resource efficient design alternative of a product. It uses existing systems and works with the assessment of many alternatives at once. The I2-Method is structured in five parts which are summarized in Figure 1. It is still under development and is continuously improved.

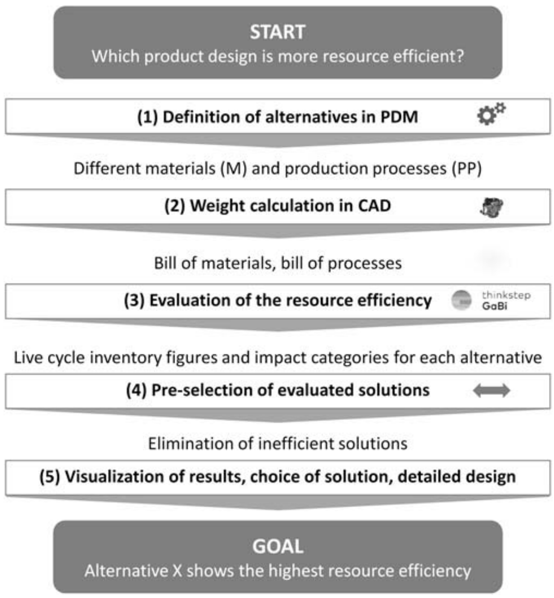

Figure 1: Structure of I2-Method

The starting question is always: "Which product design is more resource efficient?". The answer given by the I2-Method is a clear indication which alternative is the most resource efficient one. The five parts of the method are described in the following chapters.

2.1. Definition of alternatives in PDM

The first step (1) of the I2-Method is the definition of the different alternatives. All alternatives must be equivalent in their functions in order to be comparable to each other. The alternatives are defined through variations of different parameters influencing the geometry and the choice of material (M) and production process (PP). This is done within the PDM environment and prior information and experience are included in this step.

2.2. Weight calculation in CAD

The weight of each alternative is calculated within the CAD system in the second step (2) using the volume of each part and the respective densities of the materials used. All relevant information (material, production process, mass) regarding each product alternative are then aggregated in one single mBOM for all relevant alternatives. This mBOM is exported and prepared to be imported integration in step (3).

2.3. Evaluation of the resource efficiency

Step (3) is the evaluation of the resource efficiency of each product alternative. The LCA software used for the evaluation is the GaBi ts [3]. The mBOM generated in (2) is imported and the respective environmental and resource profiles of the materials and production processes are matched within GaBi ts. Previous matching lists can be used to facilitate this process.

The term "resource" is defined as "a natural source of wealth or revenue" [4]. A resource efficient product is a product that only needs a minimal amount of resources to fulfill its purpose. For the assessment of the resource efficiency within the I2-Method a few indicators are recommended in Table 1.

Table 1: Recommended resource indicators

Resource	Category	Indicator
Water	Water consumption	Waste water
		Rainwater
		Total freshwater consumption
		Total freshwater use
Land	Land use	Land occupation
		Land transformation
Air	Emissions	Particulate matter (PM)
		Photochemical ozone creation potential (POCP)
Material	Efficiency	Offcut/scrap
	Consumption	Abiotic depletion (ADP elements)
		Rate of secondary material
	Waste	General waste, hazardous waste
Energy	Energy used	Primary energy demand from ren. and non ren. resources (net cal. value)
	Energy not used	Waste heat
Climate	Climate change	Global Warming Potential (GWP)

With this list of resource indicators a comprehensive overview of natural resources is given. These indicators are well understood and can be computed by many LCA software tools on the market. The list allows every product designer using the I2-Method to choose a specific set of indicators for the product in question.

2.4. Pre-selection of evaluated solutions

After all the alternatives are defined and assessed the amount of possible design solutions is reduced in step (4). In this step all pareto-efficient solutions are identified. A pareto-efficient solution is more dominant in at least one category and is not dominated by any other alternatives [5]. This selection is done with a Java-based tool.

2.5. Visualisation of results, choice of solution

The final step (5) in the I2-Method visualises the results in a spider web chart. This chart is the final result of the I2-Method and is given to the product designer as a decision support. The product designer can weigh the previously chosen indicators differently in order to reflect his preferences.

2.6. I2-System landscape and method requirements

The I2-Method is embedded in a system landscape as depicted in Figure 2. The previously mentioned five steps of the method fit into the four system elements: PDM, CAD, GaBi ts and the decision logic. Within the PDM System the alternatives are defined and managed (step 1). The mass of the different parts is generated within the CAD system (step 2). The resulting mBOM is also generated from within the PDM, which is then handed over to GaBi ts for further assessment (step 3). The pre-selection and visualization (step 4 and 5) are finally completed within the decision logic.

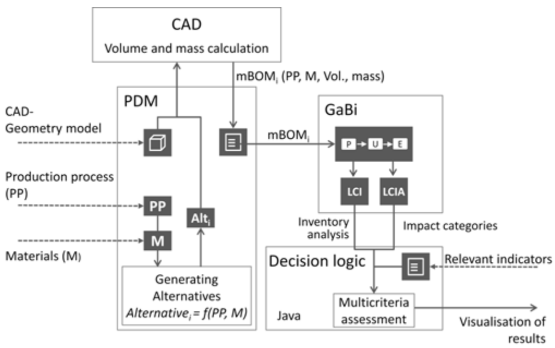

Figure 2: I2-System landscape

The I2-Method facilitates the process to address resource efficiency in the design phase of a product. The method has to comply to the following formulated requirements:

- Connection with PDM/PLM environment
- Assessment of the product life cycle
- Clear results for the product designer

The I2-Method has two main advantages. First the utilisation of already existing tools, which facilitates the introduction of the method and second the fast definition of the alternatives, which creates an efficient evaluation process with only one run-through.

3. Application of the I2-Method on Injection Mould

The previously described I2-Method is applied on an injection mould. The core slides included in the mould are demonstrators within the E³ Fraunhofer Master Project [6]. Goal of the method application is to test the I2-Method and to find the most resource efficient design of the injection mould.

The injection mould consists of four parts as depicted in Figure 3:

- Upper mould (UM)
- Lower mould (LM)
- Core slide 1 (CS1)
- Core slide 2 (CS2)

Marked in yellow is the product, an ice scraper, which is produced with the injection mould.

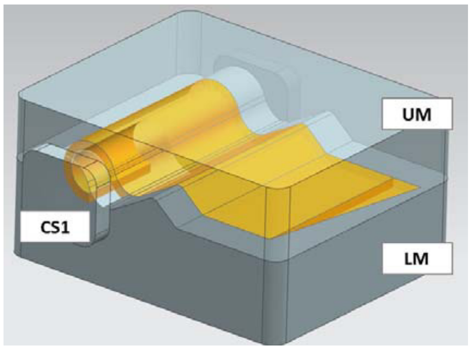

Figure 3: Injection mould with four elements

The functional unit of the following assessment is one injection mould for the production of ice scrapers. The modelling of the injection mould is based on data provided by Alkhayat [7].

3.1. Definition of alternatives in PDM

In total five different alternatives (A1 to A5) are defined within the PDM system. The first three alternatives vary the size of the product. A1 serves as the reference for the following four alternatives. In A2 the ice scraper is longer and thicker. The design of the ice scraper in A3 (as seen in the cross-section in Figure 4) is as such, that no core slides are needed anymore. A4 varies the steel used for the mould and A5 changes the production process of the core slides from conventional metal processing to laser metal deposition (LMD). The overall function of the product remains the same within all alternatives.

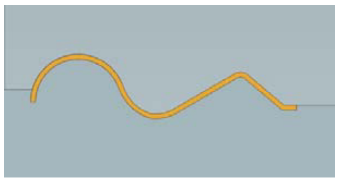

Figure 4: Cross-section of A3 without core slides

All five alternatives are summarized with their material, mass and production process in Table 2. The entire part is made out of the same material.

Table 2: Overview of injection mould design alternatives

Alternative	Part	Material	Mass [kg]	Production Process
A1	UM	Steel (31CrMo12-5)	10.56	n/a
	LM		12.87	n/a
	CS1		1.20	conventional
	CS2		1.19	conventional
A2	UM	Steel (31CrMo12-5)	10.56	n/a
	LM		12.59	n/a
	CS1		1.04	conventional
	CS2		1.03	conventional
A3	UM	Steel (31CrMo12-5)	10.56	n/a
	LM		14.78	n/a
	CS1		0	conventional
	CS2		0	conventional
A4	UM	Steel (X6CrMo17-1)	10.56	n/a
	LM		12.87	n/a
	CS1		1.20	conventional
	CS2		1.19	conventional
A5	UM	Steel (31CrMo12-5)	10.56	n/a
	LM		12.87	n/a
	CS1		1.20	LMD
	CS2		1.19	LMD

3.2. Evaluation of the resource efficiency

The resulting mBOM from step (1) is imported into GaBi ts and matched with existing environmental datasets of materials and production processes. A few indicators have been chosen from among the entire catalog to assess the injection mould efficiently. The results are summarized in Table 3.

Table 3: Evaluation results for the injection mould

Resource	Indicator	Unit	Alternative	Amount
Water	Total freshwater consumption	[kg]	A1	622.1
			A2	556.1
			A3	165.4
			A4	1225.6
			A5	1149.2
Land	Land occupation	[m²/a]	A1	1.28
			A2	1.16
			A3	0.45
			A4	2.26
			A5	2.19
Air	Particulate matter (PM)	[kg PM2.5-eq.]	A1	0.027
			A2	0.025
			A3	0.019
			A4	0.106
			A5	0.031
Material	Abiotic depletion (ADP elements)	[kg Sb-eq.]	A1	0.0141
			A2	0.0136
			A3	0.0122
			A4	0.0458
			A5	0.0129
Energy	Primary energy demand	[MJ]	A1	1366.5
			A2	1218.9
			A3	340.5
			A4	2121.8
			A5	2554.7
Climate	Global Warming Potential (GWP)	[CO2-eq.]	A1	83.6
			A2	74.9
			A3	24.0
			A4	148.3
			A5	151.4

3.3. Pre-selection of evaluated solutions and visualization

Step (4) and (5) are summarised in this part. The pre-selection of the results comes to the conclusion that A2 and A3 are the two pareto-efficient solutions the designer should further pursue in the product development. Figure 5a) is the summary of all alternatives with their impact in each indicator. Figure 5b) shows the final result with A2 (in blue and A3 (in green). A2 dominates through the lowest total weight. A3 dominates in all other categories but has a slightly higher total weight than A2.

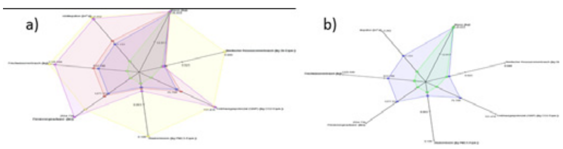

Figure 5: Visualisation of the pre-selection

4. Discussion and Outlook

The I2-Method was successfully applied on an injection mould. The requirements were addressed as follows:

- The connection with the PDM/PLM environment was accomplished through the mBOM exchange.
- The production phase of the injection mould was assessed. The entire life cycle remains a task for the future.
- A clear result was generated and could be provided to the product designer for further consideration.

Through the application of the I2-Methode different product alternatives were created, which can be used for later assessments. The application shows that the method is capable of delivering an efficient solution to assess the resource efficiency of product designs within the product development.

In the future a detailed analysis of the impacts on the product resulting from the different alternatives should be made. A comparison of the I2-Method with the results from other assessment tools, which are based on different datasets and have different workflows, would also be a challenge for the future. Further, an implementation of the entire method in one software package is in planning.

Acknowledgements

This work is part of "E³ production – sustainable manufacturing" and supported as a Fraunhofer Master Project.

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