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PROCESS-ORIENTED PERFORMANCE INDICATORS FOR MEASURING ECODESIGN MANAGEMENT PRACTICES

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1. Introduction

Literature reports several business benefits gained by implementing ecodesign in manufacturing companies, such as enhanced capabilities for innovation, development of new business models and exploration of new markets, as well as better mechanisms for complying with customer, legal and standards requirements [Bevilacqua et al. 2007], [ISO 2011], [Plouffe et al. 2011]. However, there are many categories of challenges and barriers that still hampers ecodesign implementation [Boks and Stevels 2007], [Boks 2006], specially those connected to capturing and measuring the reported business benefits of ecodesign. Additionally, since ecodesign implementation has been primarily evaluated in terms of product-related measures [Handfield et al. 2001], e.g. energy, material, physical properties etc. [Issa et al. 2015], key performance indicators (KPI) for measuring the performance, namely the effectiveness and efficacy [Neely 2005], of ecodesign implementation from a business-oriented perspective is still not fully utilized.

In order to overcome many of the challenges facing ecodesign implementation, the Ecodesign Maturity Model (EcoM2) has been proposed as a management framework based upon a systematic step-by-step approach, which aims at supporting companies in the integration of ecodesign into product development processes [Pigosso et al. 2013]. It encompasses three main elements:

1. **ecodesign practices**: comprehensive selection of over 600 practices that are classified in two main categories, according to their characteristics and object of interest [Pigosso et al. 2014]:
    a. **ecodesign management practices:** a collection of 62 practices related to the integration of environmental issues into the strategic and tactical levels of the product development;
    b. **ecodesign operational practices:** product-related practices directly connected with technical characteristics of product design and elements of its material life cycle;
2. **maturity levels**: set of successive stages for the integration of sustainability aspects into product development processes;
3. **application method**: a prescriptive continuous improvement approach to support companies during the implementation and management phases.

The model focuses on process improvement from a managerial perspective, rather than on product's performance improvement from the technical point of view. Therefore, the model is designed to support the systematic integration of ecodesign considerations, aiming to deploy action into subsequent improvement projects [Pigosso et al. 2013]. The basic underlying assumption is that if best practices are properly taken into consideration during the product development processes, the natural consequence will be that developed products will achieve a better sustainability performance [Pigosso et al. 2013].

Within this context, the focus of this research is positioned at the performance evaluation of management practices, which are the ones able to translate the ecodesign elements into more strategic and general business benefits, leading the path towards the construction of a business case [Carroll and Shabana 2010] for ecodesign implementation and management.
In order to support the performance measurement of ecodesign implementation from a process-oriented perspective, this paper aims at performing a first exploratory study of the currently available process-related KPIs for product development in the academic literature that can be potentially applied to measure ecodesign management practices. The process-related indicators are meant to capture the performance of the business process in itself, regardless of the product underdevelopment. It takes a portfolio perspective, rather than focus on individual products. This paper is structured as follows: the subsequent section presents the main components of the research methodology carried forth in order to meet the research's objective, section 3 presents the results and the unfolded discussion, and section 4 points some final remarks and considerations for future studies to be performed in connection to this paper.

2. Research methodology

In order to gather the relevant process-related KPIs from the literature and cross-relate them with the ecodesign management practices, the methodology employed in this research involved two phases:

1. **Systematic literature review (SLR)**, based on the 3-step procedure defined by [Biolchini et al. 2005]:
   i) **review planning**: a review protocol was tailored to cover the keywords "key performance indicators" and 6 synonyms ("metric", "index", "indices", "measure", "indicator" and "threshold"), and "product development" and 3 synonyms ("product design", "engineering design" and "concurrent engineering"). The selected databases for searching both conference and journal papers were ISI Web of Science and Scopus due to their comprehensiveness and relevance to the fields of study [Adriaanse and Rensleigh 2013], [Gavel and Iselid 2008]. Two inclusion criteria were defined for the papers to meet: (1) contain, at least, one KPI for product development (either proposing, report or re-applying) and (2) focus on product development from a process perspective, as opposed to product-oriented characteristics (geometry, properties, material, energy, water etc.). Based on the proposed criteria, the papers were analyzed and selected by: (a) reading the title, (b) reading the abstract and keywords, (c) reading the introduction and conclusion and (d) reading the full paper.
   ii) **review execution:** once the papers were selected, the KPIs were extracted and catalogued according to their name, description and/or formula, and bibliographic information. Eventual additional information and comments that had been pointed out by selected papers were also recorded in order to support the cross-content analysis with the ecodesign management practices.
   iii) **analysis of results:** the list of retrieved KPIs was finally catalogued and systematized in a digital spreadsheet for easy access and cross-relation analysis with the ecodesign management practices;
2. **Cross-content analysis** of the 62 management practices prescribed by the EcoM2 and the process-related KPIs gathered from the SLR. This cross-content analysis was performed by inspecting and comparing the name, nature and use of the proposed KPIs with the statement characteristics of each one of the management practices. The KPIs that were potentially suitable for capturing the practice's performance were then matched with the correspondent practice. Therefore, if no results were found, the practice was automatically marked as not having a correspondent KPI ("N/A"). If any result was found, the KPI was analyzed in terms of its meaning, focus and applicability to the practice under analysis – if the KPI matched the content of the practice's statement, it was selected and assigned as a correspondent practice. As an illustrative example of this analysis, consider the management practice "include the environmental goals into the product target specifications". The relevant keywords of this practice statement, namely a combination of the keywords "environmental goals" and "product

target specifications", along with potential synonyms, were inserted as search strings in the digital spreadsheet derived from the systematic literature review. In this example, the search for "environmental goals" and synonyms ("environmental objectives" or "environmental aims") returned the indicator "Number of employees with incentives linked to environmental goals", which is not applicable to this specific practice due to its focus on human resources management for ecodesign. Subsequently, the search for the combination of the keywords in "product target specifications" returned the indicators "% of technical specifications met or exceeded, averaged across completions", "met performance specifications" and "met quality specifications" – none of them being directly applicable to the practice once they are focused on economic and technical performance in the development process. However, a synonym that is importantly linked to this practice is "requirement" – the search for this keyword resulted in 16 indicators related to requirements from an economic perspective (e.g. "requirement verifications trend", "accuracy of interpretation of customer requirements" etc.) and one indicator which was broadly regarding sustainability, namely "degree to which the product requirements have the potential to improve sustainability". This last indicator was aligned to the practice's statement and objectives, being therefore selected as a correspondent KPI.

3. Results and discussions

From the execution of the SLR proposed in the previous section, 711 papers were retrieved from Scopus, 270 papers from ISI Web of Science and 198 papers were indexed in both databases, in a total number of 1.179 papers retrieved. By applying the inclusion criteria and following the procedure for study analysis and selection, 43 papers were fully read and finally selected, representing 3.6% of the total number of retrieved papers. The selected papers were published in a total of 20 different journals and 12 scientific conferences. After consolidation of indicators and removal of duplicates, a total of 787 KPIs were catalogued and systematized from the 43 selected papers, with an average of 18.3 KPIs per paper. The majority of the studies and KPIs were discarded due to its emphasis on technical features of the product, such as geometry, shape, material, physical and chemical properties. Subsequently, the KPIs were cross-analyzed against the set of 62 ecodesign management practices in order to establish whether the KPI was suitable for capturing the practice's performance. The results are summarized in Table 1.

Table 1. Ecodesign management practices and process-related KPIs

#	Ecodesign management practices	Process-related KPI
1	Examine the relevant internal and external drivers for the development of products with a better environmental performance	N/A
2	Assess technological and market trends (including new customer requirements) related to ecodesign	N/A
3	Ensure alignment among strategic and operational dimensions concerning environmental issues in product development	Product development alignment with business strategy [Tolonen et al. 2015]
4	Clearly define the goals to improve environmental performance of the products under development	N/A
5	Include the environmental goals into the product target specifications	Degree to which the product requirements have the potential to improve sustainability [Ussui and Borsato 2013]
6	Integrate the environmental dimension in the strategic decision making process jointly with the traditional aspects	Number of sustainability aspects covered by the elements of business planning [Ussui and Borsato 2013]

7	Establish product-related vision, strategy and environmental roadmaps in the strategic level at the company	N/A
8	Strategically consider the product environmental performance in the company portfolio management	N/A
9	Develop business, product and market strategies considering the environmental trends	N/A
10	Incorporate product-related environmental goals into the technological strategy	N/A
11	Identify customers' and stakeholders' requirements and priorities concerning the environmental performance of products	Accuracy of interpretation of customer requirements [Costa et al. 2014]
12	Collect information about applicable legal issues and standards related to the environmental performance of products	Degree to which the product meets environmental legislation requirements [Ussui and Borsato 2013]
13	Identify and/or develop new technologies that can contribute to improve the environmental performance of the developed products	N/A
14	Perform functionality analysis to determine requirements for a product and find new ways to deliver the functions with a better environmental performance	N/A
15	Improve the interaction between product and service developments in order to explore the potential to offer solutions with a better environmental performance	Degree to which design process considers service well [Hauser 2001]
16	Define a strategic roadmap for the development and implementation of new technologies that allows a better environmental performance over the product life cycle	N/A
17	Evaluate the environmental performance of technologies	N/A
18	Consider the environmental performance as one selection criteria for the product concept and design options	Degree of adoption of methods to support the development of new concepts for sustainable products [Ussui and Borsato 2013]
19	Evaluate the environmental performance of products during the product development process	Number of sustainability aspects the selected concepts have the potential to improve [Ussui and Borsato 2013]
20	Establish priorities on the environmental impacts to be minimized over the entire life cycle of the product	N/A
21	Consider the trade-offs among the environmental requirements and the traditional requirements of a product (such as quality and cost)	N/A
22	Identify the ecodesign guidelines that can be applied in product design in order to increase the environmental performance of the product under development	N/A
23	Develop and/or customize environmentally product-related guidelines to support product development	N/A

24	Incorporate the environmental aspects in the identification, qualification and management of suppliers	Percentage of selected suppliers certified ISO 14000 [Ussui and Borsato 2013]
25	Consider and involve the total value chain for improving the environmental performance of products	Sustainability assessment of suppliers [Nappi and Rozenfeld 2013, 2015]
26	Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of products	Response to environmental programs for suppliers [Nappi and Rozenfeld 2013, 2015]
27	Develop a "green" incentive scheme for the ecodesign implementation and management	Number of employees with incentives linked to environmental goals [Nappi and Rozenfeld 2013, 2015]
28	Select and/or develop new manufacturing and assembly processes with better environmental performance	Degree to which selected processes, equipment and manufacturing technologies are energetically efficient (Ussui and Borsato, 2013)
29	Optimize the existing production processes in order to improve the environmental performance of products during manufacturing	N/A
30	Develop the technical support processes (e.g. maintenance, change of spare parts, etc.) aiming to improve the environmental performance of the product over its entire life cycle	New environmentally sound processes introduced [Nappi and Rozenfeld 2013, 2015]
31	Define the end-of-life and reverse logistics strategies to be addressed during product development in order to improve the environmental performance of the product in the end-of-life phase	Degree to which the definition of product life cycle considers elements that improve sustainability at the end-of-life [Ussui and Borsato 2013]
32	Improve the environmental performance of packaging and distribution during the product development and related processes	Degree to which sustainable alternatives for packaging were verified [Ussui and Borsato 2013]
33	Elaborate and communicate recommendations to consumers on how to improve the environmental performance of the product during the use and end-of-life phases	N/A
34	Communicate the environmental performance and benefits as part of the total value proposition of the product, exploring the green marketing opportunities	N/A
35	Monitor the product environmental performance during use and end-of-life phases of the life cycle	N/A
36	Communicate to customer and stakeholders the improvements on the product environmental performance and consequent economic gains	N/A
37	Supply the product development process with information related to the environmental performance of materials, processes and components in the whole product life cycle phases	Environmental information availability and accuracy [Nappi and Rozenfeld 2013, 2015]
38	Define and measure performance indicators for the environmental performance of stakeholders such as suppliers, after sales, service providers, recyclers, etc.	Number of sustainability aspects (social, environmental and economic) considered for defining performance indicators [Ussui and Borsato 2013]

39	Structure a systematic procedure to gather ecodesign-related knowledge	Number of knowledge sources / Level of knowledge sourcing / Level of knowledge search [Choi and Ko 2010]
40	Perform internal and external benchmarking of the environmental performance of products and/or ecodesign best practices	N/A
41	Formulate the company environmental policy and/or strategy	N/A
42	Deploy and maintain an environmental policy and/or strategy in the product level	N/A
43	Establish a prioritized program for the implementation and management of ecodesign	N/A
44	Clearly define the product-related environmental goals for the whole company	N/A
45	Increase consciousness and awareness of the company in regards to the application opportunities and benefits of ecodesign	Level of employee awareness of R&D program/project's goals [Costa et al. 2014]
46	Ensure commitment, support and resources to conduct the activities related to ecodesign	Ability to accrue political support within the firm [Griffin and Page 1993]
47	Deploy the responsibilities and authorities among people of different areas and hierarchical levels	Comparison of allocation of duties and responsibilities against their achievement [Kulatunga et al. 2011]
48	Ensure appropriate communication among departments and different hierarchical levels concerning ecodesign	Communication level between departments [Choi and Ko 2010]
49	Provide ecodesign-related training for the employees involved in the product development and related processes	Sufficient training and technical background [Yim et al. 2015a, 2015b]
50	Make environmental considerations a part of the daily routine of the employees involved with product development	Number of function with environmental responsibilities [Nappi and Rozenfeld 2013, 2015]
51	Integrate ecodesign into the product development and related processes standards and procedures	Application of ecodesign [Nappi and Rozenfeld 2013, 2015]
52	Conduct management reviews to evaluate the effectiveness of the environmental issues consideration in the product development and related processes	Number of critical/major issues assessed at the phase review [Hauser 2001]
53	Select and customize ecodesign methods and tools according to the company's needs	N/A
54	Formulate, update and monitor mandatory rules (internal standards) and/or product requirements in order to comply with environmental product-related legislations and/or regulations	N/A
55	Effectively integrate product-related environmental goals into the corporate strategy	N/A
56	Select the relevant people from functions across the company to be involved in the ecodesign activities	N/A

57	Implement the Life Cycle Thinking into the product development and related processes	N/A
58	Measure and monitor the environmental feasibility of new product development projects	N/A
59	Clearly define the environmental indicators and the methodology to be used during the gates (phase assessments)	Number of sustainability aspects (social, environmental and economic) considered for defining performance indicators [Ussui and Borsato 2013]
60	Check the environmental performance of products during the phase assessments (gates)	N/A
61	Define and measure environmental performance indicators for product improvement	Number of sustainability aspects (social, environmental and economic) considered for defining performance indicators [Ussui and Borsato 2013]
62	Define and measure performance indicators for the environmental performance of the ecodesign program	

Considering all the 62 ecodesign management practices, 32 of them (51.6% of the total) did not have a correspondent process-related KPI to be assigned. The remaining 30 practices were assigned to a total of 27 different KPIs, of which 1 KPI ("Number of sustainability aspects (social, environmental and economic) considered for defining performance indicators" [Ussui and Borsato 2013]) was assigned to 4 different practices, and the other 26 KPIs covered only one practice each.

In terms of distribution of studies, the KPIs are considerably concentrated in two main sources that are mainly reporting sustainability-related indicators – 10 KPIs (37.0% of total number of KPIs) were retrieved from the work of [Ussui and Borsato 2013] and 7 KPIs (25.9% of total number of KPIs) were directly extracted from the works of (Nappi and Rozenfeld, 2015, 2013). Both sources sum up a total of 69.2% of all the KPIs that were ultimately related to the ecodesign management practices.

The remaining 10 KPIs were extracted from works dealing with (i) indicators for product portfolio management [Tolonen et al. 2015]; (ii) lean metrics for the management of research and product development [Costa et al. 2014]; (iii) utilization of mechanisms of adaptive control feedback to support performance measurement in product development [Hauser 2001]; (iv) integrated set of metrics for measuring innovation [Choi and Ko 2010]; (v) classic studies on success and failure of product development [Griffin and Page 1993]; (vi) development of a performance measurement system for research and development (R&D) in the construction industry [Kulatunga et al. 2011]; (vii) studies on project risk classification and indicators [Yim et al. 2015a, 2015b]. It is noteworthy that none of the described studies falls within the specific areas of ecodesign implementation or management.

The selected KPIs to measure the ecodesign management practices are still generic and do not fully reflect and translate the specific needs of the management practices at hand. The two sustainability-related papers touches upon the sustainability concept at all 3 dimensions (i.e. economic, social and environmental) of the bottom-line approach [Elkington 1997], whereas the remaining papers are generally concerned with economic measures dealing with the efficiency and financial returns of product development, innovation and project management processes. There is a particular lack of indicators that would translate the deployment of environmental-related strategies, policies and trends into actionable steps within the organization. Furthermore, the deployment of this strategy into the procedures and tools of the tactical level is not supported by qualified indicators either. Therefore, a fine-tuning is required in order to tailor the current available KPIs to capture the performance of a given set of ecodesign management practices which is to be applied in a company. These results indicate that the field of product development, and ecodesign specifically, has not been focused on generating indicators for managing ecodesign implementation at the strategic and tactical levels, where the business benefits rest at. To a certain extent, these results also mean that ecodesign implementation is not being captured, measured and discussed from a process-related perspective, hindering its application and casting many questions around the trade-offs and potential gains a company can have from assuring consistency

between product and portfolio. Some of the reviewed papers have reported indicators that were proposed, captured or elicited from industrial practice. Therefore, a potential complementary source of indicators are the manufacturing companies that are applying ecodesign into their product development processes. This addition might overcome the current situation where less than half of the ecodesign management practices could be directly represented by one of the process-related indicators gathered from the literature. Additionally, practitioner-based perspective could constitute an investigation into the "state-of-the-practice" stance, with a special focus on how companies are currently and pragmatically measuring their ecodesign process. Therefore, it is still a challenge to build a compelling rationale and a structured chain of relations for grasping and measuring the real strategic and organizational benefits caused by the implementation of ecodesign practices.

4. Final remarks

This paper aimed at exploring the available process-related KPIs for product development and their potential applicability to measure the ecodesign management practices proposed by the EcoM2 framework. This work is encapsulated by an on-going research project and the results and analysis reported in this paper are preliminary and constitute stepping-stones towards a broader and deeper understanding of ecodesign performance measurement from a process perspective. A systematic literature review was executed to gather the KPIs suggested by the literature, followed by a cross-content analysis with the ecodesign management practices, which are also well documented in the literature. The applied methodology presents a set of limitations, mainly concerning the pure theoretical nature of the KPI search procedure and the limited validation of the matching between the collected KPIs and the correspondent ecodesign management practices. This matching procedure captures the authors' perspectives upon the theme and would benefit either from robust triangulation or wider expert validation process, supported by other academic specialists and industrial practitioners. Furthermore, testing in specific case must be performed in order to build a solid repository of process-related KPIs for ecodesign management with higher impact in industrial applications.

The results presented show that there is considerable room for improving the development of specific KPIs for measuring the actual performance of ecodesign implementation from a process- and business-oriented perspective. The current proposed KPIs are either too generic in sustainability terms or cover important topics of product development from a pure efficiency and financial return standpoint. Therefore, this research configured the initial and preliminary steps of building solid knowledge in capturing and measuring ecodesign performance with a view to creating and strengthening a set of compelling arguments and rationale for improving the way companies decide for and implement ecodesign. From a pragmatic perspective, it is expected that the reported findings: (i) enhance the engineering design practice in the product-related levels by supporting and informing a more consistent alignment between product and portfolio; (ii) are applied in an engineering management context within companies interested in creating the foundation for a forward-looking practice into systematically measuring ecodesign performance; (iii) are used as a preliminary source of KPIs for practitioners to be applied, adapted, customized and tailored for measuring the performance of their ecodesign management practices; (iv) a stepping-stone for the creation of new and aligned KPIs that would translate the needs of the ecodesign practices and would fill the initial existing gap of process-related indicators for the un-matched 32 practices. Future research engagements can cover the scopes of: (i) deriving and proposing consistent tailor-made KPIs for all ecodesign management practices; (ii) submitting the task of KPIs/practice assignment and matching to different ecodesign specialists and compare the results, with a view to stronger validation and testing; (iii) designing empirical studies (e.g. case studies for theory testing, surveys etc.) to capture specific process-related KPIs that companies are using for ecodesign implementation, from a strategic and tactical stances, and therefore build a "state-of-practice" database, amounting to a more robust and practically oriented indicator repository.

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