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Bridging the gap using Environmental Value Stream Mapping

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From Strategic Goals to focused Eco-efficiency Improvement in Production - Bridging the gap using Environmental Value Stream Mapping

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Abstract

The combination of environmental and economic performance measurement is a key prerequisite for manufacturing companies to achieve high eco-efficiency and thus crucial to maintain their competitiveness in global markets. Despite the availability of several standards and guidelines proposing environmental and economic performance indicators for manufacturing companies, a user-oriented approach to enable an eco-efficiency assessment and translate strategic goals into focused improvements at an operational level has not yet been formulated.

This paper shows how the novel approach of environmental value stream mapping (EVSM) can be used to fill this gap. EVSM is introduced as an interface between a multi-dimensional performance measurement system and a manufacturing system integrating environmentally and economically relevant process flows in one process model. After describing the basic structure of an environmental value stream map, the industrial applicability is demonstrated in a case study from the consumer goods industry.

Keywords:

Performance Assessment; Performance Measurement; Value Stream Mapping

1 INTRODUCTION

The relevance of corporate environmental performance has increased during the last two decades. This is reflected by the amount of Corporate Responsibility Reports (CRR) published between 1993 and 2011, as presented in Figure 1.

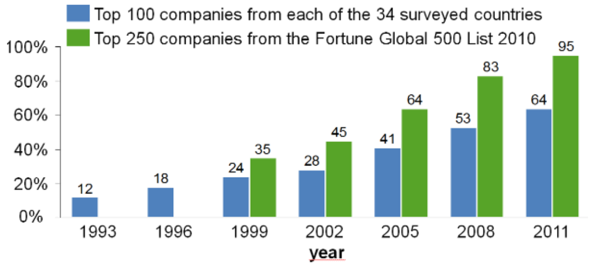

Figure 1: Share of selected companies publishing CRR [1]

In 2011, 95% of Top 250 companies of the Fortune Global 500 List published a CRR. Although the figure particularly surveying the manufacturing sector is slightly smaller, it increased substantially. In 2008, 41% of the manufacturing companies from the top 100 organizations within the 34 surveyed countries published a CRR, whereas there were already 61% in 2011 [1].

In addition to just reporting environmental performance, manufacturing companies are formulating goals on a strategic level and cascade them into tactical and operational objectives. Consequently, production managers need to increasingly incorporate an environmental perspective in their so far only economically oriented performance management to improve both perspectives simultaneously (eco-efficiency). And they are aware of the role they are asked to play. In a recent study including 300 factory planning experts from Germany, 73% of the peers rated environmental sustainability as ‘important’ or ‘very important’ [2].

However, production managers face a major challenge when operationalizing strategic goals. They need to identify to which goal(s) they can contribute to within their decision domain and how they can thereby increase the overall system performance. This means to pinpoint performance drivers and to improve their production processes in a focused and thereby effective as well as efficient way. Which processes embody the highest potential for contributing to corporate strategy is firstly dependent on the relevance of goals formulated by corporate strategy for the considered production system and secondly by the improvement potential of each process itself. In both cases an interface is needed to either translate strategic goals top-down to shop-floor level or to analyze the underlying production system, to feed data bottom-up into existing performance measurement systems (PMS) and to identify areas for improvement.

This paper proposes EVSM as an interface between an existing PMS and the actual production processes. The scope of the presented research is limited to multi-machine systems in discrete part manufacturing. The paper is structured as follows: First, the need for coupling corporate strategy with shop-floor management is stressed. Second, the structure of an EVSM is outlined. Third, the industrial applicability is demonstrated in a case study from consumer goods industry.

2 THEORETICAL BACKGROUND AND MOTIVATION

2.1 Performance Measurement System

Traditionally, levels of information density and range of decision making within an organization are described as strategic, tactical and operational. According to Duflou et al. [3], manufacturing activities can further be subdivided into global supply chain, multi-factory system, facility, multi-machine system and unit process. In the left section of Figure 2 the integration of both perspectives is displayed.

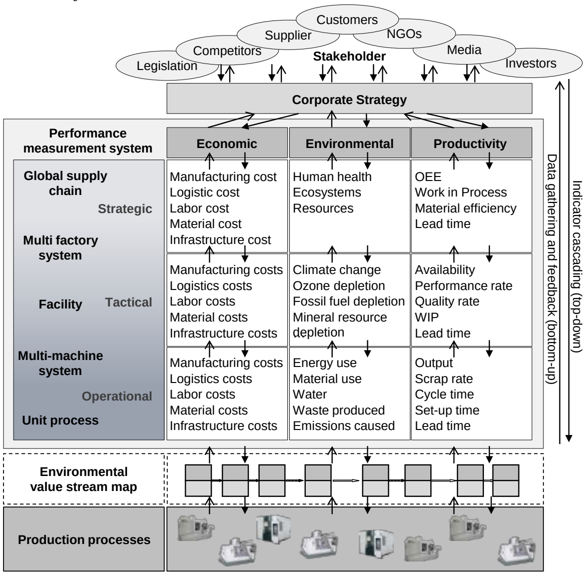

Figure 2: Environmental value stream mapping as interface between multi-dimensional performance measurement system and production processes

Although being subdivided into managerial levels, a manufacturing company needs to satisfy competing interests from several stakeholders at once. Corporate strategy carries the responsibility of analyzing actual stakeholder requirements, adapting potential business opportunities in the future and of translating both into strategic goals [4]. To incorporate these goals within an organization and to ensure that all activities are aligned with the strategic path defined, it is crucial to implement a performance measurement system with specific Key Performance Indicators (KPIs) at each level [5]. As a result strategic goals supplemented with associated KPIs can be cascaded to subordinate managerial levels, performance can be managed and assessed at each level independently as well as in the context of the overall system. Therefore, a PMS needs to be segmented into relevant performance dimensions in addition to the managerial dimensions described above. Particularly when assessing eco-efficiency, an integrated approach is crucial because interrelations among environmental and economic performance needs to be considered when aiming for an integrated improvement. According to Herrmann et al. [6] eco-efficiency management is therefore only feasible with multi-dimensional criteria. KPIs need to be formulated not only addressing economic performance but also environmental impact of the manufacturing company. Figure 2 shows an example of a performance measurement system defining indicators in the dimensions of cost, environmental impact and productivity. In this case, productivity is interpreted as an indicator typology encompassing KPIs to assess the effectiveness and efficiency of manufacturing activities, thereby including quality and time related indicators [7]. The exemplary system presents a production manager's perspective on how KPIs are cascaded into a tactical and operational level. The indicator dimensions and the KPIs on strategic level are defined by corporate strategy based on external and internal stakeholder requirements. In a top-down procedure, superordinate indicators are interpreted and transferred onto appropriate KPIs at subordinate level. In contrast to goal definition and indicator selection being derived from strategic to operational level, data gathering is conducted vice versa. The data needed to compose the measurement system is derived from production and is aggregated and interpreted in a bottom-up procedure, feeding the selected indicators with the required values in the domain of cost, environmental impact and productivity.

Against the background of an existing multi-dimensional PMS, two challenges emerge from a production manager's perspective. First, data needs to be gathered from production to feed the existing PMS at operational level. Second, improvement areas in which a specific production system can contribute to the overall systems performance need to be identified and prioritized. Considering the structure of a PMS for eco-efficiency measurement, it is crucial to reflect the multi-dimensional approach with a multi-dimensional production process assessment. Only by taking into account environmental as well as economic aspects at once, interrelations can be identified and later exploited to contribute to the strategic goal of eco-efficiency improvement. To bridge the gap between a multi-dimensional PMS for eco-efficiency assessment and production processes, a methodology is needed being able to:

- Condense data gathered from production with an integrated approach in the multiple performance dimensions.
- Identify and prioritize areas for improvement taking into account interrelations among the performance dimensions.

2.2 Related work

According to Thiede et al. [8], environmental performance assessment in manufacturing demands for a comprehensive and system oriented approach to avoid focusing on aspects of little relevance. In order to improve the overall eco-efficiency, this requirement is extended to economic performance dimensions such as costs and productivity. Subsequently, a methodology is needed to assess multi-machine systems and unit processes in particular.

Ongoing research can be identified in the environmental assessment of multi-machine systems, some of it also considering economic aspects. A comprehensive overview is given by Duflou et al. [3]. Within research in this field, input/output models seem to be most suitable to assess environmental impact of production processes [6]. As presented by Thiede, some of them are also including economic aspects [9]. Apart from this research focusing on environmental and economic impact of production systems, conceptual modeling approaches also describe the underlying structure of production systems. As mentioned before, the resulting holistic understanding of the overall system is crucial when considering multi-criteria eco-efficiency improvements. Value stream mapping seems to be a promising approach to combine system analysis and system description. It is a commonly known method and widely accepted in practice. Erlach and Westkämper [10] introduced an adaption of value stream mapping incorporating energy streams. Sproedt and Plehn [11] proposed a conceptual model for discrete-event simulation also including environmentally relevant material, water, waste and emission flows. In the following an EVSM approach is introduced to meet the needs described before.

3 ENVIRONMENTAL VALUE STREAM MAPPING

EVSM is proposed to operationalize strategic goals resulting from a PMS with environmental as well as economic focus and to identify areas within a multi-machine system most suitable to contribute to the overall performance.

Value stream mapping is a well-known method from lean production. Its aim is to represent all activities in production (production processes, transportation, and storage) and the data relevant (cycle times, setup times, scrap rates and lot sizes) to measure the corresponding economic performance. A detailed introduction to the method is given by Rother and Shook [12]. The adaption of the method in this context is presented in Figure 3.

Covering only economic aspects, traditional value stream mapping is not sufficient for an integrated eco-efficiency assessment. Therefore, it was enhanced by environmentally relevant input and output flows. The model can be characterized as the integration of a traditional value stream map (VSM) with an input/output process model as proposed by Herrmann et al. [6]. Economically relevant data is displayed by using the traditional notation of a value stream from raw material to final customer. Environmentally relevant process flows are represented by inputs and outputs at each unit process.

In general, the same symbolic notation is used for the visual representation of the environmental VSM as for a standard VSM presented by Rother and Shook [12] The value stream from raw material to final customer is described with grey boxes representing operations and work centers, triangles are used to represent storages and arrows for different modes of transport. Similar to a standard VSM, production parameters such as cycle time, set-up time, scrap rate and lot size are included. In order to incorporate environmentally relevant process parameters, two additional boxes for each unit process are attached. The additional input and outputs are categorized according to the prevalent environmental KPI classifications on operational level, namely: energy, materials, water, waste and emissions [13]. The blue box on top contains information about all relevant energy, material and water inputs. The green box at the bottom includes all environmental relevant process outputs, categorized into waste and emissions. The input and output boxes are further subdivided horizontally in order to account for different consumption and emission rates in respective machine states.

The environmental VSM is thus able to capture all information necessary to feed indicators defined on operational level. Based on a representative product, economic aspects are covered with information given in the grey boxes (e.g. cycle-time, scrap rate) and the lead time analysis at the bottom of the map, which displays the value added time, overall lead time and their ratio. Furthermore, average stock levels can be derived from the lead time analysis which enables, in combination of lot sizes, cycle times and set-up times an analysis of Work in Process (WIP). Environmental impact can be derived from the attached boxes presenting input/output streams in the categories of energy, material, water, waste and emission.

The structure of the environmental VSM renders a transparent picture of production processes with the sum of all process inputs to the system equaling all process outputs plus the products produced. All input and output streams from each unit process can be aggregated to the overall performance, which is presented in the right section of Figure 3. Following the approach of an input/output model, scalable results are therefore possible. The performance can be assessed from a unit process, multi-machine perspective as well as with a focus on single products. The resulting overall system assessment can be used to further analyze the relevance of each process in its contribution to strategic goals, the basis to identify areas for focused improvement activities. .

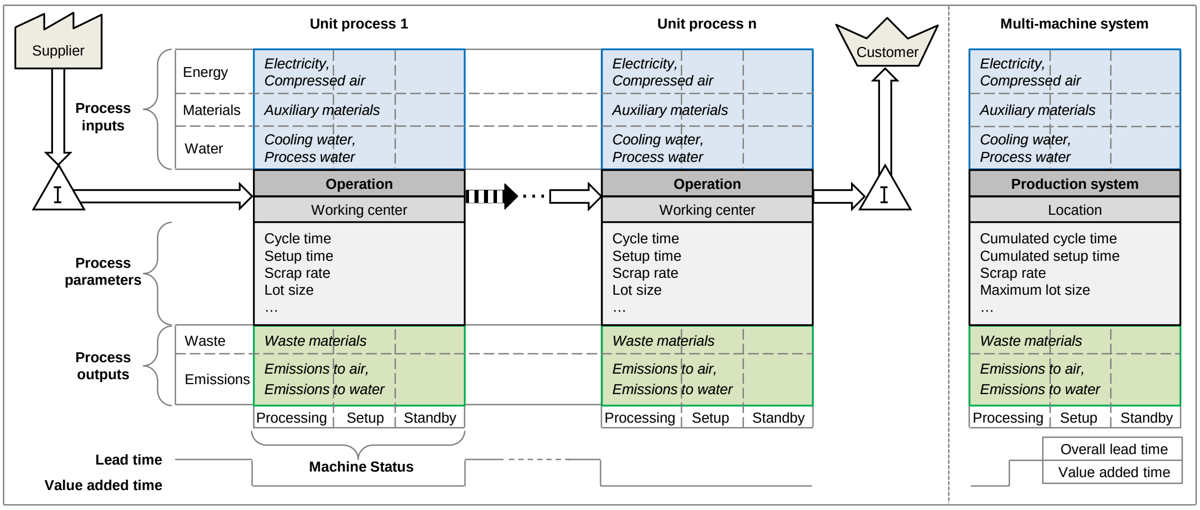

Figure 3: Basic structure of an Environmental value stream map

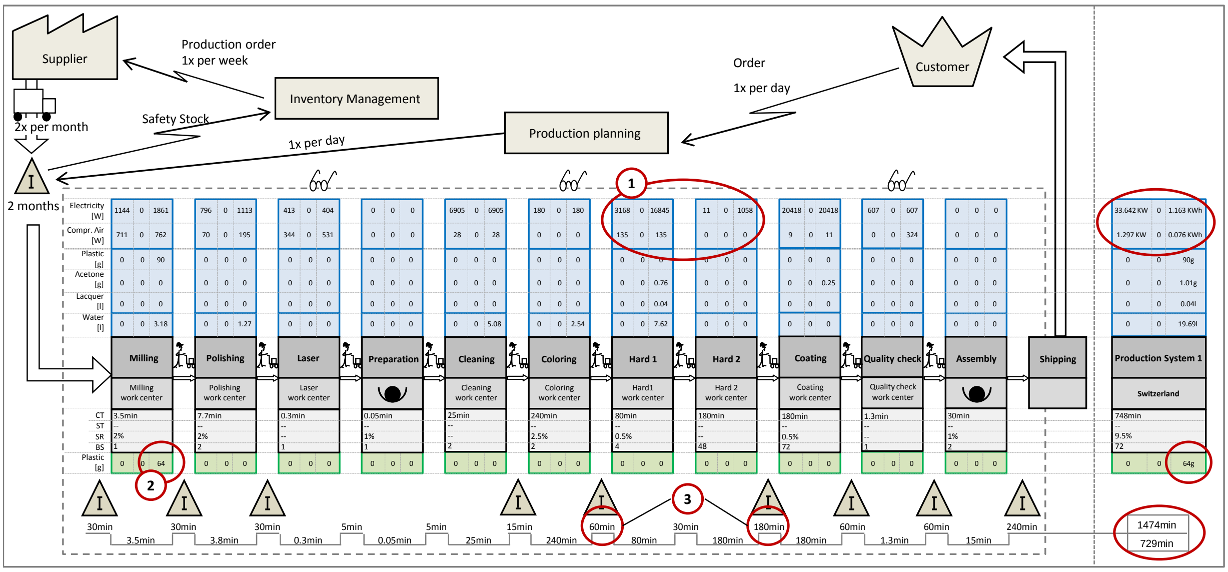

Figure 4: Environmental value stream map of a manufacturing company from consumer goods industry

4 CASE STUDY CONSUMER GOODS INDUSTRY

4.1 Data gathering and EVSM in practice

The organization regarded in this case study is a small company of the Swiss consumer goods industry with 55 employees. It is a specialist manufacturer of customized glasses, which are produced in a make-to-order environment. The scope of the study was set on the production system, excluding rework and shipping. Regarding the start of production, raw material (in this case two plastic blocks) is taken from raw material stock. The raw glasses are then milled, polished, colored and coated according to customer specifications. Afterwards, the glasses are quality-checked, stacked and prepared for transport. Finally, the finished products are put into goods-out inventory, from which they are commissioned and shipped to customers.

During a first workshop and based on internal documentation a stakeholder analysis was conducted with senior management to determine the relevant KPIs on corporate strategy level, namely: costs, environmental impact and cash-to-cash cycle. Following the procedural framework described by Plehn et al. [4], one three-hour workshop was conducted to delimitate the system as defined in ISO 14955 [14], containing all necessary systems and subsystems to perform the manufacturing process described before. During this workshop, a representative product was selected to be tracked in the EVSM. Another four-hour workshop was used to set up the basic structure of the environmental VSM and to determine the required data to fill the map with corresponding process parameters as well as input and output streams.

Data gathering was conducted according to the three operational steps introduced by DENA [15]:

- Basic data acquisition of available data, without external sensors or measurement procedures.
- Detailed measurement of the energy and resource consumption with the implementation of external sensors.
- Monitoring and analysis of the revealed data for the implementation of optimization measures.

As basic data acquisition from the company's ERP system does not support all requested information of the ESVM, a detailed measurement was conducted to gather detailed energy consumption information ($P_{in}(t)$, $V_{air,in}(t)$) in various machine states, e.g. on, off or standby. A multichannel measurement system, based on commercially available sensor components for effective power (W) and air flow (Nm^3/h), was used to capture synchronized data. A sampling rate of 1Hz was found to be sufficient in relation to energy pricing, which requires peak values within 1/4h timeframes [16]. To cover fast machine dynamics, spindle start or stop, a sampling rate of minimum 5Hz was deployed. A detailed description of the applied energy and compressed air measurement as well as corresponding critical requirements is presented by Gontarz et al. [17, 18]. While energy inputs are rather easy to measure, outputs such as waste heat are mostly unquantifiable or require extensive measuring effort. Therefore, energy outputs were neglected in this case study.

Apart from energy inputs and outputs material and water consumption were assessed. Basic data acquisition was conducted using the data provided in the company's ERP system. Information about the amount of material and water consumed was derived from the balance sheet and assigned to the unit processes based on semi-structured interviews with the production manager. Detailed measurement was not conducted due to associated measurement costs. A similar procedure was chosen to determine the amount of waste produced per process. Emissions to air did not exist in the analyzed production system and were neglected. Emissions to water were found to be not relevant, due to an existing and advanced water treatment system with negligible costs and environmental impact.

In addition to the environmentally relevant input and output flows, the process parameters cycle time, set-up time, scrap rate and lot size were derived from the production data acquisition and validated with the production manager. Inventory data was extracted from the company's ERP system. Figure 4 shows the resulting environmental VSM of the delimitated multi-machine system.

4.2 Using EVSM to identify areas for improvement at operational level

As mentioned before, senior management formulated several goals on strategic level. Using the data gathered and displayed in the environmental VSM, the unit processes within the delimitated multi-machine system were analyzed according to their potential contribution towards the formulated goals.

Costs

Analyzing the cost structure on operational level, labor costs, material costs, costs of machinery and infrastructure as well as costs caused by consumables and energy were analyzed. Based on a discussion with the production manager labor costs and costs of machinery were disregarded. Figure 5 presents the relative distribution of the remaining cost drivers within the considered system. In this perspective, costs for plastic raw material have a major share accounting for 65%, followed by lacquer (8.5%) and energy consumption (5.6%). Other important cost drivers are vaporization materials (3.2%), polishing felts (2.8%) and pigments (2.6%).

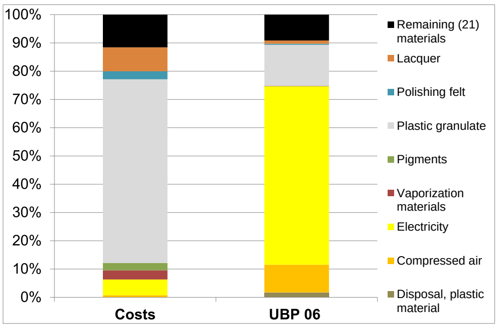

Figure 5: Relative distribution of the costs and UBP 06 points for the energy, water and material flows associated with the annual product output of the analyzed multi-machine system.

Environmental impact

To analyze the multi-machine system according to its environmental performance, the energy and material flows were assessed with the method of Life Cycle Assessment (LCA). LCA is a technique for the comprehensive, quantitative assessment of the environmental impacts of products in a life-cycle perspective and allows measuring the relevance of materials, evaluating their main impact factors and establishing recommendations for actions [19]. For multi-machine systems, options for environmental improvements are primary related to the processes directly located in the fabrication. In addition, environmental improvements can be achieved by the meaningful improvement/substitution of the required material/energy flows. To allow optimization for both, upstream processes which are associated with the annual product output, (e.g. the production and provision of electricity) were also included and assessed on the basis of background data from the ecoinvent database [20]. The use phase and disposal/recycling of the fabricated products were omitted given its limited relevance for the scope of the study (cradle-to-gate).

LCA allows the assessment of the environmental damage of all input and output flows associated with a product system on the basis of numerous Life Cycle Impact Assessment (LCIA) methods. In the case study, the senior management formulated the strategic goal of reducing overall environmental impact. To follow this very general goal, the Swiss method of ecological scarcity (ecofactors or UBP 06) was selected [21]. The UBP 06 method is a distance-to-target method that evaluates environmental damage by means of the difference between actual and critical flows according to the Swiss legal framework.

Figure 5 gives an overview of the relative distribution of environmental impacts. Electricity usage embodies a major share of the total impacts, accounting for 72.9%, i.e. 63.1% resulting from the direct usage of electricity and 9.8% form the production and use of compressed air. Another important impact is associated with the consumption of the required plastics raw material (14.6%).

Cash-to-cash cycle

The strategic goal to improve cash-to-cash cycle was deduced into lead time reduction at operational level. The data to feed this indicator and to identify areas for improvements was derived from the EVSM. As presented in Figure 4, the overall lead time was found to be 1474 minutes with a value adding time/ overall lead time ratio of 49%.

Areas for improvement

Based on the findings and using the structured presentation of the relevant data in the environmental VSM, several areas for improvement were identified together with the production manager:

- To cut raw material costs and decrease environmental impact, it is analyzed whether differentiation in raw material, using different diameters and thicknesses is feasible. So far only one type of raw material is purchased covering all customer specifications but leaving blend of up to 80%.
- To reduce energy consumption and energy costs, the unit processes Hard 1 and Coating were identified as main drivers for energy consumption. Pre-measurements revealed that further measurement is needed at machine-tool level.
- To shorten production lead time, measures are analyzed to reduce process-related waiting times without causing an increase of costs and/ or environmental impact.

5 DISCUSSION

The application of the introduced approach in the case study has shown how EVSM can be used to close the gap between an existing eco-efficiency PMS and production processes. By integrating environmentally and economically relevant process parameters and their presentation in a system-oriented process model, data is presented in a structured way and interrelations among the performance dimensions are revealed. This information can be used to feed indicators at operational level, identify goals most relevant in a specific production system and to identify areas for integrated improvements.

Still, EVSM is suffering the same limitations as conventional value stream mapping. The approach is limited in its ability to reflect dynamic aspects (e.g. bottlenecks due to changing order quantities). Furthermore, in a high product variety environment, where the value stream among products varies significantly, it is very difficult and perhaps even unfeasible to identify a representative product as basis for EVSM. In this case, several iterations of the approach must be conducted, which would thereby limit its applicability.

Nevertheless, the approach proved its applicability in practice. The high acceptance of conventional value stream mapping in manufacturing was found to be very helpful when applying the methodology of EVSM together with production managers. Furthermore, the proposed system-oriented approach combined with simultaneous multi-criteria assessment supports identification and prioritization of improvement activities. Production managers can decide which improvement activity is appropriate based on an integrated data basis as well as visualize their improvement.

6 CONCLUSION

The introduced approach of EVSM has proven its industrial applicability to enable production managers when operationalizing strategic goals in manufacturing and improving their eco-efficiency aligned with corporate strategy. By combining a conventional VSM with an input/output model, the proposed approach is suitable to consider all dimensions required in an eco-efficiency assessment of production systems. The system-oriented approach visualizes information relevant and reveals interrelations among the considered performance dimensions. Hence, production managers are supported when identifying areas for improvement which enables them to increase their eco-efficiency in a delimitated production system.

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