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RESOURCE EFFICIENCY WITHIN SEMI-CONTINUOUS PRODUCTION: AN APPROACH TO ASSESS PROCESS-INHERENT RESOURCE DISSIPATION

Horst Meier, Dennis Bakir, Björn Krückhans

Ruhr-University Bochum, Faculty of Mechanical Engineering, Chair of Production Systems, Germany

Corresponding author:
Dennis Bakir
Ruhr-University Bochum
Chair of Production Systems
Universitätsstraße 150 – IC 02/735, 44801 Bochum, Germany
phone: +49 234 3226298
e-mail: bakir@lps.rub.de

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Abstract
Within classic German manufacturing structures, costs of resources exceed all other cost factors by 46% [1]. Solitary focus on energy or labor costs as sources to raise companies profit no longer seems adequate. Nowadays material costs of the manufacturing industry are about 500 billion euro per year, connected with a saving potential of 100 billion euro per year. Also the belonging for sustainably produced products is raising and becoming a factor for guaranteed purchases [2]. A small and medium-sized enterprise fitted approach, which ensures to increase the transparency of internal process structures and allows a resource driven, ecological and economical assessment, is the main subject of this article.

Keywords
resource efficiency enhancement, resource assessment approach, eco accounting, lean manufacturing, manufacturing systems.

Current situation

Cost structure analysis of the German manufacturing sector shows that in 2011, on average, 44.6% of all efforts were spend on material [1]. Taken together with the costs on energy, which were about 2.1%, the costs on resources were about 46.7%. Though costs regarding resources are clearly exceeding often discussed labor costs, which are only about 16.8% [2]. This trend is quite comparable to most European countries.

A current evaluation of the Flash Eurobarometer, initiated by the European commission, shows that more than 56% of all interviewed companies assume cost of material higher than 30%. Due to a lack of relevant information within these enterprises there is a clear subjective estimation underlying [3]. Aggravating occurs that these costs will increase because of other effects, such as rising demand and insufficient availability of resources at the same time [4]. While by the year 2000 about 50 billion tons of resources were used for production purposes, in 2009 already 68 billion tons were employed [4]. Today the total amount of material, used in the manufacturing industry, reaches 500 billion euro with an inherent potential for further savings of 20%. This means an unemployed potential of about 100 billion euro per year [1]. Similarly the demand for sustainably produced products is still raising and will become an additional factor for a guaranteed purchase. The multilevel Eco**X**-Approach presented below is a proven remedy for the manufacturing companies which urgently need processes' transparency. Additionally it allows a sensitization of the users at the same time. Therefore the necessary production steps, beginning from the raw material stage up to the final product were analyzed and structured. Subsequent, visual attractive and easily comprehensible evaluation of the occurring resource flows and generated value-reducing performances (from the ecological and economical point of view) can be performed [2]. Similarly the complete production process or just small sub process chains, by building sub survey spaces, can be analyzed precisely. The logical consequence is to identify so called *HotSpots*, which indicate necessary optimization measures and directly prioritize them in order of expected performance or effort.

Discrete production and process production

An essential level of classification, which is important for most evaluation approaches focusing on resource flows, is the manner of production. Often quoted stereotypes, like classical mechanical engineering as a representative of discrete production or food-processing industry as a representative of process engineering, describe the focused scope of activity very well. Within discrete production there are mainly countable and solid bodies (e.g. system components), produced by using multi-variant primary forming or transforming measures with the help of different manipulation methods [5, 6]. Storage and transport usually is not problematic and dissipation mainly occurs in terms of failures and insufficient resource efficiency [7].

Within process engineering mainly shapeless products are transformed by chemical, biological and physical measures into saleable final products (e.g. production of beverages) [8, 9]. There is no singular intervention of an instrument, but there are indirect interventions in terms of adjustment of certain parameters, like specific levels of pressure or temperature. Storage of the intermediates is aggravated and additional ways of transport often imply increased imponderables in terms of product quality, combined with pollution of the route of transport. Even within the process engineering industry dissipation mainly occurs in terms of failures and insufficient resource efficiency [7].

Beverages filling as an example of the semi-batch-production

Modern interlinked production facilities do not have the discussed strict division into discrete and process production any more. They consist of a variety of modules either corresponding to discrete production or to process production but quite often they combine those modules in a semi-batch, also referred to as semi-continuous, status.

Considering a semi-continuous beverage bottling facility, the basis unit of quantity can change between different processing steps. In this way the observed object can change from a countable good (e.g. 150 empty bottles) within a discrete production process, like transport or inspection into a floating good (e.g. one hectoliter liquid with a temperature of 26 degrees Celsius) in the process production. Afterwards there are further more expected changes of the focused objects [2]. This kinds of hybrid production facilities require an integrated observation of the realized transformation processes and the interventions during the production process. The complexity of the observation process and analysis increases; the resulting optimization potentials, regarding increased resource efficiency, are remarkable.

Possibilities of evaluation

Increased resource efficiency is not just another control parameter of the classical target system of production, but describes an integrated alignment of the company, which is not limited towards a single resource such as energy [5]. This more global orientation helps to ensure a continuously increasing performance by reducing the use of resources, accompanied by the reduction of environmental effects. To assess these effects of a transparent production chain in a pecuniary way is a major requirement of European industry [3].

At least since the 1990's the evaluation of the stake of resources in the production process is discussed. The aim of most of the methods is an evaluation of the ecological effects of the total production to create a basis to quantify the methods of improvement [10]. Current methods, which consider the consequences of used resources and resulting environmental impacts, allow a better understanding of potential effects of corporate transaction. Other evaluation methods focus on life cycle inventory analysis of implied resources. Sourcing and usage of energy and material as well as originated residues are taken into account and analyzed regarding to their quality and quantity [11]. Additional aggravation derives from the fact that most of these methods are not referred to tangible processes but rather to complex product life cycles or companies as a whole. This goes hand in hand with a scope of observation, which often does not lead to an industrial-suited solution approach. Furthermore for production purposes implied resources and emerging value-reducing performance often were evaluated separately and not integrated adequately.

Based on these deliberations an evaluation approach, which includes all processes, oriented towards the aim of production and the internal of a company within a gate-to-gate concept, was developed. According to this, every process from the physical arrival of raw materials (gate 1) up to the final transportation of the created products to e.g. a storage (gate 2) were focused. Besides the clear focus on production processes another requirement is the observation of all used resources and the resulting value-reducing performances at their place of development respectively of origin. Energy flows as well as all other types of resource flows are integrated. The steps of observation are structured and logically consistent for the operator and visually attractive to enable further loops of usage and to facilitate the comprehension of the prevailing principles of operation.

EcoX-assessment and value-reducing performances

A basic requirement for the usage of the Eco**X**-approach is the deployment of a consistent process structure. The process structure identifies process steps, which are necessary to reach the aim of production. These steps can be arranged initially in a simple Input-Output relationship, which reflects real material flows related to a specific process. Already within these simple steps an increased transparency within the observed company for their own process steps and the process limits can be recognized.

The following steps, illustrated in Fig. 1, make use of a consideration based on Horváth and allocate the actual necessary resources and resulting value-reducing performances to the process steps by the use of connecting elements [10]. These value-reducing performances are originated in failures or necessary post-treatment but more often in insufficient resource efficiency [12]. Resource efficiency is understood as a proportion of transformation based on resources to value-adding performances [2]. Once the process structure is extended with these factors the company achieves a more comprehensive process transparency and has the ability to recognize on a source-based level as well as to reach for first evaluations.

A comprehensive increase of efficiency in all observed parameters occurs very rarely. The assumption that the quantity of one or at least a few elements can be reduced, while other direct depending factors increase, is more adequate. Therefore it is handy to use IT-tools, which are connected to a corresponding database and visualize the state before the implementation of measures (S_0) and compare this with the newly reached status (S_1). This kind of an adapted Sankey-analysis provides these benefits as well as an attractive visualization for the process and resource level. Quantity-proportional arrows represent the intensity of the SI-conformal resource flows within the focused process scenery [13].

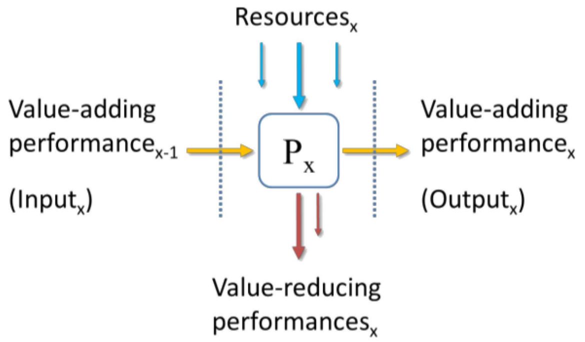

Fig. 1. Exemplary comprehension of processes.

In the following step this Sankey-observation is extended by pecuniary aspects, based on a company-individual structure of resource costs, for example cost per liter lubricating oil or cost per second allocation of the machines. The well-known process scenery is purposely maintained, merely the entity of flows changes to a pecuniary entity to get a clear idea about the real occurring efforts of every process step and the diverse connectors. Even ecological efforts were directly considered and emitted as a consolidated result by this approach.

Procedure modell for the EcoX-approach

The procedure model, outlined in Table 1, is divided in four logical units, successively to be performed, which again are split in different steps. These units describe the deployment of the necessary process structure including the discussed logical connectors, the distinct evaluation of the occurring flows and the identification of *HotSpots*, including the generation of suitable measures, as well as possible steps of iteration.

Central elements of this evaluation are indices and tracer. For example the *Resource Index* (RI) describes the comparability of material and energy flows as well as the process conditional waste. It also includes pecuniary considerations. RI illustrates the amount and costs of a selected resource in relation to the entirely affected resources within the observed process chain. For the purposes of an example, the following assumption can be taken: if a value-reducing performance (caused by a production failure which cannot be reworked) occurs in a process step five of twelve, this means that the real (resource-) efforts, which were necessary to reach this production step, can be displayed as an accumulated effort and directly be evaluated. This value differs by far from the pure price of the raw material necessary for this intermediate good.

Table 1
Procedure modell of the Eco**X**-approach.

Step	Name	Description
1	Assimilation of the necessary production structure	Differentiation of the relevant processes in a gate-to-gate scope
1.1	I/O analysis	Quantification of the Input-Output-relationships regarding a comparable state of operation
1.2	Resource balance	Expansion of the model regarding process-individual used resources
1.3	Performance balance	Expansion of the model regarding process-individual value-reducing performances
1.4	Alternative trails	Describe alternative "routes" of the production process (e.g. in case of machine breakdown, or internal recycling)
2	Assignment of costs	Deployment of the structure of resource-costs
3	Assessment of value-reducing performances	Comprehensive allocation of the originated costs at the specific point of development
3.1	Calculation of the *Resource Index*	Amount and costs of a resource in relationship to the entire used resources
3.2	Calculation of the *Resource* and the *Value-Reducing Tracer*	
3.3	Determination of the *Total Tracer*	Determination of the proportion of value added
4	Identification of *HotSpots*	Determination of the spots with high potential to increase efficiency
5	Deployment of suitable measures and prioritization	Prioritization after chosen criteria (reduction of financial effort, resources, pollution, ...)
6	Further steps of iteration	Determination of the effectiveness of the chosen measures

Tracers were expressed as percentages to ensure the visualization is obvious, clear and comparable in a cross-company and cross-process way. The whole calculation of indices and tracers as well as their visualization are to be realized by free available software, which makes the usage and handling of this method especially suitable for small and medium sized enterprises.

The *Value-Reducing Tracer* illustrates for example the dispersion of the entire value-reducing performances within the focused processes. In this way it is directly visible, which individual amount every process step owns on the entire value-reducing performance. As a result of this calculation scheme there is the *Total Tracer* (TT), which can be treated like an effectiveness. TT shows how effective, in other words intensive in costs and pollutive the process or the chosen process steps are.

HotSpots can be identified outgoing from these facts. These are process steps which exhibit an inherent potential for further improvements. A prioritization of the measures can directly be done with the help of the tracer according to the elected focus on the basis of insufficient resource productivity, increased value-reducing performances, maximum capital employment or ecological effects such as CO_2-equivalent.

The payback period of the current measures can be calculated directly for each process. After the implementation of the chosen measures arbitrary iteration loops can be executed, which should start again with a data-recording of the actual state (S_x).

Further Insights

Due to the fact that the Eco**X**-Approach is elaborated since 2012 many internal steps of sampling and variation took place. These preliminary models were implemented in the Learning-Factory of the Chair of Production Systems at the Ruhr-University of Bochum first, to be tested in an enclosed environment. After several processes of improvement these approaches were carried out with small and medium sized enterprises, as partners of the initiative. In the following there will be described a, slightly anonymized, case study examining one of these partners. Shown percentages are based on a real-life example and describe a production line of a classic producer of vendor parts regarding specific programmable controllers. The observed process chain consists of nine sub-processes, performing different steps of transformation, connected via conveyor technique.

As result the TT of 56.47%, which is shown in Fig. 2, describes a not enhanced potential at the height of 43.53% in the focused process steps – in other words a resource unproductiveness at the same height. Two identified *HotSpots*, which were deployed in the first step of iteration were very striking. They stood at the beginning and the end of the process chain (P1 and P9) and were responsible for more than the half of the total unproductiveness of the whole process chain. On the one hand P9 possessed the highest share on the total value-reducing performances. This leads to the assumption that even a small percentage of reduction may have a great impact. On the other hand the value-reducing performance in P1 exceeded the occurring Resource Tracer, so the TT was negative.

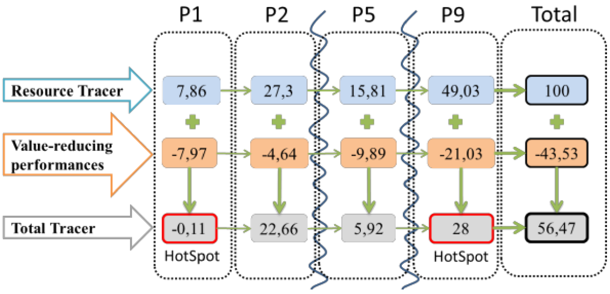

Fig. 2. Calculation of the total tracer.

Prioritized and implemented measures were the replacing of a defect wattless current compensation in P1 and a recalibration of the too sensitive adjustment inspection tool in P9. Both causes remained unnoticed for several months and generated high economic and ecologic efforts. The ROI for suppressing this effects was clearly high and a continuous improvement process was initiated.

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References

[1] Statistisches Bundesamt: Statistisches Jahrbuch 2012 – Deutschland und Internationales, Wiesbaden, 2012.

[2] Meier et al., *Practical Approach to Analyze and Optimize Energy Efficiency within a Press Hardening Process in Advances*, Sustainable and Competitive Manufacturing Systems, S. 1613–1626, Heidelberg, 2013.

[3] European Commission: Flash Eurobarometer: Attitudes of European entrepreneurs towards eco-innovation, Brüssel, 2011.

[4] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit: GreenTech made in Germany 3.0 – Umwelttechnologie-Atlas für Deutschland, Berlin, 2012.

[5] Meier H., *Wandlungsfähigkeit durch die Gestaltung modularer Produktionssysteme – Betrachtung von Technik, Organisation und Personal*, Intelligent vernetzte Arbeits- und Fabriksysteme, S. 323–332, Chemnitz, 2012.

[6] Westkämper, Einführung in die Fertigungstechnik, 6 Auflage, Wiesbaden, 2004.

[7] Böge A., *Handbuch Maschinenbau Grundlagen und Anwendungen der Maschinenbau*, 27 Auflage, Berlin, 2012.

[8] Mersch et al., *Gemeinsamkeiten und Unterschiede der Prozess- und Fertigungstechnik, Interdisziplinäre Aspekte der Produktionsmodellierung*, at-Automatisierungstechnik, H. 1, S. 7–17, München, 2011.

[9] Bohnet, Mechanische Verfahrenstechnik, Weinheim, 2004.

[10] Horváth et al., *Green Controlling – Bedarf einer Integration von ökologischen Aspekten*, Tschandl: Integriertes Umweltcontrolling, Wiesbaden, 2012.

[11] Eco-Innovation Observatory: The Eco-Innovation Challenge: Pathways to a resource-efficient Europe, Brüssel, 2011.

[12] Krings, Bewertung und kontinuierliche Verbesserung der Ressourceneffizienz von automatisierten Fertigungssystemen, Aachen, 2012.

[13] Organisation Intergouvernementale de la Convention du Mètre: The International System of Units (SI), Paris, 2006.