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Supporting manufacturing technology definition through multi-level resource consumption analysis

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Abstract

The lowering of the consumption of resources in the production is an essential contribution to sustainable manufacturing. Critical resources regarding the availability and regeneration such as valuable and rare materials as well as energy are to be spared if possible by a corresponding determination of the manufacturing technologies. From the possible alternative manufacturing variants, it is necessary to select those with the lowest consumption of resources. The decision-making requires an estimation of the consumption of resources which includes the direct consumptions of the machines just as the consumptions initiated by applying the processes. In this paper a concept is presented that allows for estimation of the consumption of material and energy in manufacturing processes. The estimation includes systematically initiated consumptions that will be analyzed the same way as the manufactured products. This way, it is achieved that effects of the technology application on the consumptions of resources become transparent over several stages.

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Keywords: Planning method; manufacturing; consumption; energy; materials; assessment

1. Introduction

In the manufacturing of series production parts the decisions made in the context of the production planning with regard to the selection of manufacturing processes and machines lead to an early commitment regarding the consumption of resources in the production. This commitment applies mostly for the entire production cycle, lasting often several years and during which thousands or even millions of parts are produced. Therefore, the expectable resource consumption has to be included in the analyses already at the beginning of the production planning. Especially valuable and rare materials as well as the consumed energy have to be spared as critical resources with regard to their availability and regenerativity.

Starting from a product whose design is already determined to a great extent, the decisions in production planning are limited to the used manufacturing processes and machines. Among the possible alternative production variants the one has to be selected that consumes as less resources being considered critical as possible. Therefore, the decision-making requires an estimation of the resource consumption. The data used for it has to be already available in the early stage of the production planning and contain sufficiently specific information to achieve selectivity in the estimation of manufacturing variants. Therefore, the data and approach have to be neither too general nor has the data collection to be very elaborate.

Besides the direct consumptions of energy and materials in the machines in the analyzed production section, further consumptions are initiated by the respective manufacturing processes. Thus, for example tools and process media are required which have to be replaced or reworked depending on the produced amount of parts. Such initiated consumptions should also be analyzed in an extensive estimation. Only in this way the right processes with regard to a sustainable manufacturing can be selected and measures for the optimization can be defined. In doing so, it has to be taken into consideration that all process steps and alternatives are analyzed with comparable system boundaries.

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In the following, a concept is presented and discussed according to which the consumptions of materials and energy in manufacturing processes can be estimated relating to the produced part. The consumptions of the single processes can be combined to process chains and allow for a comparative estimation of manufacturing alternatives in the production planning. In the estimation initiated consumptions are systematically included and for their part analyzed analogous to the manufactured products. In this way the comparison of process alternatives has influence on the far-reaching implications of the technology employment.

2. Conditions and Constraints

Each kind of decision in the product creation process requires an information basis as good as possible. The technical product life cycle covers the phases of material exploitation, production, product use and end-of-life. Environment-related questions are especially complex, as a multitude of information in width and depth from the complete technical product life cycle is necessary for accurate decision-making.

Holistic Life Cycle analysis (LCA) approaches as, e.g., standardized in ISO 14040ff [1] call for a consideration of multiple (i. e. all) environmental impacts along the complete life cycle as well as following a holistic system view with potentially extensive system boundaries. Both of these requirements lead to highly complex, time- and data-consuming methods often applicable only reactively once the product and production system are already completely defined.

In order to enhance the applicability of LCA approaches also and especially for proactive use in earlier engineering phases, simplifications in LCA methodology are discussed. Todd et al. [2], e.g., distinguish, among others, the following simplification methods:

- Reduce the LCA width through removing upstream and/or downstream components, e.g. by focusing on the production and/or product use phase only

- Reduce the LCA depth by using specific entries to represent impacts, e.g. by postulating the material use being representative for all environmental aspects

- Reduce the LCA depth by using qualitative or less accurate data, e.g. by estimating the impacts of nuclear power usage

- Reduce the LCA depth by using surrogate process data, e.g. by using database or reference product data instead of real data.

The application of such simplification methods may be advantageous and disadvantageous in different respects. On the pro side, analyses can be accelerated, pulled forward to earlier processes steps, or even facilitated at all. On the con side, accuracy and validity of results may suffer from negligible variations to completely wrong results. Thus, the feasibility of these methods depends on the actual use case.

The focus of the approach presented in this paper is limited both in width and depth:

- Material and energy analysis only

This reduction of the LCA depth by using specific entries to represent the overall impacts is feasible in cases these two specific environmental impact categories are assumed to be dominating the overall environmental footprint, which is often the case regarding machine and automotive industry products.

- Consideration of effects in the manufacturing phase only

This reduction of the LCA width by removing both upstream and downstream phases of the product life cycle is reasonable in cases where either other phases are negligible, in comparison, or boundary conditions define those other phases as being not changeable, e. g. if product design (which could also influence the material, use and end-of-life phases) as such cannot be influenced, production is however still offering design freedom. This is often the case in industrial environments, when production systems are to be designed for existing or from a design point finalized products.

Through these simplifications, however, the approach offers a lean but powerful method for an in-depth analysis of the selected environmental impacts. It provides concrete and comprehensible starting points for environmental optimizations, taking both direct material and energy consumptions and indirect environmental impacts into account. Due to the simplifications, the interpretation of the results will have to consider and evaluate potential limitations in the informative value.

Environmental impacts along the product lifecycle are to the major extent (pre)determined in product and production engineering phases. According to the product and production engineering framework presented by the authors in [3], both phases can be further subdivided along the maturation process from the concept over the layout to the detailed level, see Table 1.

Table 1. Maturation phases in product and production engineering according to [3].

	Concept level	Layout level	Detailed level
Product Definition	Functional design	Principle design	Detailed design
Production Definition	Technology definition	Process design	Process specification

All these phases offer opportunities for environmental optimizations. Investigations in [4] identified different target areas. According to the scope definition in section 1, this paper will focus on the technology definition phase within production engineering, with the product definition being already fixed and degrees of freedom lying along the maturation phases of production development.