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Simulation based assessment of lean and green strategies in manufacturing systems

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Abstract

The increase of resource (energy and material) efficiency by eliminating unnecessary consumption represents the logical continuation from lean manufacturing to lean and green manufacturing. However, economic efficiency remains the primary decision criterion for the implementation of corresponding strategies. This paper presents a simulation based approach for monetary assessment of lean and green manufacturing systems considering non-monetary green limits. Inclusion of material and energy consumption as well as resulting greenhouse gas emissions enables planners to predict the overall economic performance of a factory. Furthermore, product variant specific footprints of material and energy demands as well as resulting emissions support in-depth analysis of value streams in manufacturing.

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Keywords: lean and green; monetary assessment; simulation; ressource efficiency;

1. Introduction

Lean Management and its primary objective of increase in productivity by elimination of waste had major influence on manufacturing during the last decades. Focus of improvement was laid on monetary and temporal indicators.

However, rising energy and raw material prices [1] and increasing environmental awareness of customers [2] urge an increasing number of companies to reduce energy and material consumption. In order to remain competitive it becomes necessary to shift from pure economic benefit to *maximum monetary benefit with regard to limited energy and material consumption* [3].

Both politics and a great part of companies affirm this line of reasoning, and introduced limit values regarding resource consumption. E.g., the European Union limited carbon dioxide (CO_2) emissions of cars per kilometer [4]. With regards to production, BMW Group tries to reduce specific resource consumption by 45% compared to 2006, until 2020 [5]. Daimler AG intends to reduce CO_2 as well as nitric oxide emissions of a car's lifecycle by ca. 10 – 20% compared to its previous model, until 2020 [6]. On a long term basis, companies might be confronted with legally fixed limit values in manufacturing. Especially product specific limits appear appropriate to take branch-specific characteristics into account and to ensure comparability.

Therefore, an exclusively monetary evaluation of manufacturing systems is not sufficient, although remaining the primary decision criterion. Non-monetary values need to be included to control given limit values. Furthermore, product specific limits require product specific evaluation. Simple allocation of overall costs and consumptions to products in proportion to the manufactured quantity covers underlying coherences and sources of waste. Consequently, product-related costs and resource consumptions require consideration at their origin within the product's value stream. This allows deduction of appropriate improvement strategies.

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2. Theoretical Background

2.1. Green as continuation of lean manufacturing

Literature often describes strategies aiming at resource efficiency (green) in manufacturing as logical continuation or addition to lean philosophy due to an obvious correspondence between objectives [7], [8], [9], [10]. On the other hand, there are limits concerning analogies between both systems. Although reduction of waste is the major objective of lean philosophy, improvements concentrate on processes with substantial financial significance rather than ecological aspects. Therefore, increase in productivity is sometimes achieved at the expense of greater energy consumption [11], [12], [13], e.g. more frequent changeovers in one-piece-flow manufacturing [10].

It becomes obvious that an isolated implementation of lean or green strategies is not sufficient to make full use of existing improvement potentials.

2.2. Waste in the context of lean and green

Table 1 assigns potential sources of energy and material waste to the 7 traditional forms of “lean” waste. Actual sources of waste are taken into account rather than direct impacts of “lean waste” on resource consumption. The identified wastes of resources are categorized into five resource waste principles along the value stream stages of a product.

2.3. Efficiency and productivity

Besides economic performance of a manufacturing system, ecological aspects become increasingly relevant, as laid out in chapter 1. Efficiency can be applied to both views. It is generally defined as ratio of achieved benefit and necessary effort [14].

$$Efficency = \frac{benefit}{effort} \quad (1)$$

The overall efficiency of a manufacturing system can be described as ratio of achieved output and the sum of applied productive factors. Benefit and effort can be stated in monetary units for monetary assessment. The term productivity is often used synonymous with efficiency and describes the quantitative utilization of applied factors [15].

Efficiency assessment can be adapted to resource consumption. Referring to Reinhardt [16], energy efficiency is defined as ratio of energy used for value adding activities and overall energy input.

$$Efficiency_{en} = \frac{energy_{value\ adding}}{energy_{in}} \quad (2)$$

Material efficiency is accordingly defined as ratio of materials contained in final products and overall efforts spent on material. This covers efforts for overall material input as well as material output not included in the final product, e.g. disposal costs.

$$Efficiency_{mat} = \frac{material_{final\ product}}{material_{in} + material_{out}} \quad (3)$$

With regard to profit orientation of companies and to ensure comparability of different materials and energy sources all benefits and efforts are stated in monetary units.

2.4. Simulation of manufacturing systems

Due to complex interdependencies between lean and green manufacturing as well as general dynamics and variations in manufacturing systems, simulation has been acknowledged to be a powerful assessment approach. However, integration of resource consumption in manufacturing simulation is not commonly established, yet. [17]

On the other hand, there are various research approaches covering the integration of energy consumption to manufacturing simulation and subsequent assessment, e.g. [20], [21], [22]. Based on a study conducted by Thiede in

Table 1: Sources of energy [19],[20] and material waste

lean waste	resource waste principle	value stream stage	sources of energy waste	sources of material waste
-	a) inappropriate energy and material procurement	procurement	inappropriate energy source, contract design	inappropriate material, contract design
overprocessing	b) inefficient manufacturing equipment and process related waste	processing, transformation	transformation, level of machine efficiency	insufficient process stability, insufficient material utilization
transport	c) transport and storage of energy and material	distribution	long transport distance	transport damage, outside influences
overproduction	b) inefficient manufacturing equipment and process related waste	processing, transformation	overdimensioning	-
inventory	c) transport and storage of energy and material	distribution, processing	insufficient synchronization of energy demand and supply	limited dates of expiry, outside influences
unnecessary motion	d) inefficient production scheduling and mode of operation	processing	inefficient mode of operation, nonexistent controlling concepts	machine disturbances, startup & calibration losses
defects	e) missing recuperation and recycling	disposal, reclamation, recycling	missing recuperation (dissipation)	missing internal recycling / reprocessing / reuse
waiting	d) inefficient production scheduling and mode of operation	processing	idle mode	-