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Simulation-based methodology for the application of lean and green strategies depending on external change driver influence

Sebastian Greinacher[a,]*, Emanuel Moser[a], Jochen Freier[a], Jasmin Müller[a], Gisela Lanza[a]

[a] *wbk Institute of Production Science, Karlsruhe Institute of Technology, Kaiserstr. 12, 76131 Karlsruhe, Germany*

* Corresponding author. Tel.: +49-721-608-44018; fax: +49-721-608-45005. *E-mail address:* sebastian.greinacher@kit.edu

Abstract

Globalization, growing environmental awareness as well as rising and volatile resource prices contribute to an increasingly uncertain business environment in manufacturing. It is impossible to consider all future developments of external influences when planning and setting up a new manufacturing system. Therefore, companies must react with constant change and readjustment. This paper presents an approach based on simulation and design of experiments for the identification of suitable improvement strategies that counteract negative effects of external change drivers in discrete manufacturing systems. It covers selection of an effective strategy under consideration of its impacts. Thereupon, the ideal intervention threshold for the implementation of the selected strategy is derived. The methodology is applied to an ideal typical production line.

Keywords: Manufacturing System; Lean; Green; Adaptability; Simulation;

1. Introduction

Successful operation and adaption of manufacturing systems are highly challenging tasks. They depend on an increasing number of uncertain influence factors, so called change drivers. Globalization and increasing environmental (green) awareness result in a hardly predictable business environment [1-3]. Continuing increase in demand of resources and energy, mainly driven by emerging industries, and limited supplies contribute to increasing and volatile prices [3]. 86 % of German small and medium sized manufacturing enterprises (SME) state rising purchasing cost of raw material as a major problem. 68 % list the associated cost volatility as critical [4]. Furthermore, legal requirements and self-imposed company goals for environmental limits underlie constant intensifications [5,6].

The complexity of change driver developments and interactions with internal processes prevent prediction of ideal future configurations when setting up a manufacturing system. Instead, continuous adjustment and reconfiguration are required to adapt to the changing environment and to fulfill aspired objectives [7–9]. Although constant reconfiguration is necessary to remain competitive, it presents a growing challenge for planners and management [10]. Many companies fail to achieve their lean and green improvement targets. 35 % of SME have realized a reduction of manufacturing cost by implementation of green strategies. In contrast, 27 % have faced increased cost after strategy implementation [11]. Furthermore, the speed of productivity improvement decreases over time [12]. Many companies fail to implement a culture of continuous improvement, which adapts to dynamic changes of external influences.

2. Methodology

The presented six step simulation based methodology identifies lean and green improvement strategies in manufacturing systems. These strategies are suitable to counteract effects of external change drivers. Subsequently,

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the optimal threshold for strategy implementation is determined.

Step 1 covers the setup of a factory simulation model as experimental environment. Step 2 introduces a lean and green valuation method. Modeling of external change drivers and selected lean and green strategies are discussed in steps 3 and 4. Subsequently, consistent pairs of change drivers and counteractive strategies are identified by simulation based design of experiments (DoE) in step 5. In the final step 6, an optimized threshold for strategy implementation is identified depending on external change driver development.

2.1. Simulation model

A discrete event simulation (DES) model has been set up in Plant Simulation v12. It serves as experimental environment to analyze the dynamic effects and interactions within a manufacturing system, which are too complex to be modeled in detail analytically [13]. The simulation based approach allows modifications of the current system and the application of dynamic future scenarios under uncertainty. The model is structured into multiple reusable modules. The modules include the process, inventory, peripheral, and production planning and control module (PPC). Energy consumption is integrated by time- and state-based consumption rates [13,14]. Material consumption and waste are modelled by discrete product- and module-specific rates.

Manufacturing equipment and machine operations are represented by the process module, for which different operational states are defined. Consumption rates are assigned to each operational state, e.g. personnel demand or electrical power. The inventory module covers warehouses and buffers with their respective capacity. Consumption rates are defined in conformity with the process module. The peripheral module includes conversion of energy sources and simplified energy consumption of technical building services. All modules are connected by the production planning and control (PPC) module. It generates manufacturing orders and integrates all modules into the value stream by provision of material, energy and information flow rules.

2.2. Valuation Method

Lean and green performance of the analyzed manufacturing system are assessed by the following valuation method. All key performance indicators (KPI) are calculated per average final product type. Green assessment covers specific energy consumption, energy efficiency and material efficiency. Lean assessment includes quality rate, throughput time, on-time delivery, and manufacturing cost.

Specific energy consumption $E_{i,es}$ is calculated per product type $i \in I$ and energy source $es \in ES$. It is equivalent to the product's energy consumption along all stations *s* of the value stream. *S* represents the last station of the product's value stream.

Since all KPIs relate to a final product, the **quality rate** *Q* of all remaining stations of the product's value stream must be taken into account.

$$E_{i,es} = \sum_{s=1}^{S} \left(\frac{E_{i,s,es}}{\prod_{c=s}^{S} Q_c} \right) \quad (1)$$

Energy efficiency $E_{eff;i}$ is defined as ratio of monetarized energy consumption during value-added processes versus monetarized overall energy consumption of a product, following [15]. Pr_{es} represents the price per energy unit. Value added energy includes all energy consumed by a process module or requested from peripheral modules during processing. Overall energy consumption covers the share of the manufacturing system's overall consumption allocated to the relevant product by suitable conversion keys.

$$E_{eff,i} = \frac{\sum_{es=1}^{ES} \sum_{s=1}^{S} \left(E_{valueadded,i,s,es} \cdot \Pr_{es} \right)}{\sum_{es=1}^{ES} \left(E_{i,es} \cdot \Pr_{es} \right)} \quad (2)$$

Material efficiency $Mat_{eff;i}$ is defined as ratio of monetary value of all materials $m \in M$ within a finished product versus cost for material inputs and outputs along its value stream, referring to [15]. $Mat_{finished,m,i}$ represents the quantity of material in a finished product. $Mat_{in,m,i,s}$ and $Mat_{out,m,i,s}$ describe in- and outgoing quantities of material. $Pr_{in,m}$ is the price per unit for incoming material, e.g. raw material. $Pr_{out,m}$ is the price per unit for outgoing material, e.g. disposal cost.

$$Mat_{eff,i} = \frac{\sum_{m=1}^{M} \left(Mat_{finished,m,i} \cdot \Pr_{in,m} \right)}{\sum_{s=1}^{S} \sum_{m=1}^{M} \left(Mat_{in,m,i,s} \cdot \Pr_{in,m} + Mat_{out,m,i,s} \cdot \Pr_{out,m} \right)} \quad (3)$$

From an economic point of view, monetary based efficiency calculation allows appropriate comparison of different resources with varying prices. It should be noted that it results in fluctuating values over time due to volatile resource prices. This effect can be avoided without monetarization. However, this generates useful results for materials of similar value only.

The **throughput time** TPT_i describes the time period from start of production until completion of a product. $t_{out,i,s}$ represents the point in time when a product exits a station, $t_{in,i,s}$ represents the point in time when a product enters a station. The quality rates of all stations must be taken into account to allocate operating time for scrap products.

$$TPT_i = \sum_{s=1}^{S} \left(\frac{t_{out,i,s} - t_{in,i,s}}{\prod_{c=s}^{S} Q_c} \right) \quad (4)$$