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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;

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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].

$$Efficency = \frac{benefit}{effort} \tag{1}$$

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.

$$Efficiency_{en} = \frac{energy_{value\ adding}}{energy_{in}} \tag{2}$$

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.

$$Efficiency_{mat} = \frac{material_{final\ product}}{material_{in} + material_{out}} \tag{3}$$

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	-

2012 [23] Sproedt et. al [17] identified among others

- rare “product specific allocation of resources”,
- consideration of “material and direct emissions”, and
- focus on either “environmental or cost evaluation”

as shortcomings of the current state of the art in environmental assessment of manufacturing systems via simulation. This approach is addressing the before mentioned deficits based on preliminary work of the authors [22].

3. Methodology

This paper presents an approach for product specific lean and green assessment of manufacturing systems in discrete production environments.

3.1. Scope and objective

Key premise for companies should be the pursuit of profit. However, as pointed out in chapter 1, it becomes increasingly important to operate at an economically optimized state in accordance with defined green limits. It is not sufficient to focus lean and green assessment on overall consumptions or isolated machines. To gain full insights into dynamic manufacturing processes, it is necessary to follow a product’s value stream through manufacturing and assign costs and resource consumptions at their point and time of origin.

In order to fulfill this demand, this approach is focusing on the following components:

1. Systematic selection and limitation of object of investigation.
2. Integration of energy and material consumption in manufacturing simulation.
3. Product specific lean and green assessment of manufacturing systems.

3.2. Object of investigation

This approach is focusing on the shop floor of a manufacturing company from factory gate to gate. The manufacturing process is described as input/throughput/output-model (I/T/O). For green assessment material and energy inputs as well as resulting CO_2 emissions are taken into account, lean assessment focuses on costs and throughput time and therefore the input of manufacturing equipment and output of products and waste is taken into account. Literature provides a variety of structuring approaches for manufacturing systems, e.g. [24], [25]. A common ground is the hierarchical linkage of elements. This approach requires factory, section and machine level to gather relevant data in necessary detail on the one hand and to allow analyses with sufficient significance on the other. On machine level, the peripheral order of elements (e.g. machines or workstations) reflects their functional proximity or distance to the main value adding processes [26].

3.3. Analysis

Following the hierarchical order of manufacturing systems from factory to machine level, relevant categories (e.g. costs, energy sources) for subsequent assessment need to be defined. The condensed data on factory level presents a good starting point to narrow down assessment categories. This can be done on the basis of main consumers, deviation of key performance indicators compared to previous time periods or bottlenecks.

Subsequently, capacities can be planned and systematically allocated for in-detail analyses. Elements of the manufacturing system not affected by the selected assessment categories can be excluded from further consideration. In this way, unnecessary data collection and implementation effort can be avoided. To make sure to not exclude relevant information at this early stage and thereby alter assessment results, it is necessary to guide the user with a structured framework through analysis.

To support structured data acquisition and subsequent modeling of coherences, trees of characteristic values are developed, structured according to the I/T/O-model. “Input” contains individual characteristic value trees for energy and material demand; “Output” contains waste of materials and CO_2 emissions, while “Throughput” acts as connecting module with trees of characteristic values for time and states of manufacturing equipment as well as peripheral systems. Hierarchical dependencies within a tree of characteristics along the levels of a manufacturing system are represented by vertical calculation rules of characteristic values. E.g. process times are linked from aggregated times on factory level (e.g. overall manufacturing time, mean throughput time) down to processing time components of individual manufacturing equipment according to REFA (compare [27]).

Clearly defined horizontal dependencies between characteristic values of different trees are described by mathematical calculation rules using conversion keys. E.g. the characteristic values electricity consumption $cons_{m,\,elec}$ of a machine m and its operating time $t_{m,\,state}$ in a certain operating state *state* are connected via its corresponding electrical power $P_{m,\,s}$:

$$cons_{m,elec} = \sum_{state} t_{m,state} \times P_{m,state} \qquad (4)$$

3.4. Simulation model

Due to complex dynamic and stochastic interdependencies within a manufacturing system, we draw back on discrete event simulation (Plant Simulation v11) to generate input for the subsequent lean and green assessment. So far, Plant Simulation is the only commercial manufacturing simulation tool, which integrates electrical energy consumption of production equipment [17]. Yet, consumption of other energy sources, integration of peripheral equipment as well as waste and recyclable material is not a common feature.

The simulation model consists of combinations of the following 4 generic modules: The *production planning and control (PPC) module* generates the production program and releases orders for manufacturing. The *process module* describes manufacturing equipment of the main processes (e.g. manufacturing, assembly), which operate in different operational states. Peripheral systems are represented by the *supply module*. Its task is the transformation of energy (e.g., electricity to compressed air) to other modules. The *Indirect module* is used for simplified integration of building services.

The established principle of state based energy consumption (compare e.g. [20], [21]) is extended to other energy sources besides electricity (compressed air, gas, oil). The simulation modules can enter different operational states (*processing*: off, standby, idle, setup, processing, failure, blocked, *indirect*: off, standby, indirect operation, *supply*: off, standby, idle, transformation of energy, failure). For each operational state, product type specific input and output rates are defined per energy source. Input of the processing and indirect modules contains energy used directly for operation. Output covers resulting indirect (electricity) or direct (gas, oil) CO_2 emissions of consumed unit per energy source according to [28].

Each supply module is linked to one or more processing and/or indirect modules and provides energy sources to them, which require previous transformation (e.g. transformation of electricity to compressed air). Therefore, the summed up energy input rates of the connected process and indirect modules correspond to the output rate of transformed energy per supply module. Input of the supply module is the energy source to be transformed in a fixed rate. Emissions are calculated according to process and indirect modules. Each supply module has a maximum output capacity. If connected process modules request more energy output than what can be provided by the supply module, processing is cancelled, the module is set to idle mode.

Other than time dependent energy consumption of manufacturing equipment, material is consumed in discrete units. As visualized in figure 2, material input is separated into *raw material* and *recycling material*. Material output is separated into *finished products*, *waste material*, and *recycling material*. Discrete product type specific input and output values are defined per process module. Finished products and waste leave the assessed manufacturing system. Outgoing recycling material of one process on the other hand, is input material for another process. Each generated recycling unit is assigned a list with combinations of products and process modules in can be reused in. If both raw and recycling materials are available for processing in a process module, rules for selection need to be defined, e.g. prefer recycling material to raw material if available.

3.5. Product specific assessment

Product specific assessment requires product specific collection of data. Therefore, a product specific data list is filled during its way through manufacturing. Times (e.g. duration of processing), inputs (e.g. amount of raw material) and outputs (e.g. amount of waste material) of a product are recorded for each value stream element (e.g. manufacturing equipment). In case of outgoing recycling material ($output_{recycling,B}$ in figure 2), the existing data list remains with the main product (*product A* in figure 2) and a new blank data list is generated for the outgoing recycling material unit ($output_{recycling,B}$ in figure 2). As soon as a recycling material unit ($input_{recycling,B}$ in figure 2) becomes part of a new product (*product B* in figure 2), all efforts recorded in its data list are summed up and are assigned to the list of the new product as input of the current value stream element (P_3 in figure 2). This ensures assignment of all necessary efforts for manufacturing to the corresponding product. All efforts recorded in original units (e.g., consumption of electric energy in kWh) can be transferred to cost units by multiplication with a cost rate (e.g., costs per kWh of electric energy) and its corresponding consumption value.

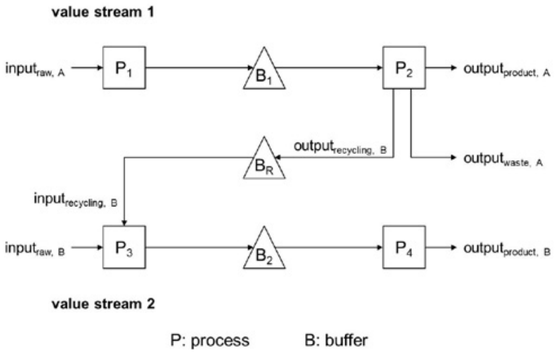

Figure 1: exemplary material in- and outputs

All efforts recorded in a product's data list are labeled *immediate efforts* because they refer to an individual product precisely. *Mediate efforts* include proportional, batch-related efforts, which result clearly from a product's batch. They can be converted to a single product by use of a conversion key (e.g., proportional conversion of a batch's changeover costs to its individual products depending on batch-size). *Indirect efforts* include efforts, which are related to manufacturing of a product but cannot be allocated unequivocally to a single product or batch. The allocation is performed by application of a conversion key as well. (E.g., a machine's energy costs during idle state are allocated according to proportional processing times of all product types processed on this machine). *Overhead efforts* include efforts, which are not related directly to manufacturing of a product. However, they are necessary for operation of the manufacturing system. Therefore a proportional allocation to manufactured products by conversion key is required. (E.g. costs for air-conditioning, administration, etc. can be allocated depending on a product type's quantitative proportion of the annual production volume).

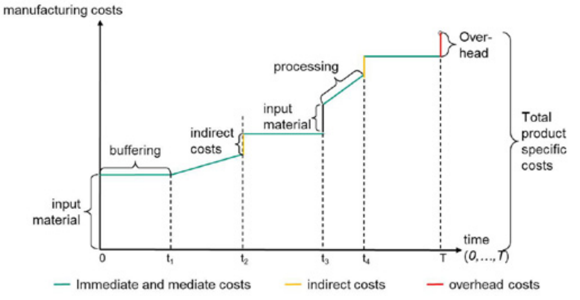

Figure 2: schematic structure of a cost-time profile

All directly value adding activity is included in immediate efforts. According to formula 2 energy efficiency Eff_{en} of a product *p* equals its immediate energy consumption $cons_{im,es,p}$ of an energy source *es* divided by the sum of its immediate energy consumption $cons_{im,es,p}$ and its specific share of mediate, indirect and overhead energy consumption ($cons_{me,es,p}$, $cons_{in,es,p}$, $cons_{ov,es,p}$). To include different energy sources in the calculation, consumption units are transformed into monetary units by multiplication with energy source specific cost rates cr_{es}.

$$Eff_{en,p} = \sum_{es}\left(\frac{cons_{im,es,p}}{cons_{im,es,p}+cons_{me,es,p}+cons_{in,es,p}+cons_{ov,es,p}} \times cr_{es}\right) \quad (5)$$

Based on formula 3, material efficiency of a product is calculated by dividing the value of material within the final product by the sum of value of ingoing materials along the product's value stream and monetary efforts for outgoing waste materials (e.g. disposal costs). Material efficiency of product A visualized in figure 2 results in:

$$Efficiency_{mat,A} = \frac{output_{product,A} \times cr_{raw,A}}{input_{raw,A} \times cr_{raw,A} + output_{waste,A} \times cr_{waste,A}} \quad (6)$$

With $cr_{raw,A}$ and $cr_{waste,A}$ being the cost rates per mass unit of raw material respectively disposal costs for waste material.

Regarding lean, cost-time-profiles (CTPs) visualize simulation results in a simple and highly intuitive way [29]. CTPs plot a product's added value during its throughput time. Immediate and mediate costs are linked to processing of a product. Indirect costs are linked to manufacturing equipment and therefore are added at the end of each processing step. Overhead costs are not linked to manufacturing and are added at the end of the product's value stream (compare figure 3). Interest rates on fixed capital are considered via the enclosed area of the plot.

Regarding green, the concept of CTPs can be adopted. Especially the comparison of CO_2-emissions and manufacturing costs in a CO_2-cost profile promises interesting results due to its comparability among different manufacturing systems.

3.6. Lean and green improvement strategies

Based on the simulation results, adequate lean and green improvement strategies can be selected and their effects subsequently assessed via simulation. CTPs give hints to adequate improvement strategies: Long buffering or processing times require time shortening strategies, e.g. single minute exchange of die or reduction of batch size. Steeply rising costs during processing can be reduced by technical strategies applied to manufacturing equipment, e.g. to reduce electricity consumption during processing. High indirect costs hint to long idle or standby times of manufacturing equipment and can be reduced by shut down strategies. High overhead costs require strategies not connected to production itself.

There is a variety of strategy collections and catalogues available for lean improvements, e.g. [30], [31]. Many companies adopted and standardized these strategies individually by implementing comprehensive production systems. In comparison, there is a shortage of standardized and structured collections of green strategies. Based on [32], [33] green strategies can be structured by their functionality into the following categories: link, separate, parallelize, substitute, restructure, reuse, install, eliminate, encapsulate, dimension, mode of operation, and sensitize.

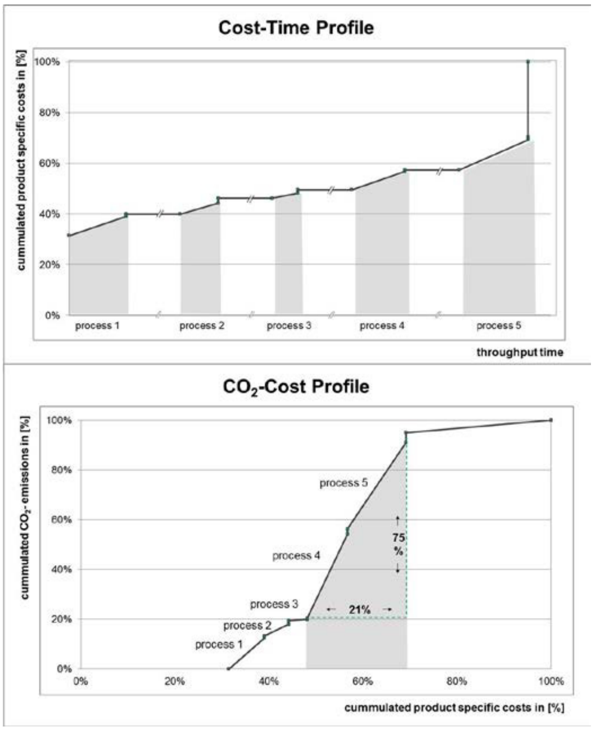

Figure 3: cost-time and CO_2-cost profile of assessed product type

4. Use Case

The product specific assessment was tested for a high running product in a medium sized metal processing company.

Immediate costs were directly assigned to the product, e.g. costs for raw material. Mediate costs, e.g. costs for energy consumption during setup, were allocated to the product via the conversion key „average lot size". For the allocation of indirect costs, conversion keys were used as well, e.g. costs for energy consumption of a machine during idle state were allocated based on the ratio of "summed up processing time of the assessed product type on the machine and the machine's overall processing time". Remaining overhead costs were distributed to the product based on "overall costs for the assessed product without overhead divided by overall production costs without overhead".

Figure 5 shows the resulting cost-time and CO_2-cost profiles. 75% of generated CO_2-emissions are caused by 2 processes, which are responsible for 21% of value adding.

5. Conclusion

This paper presents an approach for integrated lean and green assessment of production systems. Energy and material consumption were integrated into a discrete event simulation tool. The subsequent product specific assessment allows detailed analysis of times, costs, as well as energy and material efficiency per product type.

This paper is based on current research at wbk Institute of Production science. Future work aims at more detailed elaboration of the approach as well as integration of a genetic optimization algorithm to identify the ideal combination of both lean and green strategies in manufacturing systems.

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References

[1] GEM: Global Economic Monitor - Commodities. The World Bank Group,. http://data.worldbank.org/data-catalog/global-economic-monitor.

[2] BCG: Capturing the Green Advantage for Consumer Companies. 2009, http://www.bcg.com/documents/file15407.pdf.

[3] FhG: Fraunhofer-Gesellschaft: Abschlussbericht. Energieeffizienz in der Produktion. Untersuchung zum Handlungs- und Forschungsbedarf. München: FhG, 2008. http://publica.fraunhofer.de/dokumente/N-89916.html.

[4] Regulation (EC) No 443/2009 of the European parliament and of the council: setting emission performance standards for new passenger cars as part of the Community’s integrated approach to reduce CO2 emissions from light-duty vehicles. Official Journal of the European Union, L 140/1, 23.04.2009.

[5] BMW Group: Sustainable value report 2013.

[6] Daimler AG, Nachhaltigkeitsbericht 2013. http://nachhaltigkeit.daimler.com.

[7] Florida, R.: Lean and Green: The move to environmentally concious manufacturing. In: California Management Review. Vol. 39, No. 1, Fall 1996. http://hbr.org/product/lean-and-green-the-move-to-environmentally-consciousmanufacturing/an/CMR068-PDF-ENG

[8] Larson, T.; Greenwood, R.: Perfect Complements: Synergies between Lean Production and Eco- Sustainability Initiatives. In: Environmental Quality Management. Volume 13, Issue 4, Seiten 27–36, 2004. http://onlinelibrary.wiley.com/doi/10.1002/tqem.20013/pdf

[9] Bergmiller, G.; McCright, P.: Are Lean and Green Programs Synergistic? In: Proceedings of the 2009 Industrial Engineering Research Conference. http://www.zworc.com/site/publications_assets/AreLeanAndGreenProgramsSynergistic.pdf

[10] King, A.; Lenox, M.: Lean and Green? An empirical examination of the relationship between lean production and environment performance. In: Production and operations management. Vol. 10, No.3, Fall 2001. http://users.ipfw.edu/wellingj/publications/KingLenox.pdf

[11] Salonitis, K.; Ball, P.: Energy efficient manufacturing from machine tools to manufacturing systems. Forty Sixth CIRP Conference on Manufacturing Systems. Procedia CIRP 7 (2013), pp. 634-639.

[12] Herrmann, C.; Thiede, S.; Stehr, J.; Bergmann, L.: An environmental perspective on lean production. In: 41st CIRP Conference on Manufacturing Systems, pp. 83-88. 2009, Tokyo.

[13] Venkat, K.; Wakeland, W.: Is lean necessarily green?. In: Procesdings of the ISSS-2006 conference, Sonoma, CA, USA. 2006. http://journals.isss.org/index.php/proceedings50th/article/viewArticle/284

[14] Wildemann, H.: Fertigungsstrategien. Reorganisationskonzepte für eine schlanke Produktion und Zulieferung. 3. Edition. Munich: Transfer-Centrum-Verlag, 1997. ISBN: 978-3-929918-89-7.

[15] Kummer, S.; Grün, O.; Jammernegg, W.: Grundzüge der Beschaffung, Produktion und Logistik. 2. Auflage. Munich: Pearson Studium, 2009. ISBN: 978-3-8273-7351-9.

[16] Reinhardt, S.: Bewertung der Ressourceneffizienz in der Fertigung. Dissertation, Technische Universität München, 2013, ISBN 978-3-8316-4317-2.

[17] Sproedt, A.; Plehn, J.; Schönsleben, P.; Herrmann, C.: A simulation-based decision support for eco-efficiency improvements in production system, Journal of Cleaner Production, 2015, http://dx.doi.org/10.1016/j.jclepro.2014.12.082.

[18] Neugebauer, R. (Ed.): Handbuch Ressourceneffiziente Produktion. Munich: Carl Hanser Verlag, 2014, ISBN: 978-3-446-43008-2.

[19] Reinhart, G.; Karl, F.; Krebs, P.; Reinhardt, S.: Energiewertstrom: Eine Methode zur ganzheitlichen Erhöhung der Energieproduktivität. In: Zeitschrift für wirtschaftlichen Fabrikbetrieb, Jahrgang 105 (2010), S. 870-875.

[20] Thiede, Sebastian.: Energy Efficiency in Manufacturing Systems. In: Hermann, C., Kara, S. (Ed.): Sustainable Production, Life Cycle Engineering and Management. Berlin: Springer-Verlag, 2012. ISBN: 978-3-642-25913-5.

[21] Weinert, N.: Vorgehensweise für die Planung und Betrieb energieeffizienter Produktionssysteme. Berichte aus dem Produktionstechnischen Zentrum Berlin, Dissertation, Technische Universität Berlin. 2010, Fraunhofer Verlag, ISBN: 978-3-8396-0173-0.

[22] Diaz-Elsayed, N.; Jondral, A.; Greinacher, S.; Dornfeld, D.; Lanza, G.: Assessment of lean and green strategies by simulation of manufacturing systems in discrete production environment. CIRP Annals – Manufacturing Technology, 62 (2013), pp. 475-478.

[23] Thiede, S.; Seow, Y.; Andersson, J.; Johansson, B.: Environmental Aspects in manufacturing system modelling and simulation – state of the art and research perspectives. CIRP J. Manuf. Sci. Technol. 6 (1) 2012, pp. 78-87.

[24] Müller, E.; Engelmann, J.; Löffler, T.; Strauch, J.: Energieeffiziente Fabriken planen und betreiben. Berlin: Springer-Verlag, 2009. ISBN: 978-3-540-89643-2.

[25] Wiendahl, H.; Reichardt, J.; Nyhuis, P.: Handbuch Fabrikplanung. Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten. München: Carl Hanser Verlag, 2009. ISBN: 978-3-446-22477-3.

[26] Wirth, S. (Hrsg.): Flexible Fertigungssysteme. Gestaltung und Anwendung in der Teilefertigung. Heidelberg: Hüthig Buch Verlag, 1990. ISBN: 978-3-7785-1850-X.

[27] REFA: Verband für Arbeitsstudien –REFA- e.V.: Methodenlehre des Arbeitsstudiums. Teil 2: Datenermittlung. Munich: Carl Hanser Verlag, 1972. ISBN: 978-3-446-11590-0.

[28] LfU: Bayerisches Landesamt für Umwelt: Berechnung der CO2-Emissionen.. http://www.izu.bayern.de/praxis/detail_ praxis.php?pid=0203010100217.

[29] Rivera, L.: Inter-Enterprise Cost-Time Profiling. Dissertation, Virginia Polytechnic Institute and State University, 2006.

[30] Syska, A.: Produktionsmanagement-Das A-Z wichtiger Methoden und Konzepte für die Produktion von heute. Wiesbaden: Gabler, 2006, ISBN 978-3-8349-0235-1.

[31] Bicheno, J.; Holweg, M.: The Lean toolbox-The essential guide to Lean transformation. 4. Aufl., Buckingham: PICSIE Book, ISBN 0954124456.

[32] Reinema, C.; Schulze, C.; Nyhuis, P.: Energieeffiziente Fabriken: Ein Vorgehen zur integralen Gestaltung. In: wt Werkstatttechnik online, Jahrgang 101 (2011) H. 4, pp. 249-252. Düsseldorf: Springer-VDI-Verlag.

[33] Reinhart, G.; Karl, F.; Krebs, P.; Maier, T.; Niehues, K.; Niehues, M.; Reinhardt, S.: Energiewertstromdesign: Ein wichtiger Bestandteil zum Erhöhen der Energieproduktivität. In: wt Werkstatttechnik online, Jahrgang 101 (2011) H. 4, pp. 253-260. Düsseldorf: Springer-VDI-Verlag, 2011.