Performance Factory in the Context of Mass Customization

Noëlle Jufer[1], Joanna Daaboul[2], Jens Bathelt[1], Daniel Politze[3], Florent Laroche[2], Alain, Bernard[2], Andreas Kunz[3]

[1]*inspire, ETH Zentrum, Tannenstrasse 3, 8092 Zurich, {jufer, bathelt}@inspire.ethz.ch*

[2]*IRCCyN- ECN, Rue de la Noë 1, 44300 Nantes, France, {name.surname}@irccyn.ec-nantes.fr*

[3]*ETH Zurich, ETH Zentrum, Tannenstrasse 3, 8092 Zurich, {politze, kunz}@iwf.mavt.ethz.ch*

Abstract

A novel performance measurement and assessment frame called Performance Factory (PerFact) applied on a specific example focussing on mass customization in the context of the Factory of the Future is presented in this work. PerFact operates target-oriented towards the mission and vision of the company by connecting the overall mission and vision via related requirements with the Key Performance Indicators (KPIs) and their specific reference values. The performance is measured on manufactured customer-driven products, corresponding production processes and used resources. Furthermore, PerFact is able to monitor and assess the performance of both real production systems and simulated production scenarios. Moreover, the measurement system is balanced; it assesses the performance of the factory considering all perspectives relevant for each specific case.

Keywords

Performance Indicator, Performance Factory, Factory Planning, Mass Customization

1 Introduction

Today, enterprises have to meet the increasing global consumer demand for greener, more customized and higher quality products. Thus, a transition to a demand-driven industry with lower waste generation and energy consumption is needed and often referred as the 'Factory of the Future'. As many other industries, also the shoe industry is challenged by an increasing individualization of demand. Consumers are increasingly attempting to express their personality by means of individual product choice. As a result, shoe manufacturers are forced to create product programs with increasing amount of variants. As a consequence, forecasting has become more difficult than ever which results in high overstocks, increasing fashion risks and the necessity of providing often large discounts to get rid of unwanted products. Made-to-order manufacturing, as often implemented in the context of mass customization, results in a significant lower waste generation and energy consumption in comparison to mass production since only ordered shoes are produced.

2 Relation to Existing Theories and Work

2.1 DOROTHY

DOROTHY – Design of Customer Driven Shoes and Multi-site Factory[1] – is a research project within the 7th Framework Program NMP that aims at transforming the European Shoe Manufacturing in order to strengthen Europe's ability to compete in the global market [Pedrazzoli 2009]. This industry sector faces an intense and growing competitive pressure through developing countries entering the global market by offering low-cost workforce for the production of labor-intensive, low value added products. Moreover, these countries are rapidly

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[1] http://www.dorothy.ethz.ch/

modernizing their production methods and enhancing their technological capacities [Manufuture 2006]. The envisioned transformation addresses the production of customer-driven, individualized and high added value products, in line with the concept of the Factory of the Future.

DOROTHY's vision is that anywhere in the world, the customer can step into a DOROTHY shop co-designing a shoe which is manufactured in a multi-site and multi-nation factory. DOROTHY envisions shoe customization possibilities for the three major aspects fit, function and style, which is novel and has a deep impact on the whole production system. Furthermore, DOROTHY heads for mass customization, which combines the low unit costs of mass production processes with the flexibility of individual customization. This ultimately leads to shoe production processes that are triggered, directed, and scheduled by the individual customer at a global scale. Since production in the shoe sector is already a widely distributed process – in order to take advantage of different national contexts – the customer impacts on the design of global, multi-site and multi-nation production systems in terms of factory planning, operation and logistics. In order to address this challenge and to support the proposed new paradigm, DOROTHY fosters three main scientific and technological objectives and their corresponding research clusters:

- ***Cluster 1:*** Design tools for customer-driven and customer fit shoe, as added-value product/service.
- ***Cluster 2:*** Design tools for advanced industrial engineering of multi-site and multi-nation production systems and factories, based on the customer-driven shoe.
- ***Cluster 3:*** New business models supporting the multi-site, multi-nation shoe industry associated with the DOROTHY paradigm.

DOROTHY's design concept promotes the full integration of the digital factory with extended multi-site, multi-nation manufacturing processes. The DOROTHY foundation relies on a standardized, digitized factory description realized by the shared factory data-model and its extended formalism, which is the actual building block for all the clusters.

2.2 Mass Customization Value Chain Process Description

A DOROTHY company is implementing Mass Customization (MC), which is defined as offering customized goods but at a price close to that of mass production [Pine 1993]. The MC value chain (MC Process) consists of several subprocesses. In this paragraph, an updated MC Process, based on [Blecker, et al. 2004] (Figures 1a and 1b) is presented and discussed. The main difference between MC and Mass Production (MP) lies in their logic of operating. For MP, the logic is the following: lower prices lead to greater sales, greater sales in higher volumes, higher volumes in lower costs, and closing the loop, lower costs induce lower prices. Nevertheless in MC, the logic is that customization leads to more satisfied customers and continuous innovation, which both lead to greater sales and higher profits accompanied by better understanding of the customers. Finally, higher profits and increased customer knowledge allow the company to better satisfy customers by offering more variety reflecting their real desires [Pine 1993]. Thus, MP is efficiency-driven and based on economies of scale, while MC is customer-driven and based on offering higher variety at affordable prices. This is reflected in their respective value chains. Even though both processes (MP and MC) consist of the same subprocesses, MP is pushing high volumes of products to the end customer and separates innovation from production, while MC is customer-driven, whereas innovation and production are integrated [Pine 1993]. Value in the latter is generated by satisfying individual customer requirements, while for MP it is generated by high quality, low cost products. Therefore, previous performance measurement systems that were adequate for MP's logic need to evolute in order to meet the new operating logic of MC.

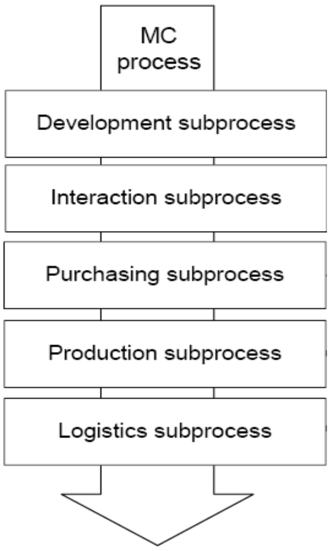

Figure 1a: MC process from [Blecker, et al. 2004]   Figure 1b: Updated MC process

One fundamental difference between MP and MC lies in the *Interaction subprocess*, which plays a dominant role in the MC, but not in the MP process. In case of MC, all other subprocesses are influenced by the *Interaction subprocess*. (Figure 1a, 1b), which includes the following steps: At first, the customer is identified by saving data about his name, contacts, address, etc. Then, depending on the product and on the type of implemented MC, some measurements are taken. Next, the customer personalizes his/her product with the help of a salesman or directly via the product configurator either in a real shop or online. Following, the placement of order is achieved. Mainly these steps, which form the order placement, reflect the main difference between MP and MC. In the first, the customer chooses what to buy from what he can find on the shelves, while in the later, the customer will buy what satisfies his exact requirements. Then, this choice will be communicated to the manufacturing enterprise via a shop or software. This process of customization and placing order highly impacts the overall customer perceived value. Thus, the easier and less time consuming it is, the more the customer is satisfied from the customization service offered by the company. Moreover, successfully and accurately capturing, translating and communicating customer data, requirements, and needed measurements, is a key factor for MC implementation.

Order processing is following order placement. Two cases appear, the first being if the personalization takes place in the shop. In this case, the order processing is done in the shop, and then the salesman fulfils the order by performing the final product assembly or by adding additional goods or services to the product. Finally, he delivers it to the customer. In the second case, personalization does not take place in the shop, but in the factory either at the fabrication level or at the assembly level. In this case, the orders are sent to the factory that processes them, and then plans for their production (setting routes, allocating resources, scheduling machines, etc.). Next, purchasing of needed material or semi-finished products is done. Following, the specific products of the order are fabricated, and then assembled to be finally delivered to the customer's preferred delivery address.

Before starting the customization process, a catalogue of customization options is developed and provided by the company, which already has developed and designed a product for MC, and have made all the necessary changes in its value chain to cope with such a strategy.

2.3 Performance Measurement Systems

In the past decades, manufacturing enterprises relied on performance measurement systems, which were based on traditional accounting systems to monitor and improve their operations [Jackson 1988], [Kaplan, Norton, 1992]. According to [Jarkon 1988], it was shown that these systems do not cover the relevant performance issues of production. One significant limitation of traditional performance measurement systems is that they focus on controlling and reducing labor costs. However, labor cost currently constitute on average only 12% while overhead comprises 50-55% of the manufacturing costs. Furthermore, the traditional systems are static and do not support neither the concepts of flexible lean production nor continuous improvement [Jarkon 1988]. [Gregory 1993] concludes in his state-of-the-art analysis of performance measurement systems that there is a need for a novel operations-based system with the capability of evolving with the company.

Furthermore, the interdependent planning and design processes of the Factories of the Future and its products have to be coordinated and synchronized in order to get more agile and to swiftly respond to the fast changing market demand and conditions [Weimer, et al. 2008]. Moreover, the factories need to know about the impact of these market-responding adoptions on their performance – either on the product, the factory or on both. Recently, efforts to fully represent the factory and its products digitally and also virtually emerged, [Bacs 2007], [Pedrazzoli, et al. 2007]. Such a representation offers the advantage of being able to test the planned adaptations on the factory and/or its products virtually before realizing it. This enables the assessment of different change scenarios and to choose the most adequate one for being realized.

By measuring the performance through an adequate performance measurement system, which focuses on the needs of product and factory design [Ghalayini, et al. 1997], [Ahmad, Dhafr, 2002] the factory's management receives needed information on the relevant performance drivers of their company. This will support them by making efficient and effective decisions on changes in the product range, the product structure and/or factory processes (manufacturing, logistics and assembly). In addition, the measured values of the PIs enable a significant comparison of different change scenarios against adequate criteria. Last but not least, the verification and the grade of the target achievement can be observed and thus will provide a valuable feedback and input for the efforts of the continuous improvement processes which are well established in excellent leading companies [EFQM 2003].

The novel performance measurement and assessment system PerFact, presented in this work, considers the above requested elements. In PerFact, the PI values can be measured on real and/or virtual production processes considering synchronized product and factory data. Thus, PerFact is able to monitor and assess the performance of both real production and production scenarios. Moreover, PerFact operates target-oriented towards the vision and mission of the company by connecting the overall vision and derived major requirements with the PIs and their specific reference values. PerFact can be applied to both, MP and MC since the architecture of PerFact allows an implementation in any manufacturing companies [Jufer, et al. 2010]. Nevertheless, every single instantiation in a particular company is unique due to company specifics, such as Mission, Vision, Perspectives, MC, MP, etc.

3 Research approach: The Performance Factory

The Performance Factory (PerFact) [Jufer, et al. 2010] is a novel holistic and balanced performance assessment system designed to monitor the Factory of the Future. It considers the strategic, operational and tactical level and works target-oriented towards the mission and vision of the company. Moreover, it builds on the relevant issues of lean, flexible and/or customer-driven production since the performance calculation is based on the three main elements of currently deployed and established factory data models as already been used at Tecnomatix, Process Designer (Siemens PLM Software[2]) or Delmia (Dassault Systèmes[3]) and which are also applied in DOROTHY:

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[2] http://www.plm.automation.siemens.com/en_us/products/tecnomatix/

[3] http://www.3ds.com/products/delmia/welcome/

- manufactured products
- required processes
- related manufacturing resources or factory structures

In addition, the data model developed in DOROTHY considers the needs of a mass customization production. These factory data models comprehensively describe the behaviour and status of a factory in various scales in order to represent a valid image for the monitoring of the factory and its related processes. This enables performance monitoring and assessment of running operation and planning scenarios as well. Furthermore, the performance assessments are dynamically supported by an agent based system in order to support the concepts of flexible lean production and continuous improvement as described in [Politze, et al. 2010]. The architecture of PerFact is depicted in Figure 2.

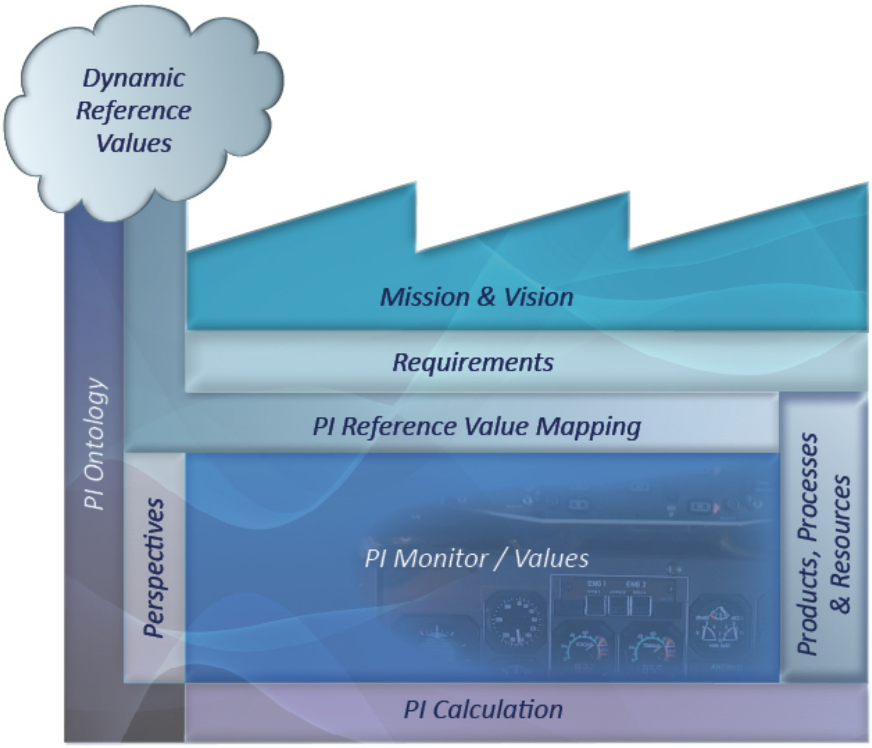

Figure 2: Architecture of the Performance Factory (PerFact)

PerFact consists of a roof, several floors, pillars and a foundation. On the top of PerFact's architecture (within the roof), the vision and mission of the company is documented. All business processes of the company are dedicated to these targets. Furthermore, the main strategic goals of the company are derived from the vision and mission. Underneath the roof – on the top floor – the major requirements and out of them the Key Performance Indicators (KPIs) are deduced from the company's main strategic goals. It is envisioned to manage the requirements and their relation to the KPIs with a formal model that was proposed in [Politze, Dierssen, 2008] to formalize and manage functional requirements. One level below, the KPIs are divided into PIs and their related reference values are mapped. Moreover, a Perspective-pillar on the left hand side is arranging all available PIs according to different areas of development/growth like (customers, business, processes, finances, etc.). The reference values are directly connected to the shop floor of PerFact containing the PI Monitor. Within this central element, the comparison of the measured values with the reference values of the PIs is interpreted and visualised. The presented result enables the monitoring and assessment of the factory's performance. All dependencies between the PIs are formalized and accessible through a PI Ontology-pillar at the very left side. The values displayed by the PI Monitor are based on the PI Calculation situated at the foundation of PerFact's architecture. Here, the actual values of the PIs are calculated according to the PI Ontology and with regard to Product, Process and Resource (PPR) data. This

PPR data is represented by another pillar on the right, which is either retrieving real data from the ongoing production or virtual data from a simulation.

4 Findings: Application of PerFact in the Context of Mass Customization

In this section, the Performance Factory is applied exemplary to a DOROTHY company already using the novel tools to be developed in the DOROTHY project and heading towards mass customization. The presented example follows the utility pattern and related structured course of action of PerFact, as described in [Jufer, et al. 2010]. The first three steps (1-3) belong to the strategic level, the following three steps (4-6) to the operational level and the last step (7) to the tactical level of the presented exemplary DOROTHY company.

Step 1: Definition of the *Mission & Vision* of the DOROTHY company by the management: The mission is defined as "get measured and design YOUR shoe" and the vision is defined as "in the next five years, our market share will rise by 20% due to DOROTHY customers".

Step 2: Definition of the *Requirements* by the management: This step includes the detailing of the mission and vision into strategic targets formulated as major functional requirements (2a) and the refinement from the strategic targets into more specific requirements (2b). The functional requirements on the lowest level finally represent the Key Performance Indicators (KPIs) (2c). In order to achieve a better differentiation, easier retrieval and simplified handling and description, the KPIs should be consequently rephrased into headwords. The strategic targets are formulated as major functional requirements as follows:

2.1 To provide individualized, customized shoes

2.2 To master the production of individualized, customized shoes

2.3 To gain market share thanks to individualized, customized shoes

In line with the three clusters from DOROTHY, further requirements may be derived by refinement out of these strategic targets. In this example two more specific functional requirements have been derived for each of the strategic targets from above.

2.1.1 To fulfil the customer requirements/demands for a customized shoe

2.1.2 To produce customized shoes according to the customer requirements/demands

2.2.1 To effectively produce customized and standardized shoes

2.2.2 To efficiently produce customized and standardized shoes

2.3.1 To apply an adequate business model that supports the new DOROTHY business area

2.3.2 To attract new customers with the new business model and our reputation

Since these requirements form the most specific ones, they are considered as KPIs. Thus, they have been given a more concise name and additionally, the management defines reference values for every KPI representing the envisioned degree of target achievement. The KPIs and their related reference values r_i are in this example defined as follows:

2.1.1 Customer satisfaction, r_1=0.80

2.1.2 Production flexibility, r_2=0.90

2.2.1 Production effectiveness, r_3=0.90

2.2.2 Production efficiency, r_4=0.85

2.3.1 Business smoothness, r_5=0.95

2.3.2 Company image, r_6=0.95

Step 3: Includes the definition of the *Perspectives* (3a) and the *PI Reference Value Mapping* (3b and 3c). Similar to the concept of the Balanced Scorecard [Kaplan, Norton, 1992], the perspectives represent the main areas of development/growth of the factory. For the DOROTHY Company every subprocess of the MC Process represents one perspective (3a):

3.1 Product Development

3.2 Customer Interaction

3.3 Purchasing

3.4 Production

3.5 Logistics

3.6 After Sales/Services

The final tasks of the strategic level are the mapping of the PIs (3b) and their related reference values (3c): The already defined KPIs and the perspectives constitute a matrix whereas the KPIs are represented in the columns and the perspectives in the rows. Every single KPI represents an n-tuple, whereas *n* equals the number of perspectives. Furthermore, a KPI consists of in maximum one tuple-PI for every perspective. In general, the name for as specific performance indicator is denoted as PI(KPI|Perspective). As soon as a specific PI is determined – based on formulas and knowledge stored in the *PI Ontology* – its corresponding reference value has to be set in a next step. Thus, for the DOROTHY company example the following PIs (3b) and reference values r_{ij} (3c) for the KPI *2.1.1 Customer Satisfaction* (CS) are defined as follows, whereas all listed PIs are normalized within [0, 1].

PI(CS|Development) = (#orders - #returns due to development issues) / #orders, r_{11}=0.90

PI(CS|Customer Interaction) = #shop visitors ordering / #shop visitors, r_{12}=0.60

PI(CS|Purchasing) = (#orders - #returns due to purchasing problems) / #orders, r_{13}=0.90

PI(CS|Production) = (#orders - #returns due to production errors) / #orders, r_{14}=0.90

PI(CS|Logistics) = (#orders that are correct & in time & without transportation defects / #delivered orders, r_{15}=0.90

PI(CS|After Sales/Services) = # repetitive customer / # customer, r_{16}=0.60

Step 4: From the *Products, Processes & Resources (PPR)* data, the current values of the PIs are measured by sensors, simulation, etc. In this example, for the KPI *2.1.1 Customer Satisfaction*, the returns will be captured via PPR and the reason for the customer to return a product will be allocated to Product Development, Purchasing and/or Production. The allocation can be done by both providing the customer a form on which he is asked to state the reason for the return and/or by a business unit processing the returns. Then, this data will be integrated in the PPR data management system from where the total amount of orders, the amount of delivered orders, the amount of returns due to Development, Purchasing, and/or Production, etc. can be measured.

Step 5: The *PI Calculation* is performed by using the PI formulas defined in step 3 and the PPR-data of step 4. The PPR-data represents the input values to the PI formulas. The value for the KPI *2.1.1 Customer Satisfaction* is defined as arithmetic mean of the calculated values of its tuple-PI.

Step 6: In the *PI Monitor*, the reference values (defined in step 3c) are compared with the calculated actual values (step 5) and the result is visualized for every defined PI and KPI.

Step 7: The *Dynamic Reference Values* represent a future-oriented planning tool. Within this element, the performance assessments are dynamically adapted in order to support the concept of continuous improvement which foresees an increase of the performance in the long term. Thus, the reference values will be periodically adapted to the already achieved performance by using historical PI values. As an example, the reference value r_{12} of the PI(CS|Customer Interaction) may evolve in the following way: r_{12}=0.60 in 2000, r_{12}=0.75 in 2010 and r_{12}=0.85 in 2020.

5 Conclusion

Today, a considerable number of manufacturing companies are shifting towards mass customization. As the products, processes and the entire value chain adapt to this new paradigm, the performance measurement systems should take this into consideration. PerFact, as shown in this work, can be applied according to the requirements of a MC factory like the DOROTHY factory. It represents a suitable performance measurement system which can monitor the entire factory with respect to the mission, vision, major requirements, the manufactured customer-driven products, corresponding production processes and used resources. Furthermore, PerFact meets the requirements of an adequate measurement and assessment system for a modern manufacturing company in line with the concept of the Factory of the Future.

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References

Ahmad M, Dhafr N. (2002) Establishing and improving manufacturing performance measures. Robotics and Computer Integrated Manufacturing, Vol 18, 2002, p. 171-176.

Bacs C. (2007) New Datahandling- and Rapid Virtual Prototyping Approach for Mechatronic Systems. Proceedings of The 15th International Conference On Engineering Design (ICED07), Paris, France, 2007, August 28-31.

Blecker T, Friedrich G, Kaluza B, Abdelkafi N, Kreutler G. (2004) Information and Management Systems for Product Customization. Boston, MA, Kluwer Academic Publishers.

EFQM, European Foundation for Qualitiy Management (Ed.). (2003) EFQM Excellence Model. Brussels, 2003.

Ghalayini A. M, Noble J. S, Crowe T. J. (1997) An integrated dynamic performance measurement system for improving manufacturing competitiveness. Int. Journal of production economics, Vol 48, 1997, p. 207-225.

Gregory M. J. (1993) Integrated performance measurement: a review of current practice and emerging trends. International Journal of Production Economics, 30/31, 1993, p. 281-296.

Jackson P. (1988) The Management of Performance in the Public Sector. Public Money and Management, Vol 8, No. 4, 1988, p. 11-16.

Jarkon J. G. (1988) The Productivity Paradox. Special Report. Business Week, 1988, June 16, p. 100-108.

Jufer N, Politze D. P, Bathelt J, Kunz A. (2010) Performance Factory – A new approach of performance assessment for the Factory of the Future. Proceedings of the 7th International Conference of DAAAM Baltic, INDUSTRIAL ENGINEERING, Editor R. Kyttner, Tallinn, Estonia, April 2010.

Kaplan R, Norton D. (1992) The Balanced Scorecard: Measures That Drive Performance. Harvard Business Review, Harvard Business Review, 1992, Vol. 70, p. 71-79.

Manufuture (2006) Strategic Research Agenda, Vol 09, 2006, p. 8.

Pedrazzoli P, Rovere D, Constantinescu C, Bathelt J, Pappas M, Dépincé P, Chryssolouris G, Boër C. R, Westkämper E. (2007) High Value Adding VR Tools for Networked Customer-driven Factory. Proceedings of The 4th International Conference on Digital Enterprise Technology, Bath, UK, 2007, September 19-21.

Pedrazzoli P. (2009) Design Of customeR dRiven shOes and multi-siTe factory - DOROTHY. Proceedings of the 15th International Conference on Concurrent Enterprising (ICE09), Leiden, Netherlands, 2009, June 22-24.

Pine B. J. (1993) Mass customization: the new frontier in business competition. Boston, Harvard Business School Press, 1993.

Politze D. P, Dierssen S. (2008) A Functional Model for the Functions Oriented Description of Customer-Related Functions of High Variant Products. Proceedings of NordDesign, Tallinn, Estonia, 2008, May 19-22.

Politze D. P, Jufer N, Bathelt J, Kunz A, Wegener K. (2010) AMOR – An Agent for Assisting Monitoring, Optimization and (Re-)Design in Factory Design. 43rd CIRP Conference on Manufacturing Systems, Vienna, Austria, 2010, May 26-28.

Weimer T, Kapp R, Klemm P, Westkämper E. (2008) Integrated Data Management in Factory Planning and Factory Operation – An Information Model and its Implementation. 41st CIRP Conference on Manufacturing Systems, Tokyo, Japan, 2008, May 26-28.