Dissertation title:

Advanced Manufacturing Analytics – Data-Driven Optimization of Manufacturing Processes

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Nowadays, manufacturing companies are faced with strong global competition, which is characterized by high pressure on prices and costs, high complexity and a turbulent environment. In this context, transparent, agile and continuously improved manufacturing processes have become a critical success factor.

Traditional concepts for manufacturing process optimization, e.g., Lean Production and Total Quality Management, represent management-driven and experience-based approaches. The increasing use of cyber-physical systems as well as the digitalization of manufacturing operations management by manufacturing execution systems (MES) lead to enormous amounts of structured and unstructured manufacturing data. These data offer great potential for novel data-driven approaches for manufacturing process optimization by systematically extracting new knowledge for continuous process improvement.

Existing approaches for data analytics and business intelligence in manufacturing, such as, MES and online analytical processing (OALP) systems, suffer from four major technical weaknesses that prevent comprehensive knowledge extraction: (1) The approaches are based on isolated data extracts not taking a holistic view on the process. (2) They focus on descriptive and reactive analysis of metrics without supporting pattern recognition in data. (3) Analysis results are provided primarily for managerial personnel without addressing the shop floor level. (4) The implementation is done case-by-case in absence of generic business intelligence architectures for manufacturing.

This thesis is about the development and evaluation of a business intelligence platform for continuous data-driven manufacturing process optimization, the so called *Advanced-Manufacturing-Analytics-Platform (AdMA-Platform)*, addressing the above weaknesses. The conceptual foundation of the thesis is comprised of a comprehensive presentation of processes and IT systems in manufacturing as well as of central concepts for data-driven optimization from the field of business intelligence. Following this, an extensive analysis of weak points of existing business intelligence applications for manufacturing including MES and existing data mining approaches is conducted. In

addition, a real-world case example from the automotive industry is presented comprising the manufacturing of camshafts. At this, technical challenges for data-driven process optimization considering a concrete manufacturing quality problem are investigated. This provides the basis for the development of the AdMA-Platform.

The conceptual architecture of the AdMA-Platform (Gröger et al. 2012b, Gröger und Stach 2014) is comprised of three layers for data integration, process analytics and process optimization. It integrates all technical components necessary for data-driven manufacturing process optimization in a holistic approach. At this, the architecture and the components are generic in order to be applicable for different manufacturing processes independent of an individual case.

The *Manufacturing Knowledge Repository* (Gröger et al. 2012c, Gröger et al. 2014b, Gröger et al. 2014c) is at the core of the data integration layer. It integrates structured and unstructured data across the entire manufacturing process and additionally supports a process-oriented management of analysis results, e.g., data mining models. For this purpose, it combines a process warehouse approach based on a generic multidimensional data model for manufacturing processes with a repository-based storage of unstructured data. To implement this approach, a link-based integration architecture is presented enabling the flexible ad-hoc integration of structured and unstructured data using information-rich links.

The process analytics layer comprises generic analytics services realizing not only traditional descriptive analytics but predictive analytics and prescriptive analytics on top of the Manufacturing Knowledge Repository. *Predictive Manufacturing Analytics* (Gröger et al. 2012a) encompasses data-mining-based analytics for data-driven root cause analyses and predictions across the entire manufacturing process, e.g., to systematically identify influence factors for deteriorating manufacturing quality. *Prescriptive Manufacturing Analytics* (Gröger et al. 2014a) refers to a novel data-mining-based approach for proactive process optimization during process run time. It enables the data-driven generation of concrete action recommendations in order to avoid a predicted metric deviation.

The process optimization layer mainly focuses on user access. For this purpose, the *Mobile Manufacturing Dashboard* (Gröger et al. 2013a, Gröger et al. 2013b, Gröger

und Stach 2014) is presented. It supports mobile and personalized information provisioning not only for production managers but for workers using mobile devices, such as, tablet pcs, in order to integrate the AdMA-Platform with the shop floor level.

On the basis of a prototypical implementation of the entire AdMA-Platform, an experimental evaluation is described in the thesis focusing on the application of the prototype in the case example of camshaft manufacturing. This investigation demonstrates that the AdMA-Platform enables both the data-driven identification of root causes for the quality problem across the entire manufacturing process and the data-driven generation of concrete action recommendations to proactively avoid the quality problem at process runtime. In addition to that, a comparative evaluation is conducted referring to a criteria-based assessment and comparison of the AdMA-Platform with existing business intelligence applications in manufacturing.

All in all, the AdMA-Platform systematically exploits the huge amounts of manufacturing data for continuous manufacturing process improvement using novel predictive analytics and prescriptive analytics in combination with targeted information provisioning on top of a holistic data basis. In this way, the AdMA-Platform offers new potentials for enhancing the competitiveness of manufacturing companies.

[Reference: Christoph Gröger: *Advanced Manufacturing Analytics – Datengetriebene Optimierung von Fertigungsprozessen*, Josef Eul, Lohmar, 2015.]

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