

## **Doctoral thesis in Cluster D “Netzwerke in der Produktion”:**

### **A Service-oriented Integration Platform for Flexible Information Provisioning in the Real-time Factory**

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#### **Summary:**

Constantly changing business environments force manufacturing companies to continuously adapt their products, processes and services in order to remain competitive. This adaptation requires also changes in Enterprise Application Integration (EAI) processes, which seamlessly integrate applications across the factory. Therefore, EAI middleware solutions for the manufacturing industry need to not only integrate a large number of heterogeneous applications and legacy systems but also establish a lifecycle management strategy that supports the planning, execution, monitoring and analysis of EAI processes. Nowadays, the support of digital planning tools for the required adaptation has become indispensable. In manufacturing, the leverage of digital tools for visualization, simulation and virtual reality applications is known as the Digital Factory. In order for the Digital Factory to be effective, a dynamic picture of the factory absolutely indispensable. The reflection of the current state of the factory into the future can only be useful to engineers if a permanent feedback loop from the real factory, which enables the monitoring and analysis of the past experience from earlier states of the factory, is provisioned. This concept is known as Real-time Factory. However, the realization of the Real-time Factory presents a number of research issues regarding the integration of applications and information systems across the factory, such as the heterogeneity of systems, the lack of integration at the application level, the lack of automation tools for the monitoring and analysis of the operational environment and missing mechanisms for the agile adaptation of EAI processes.

In this thesis, a service-oriented integration architecture for manufacturing environments is introduced. This architecture is based on a service bus that allows a loose coupling of distributed services in event-driven manufacturing environments. This platform provides flexible communication between Digital Factory and shop floor components by introducing an application-independent canonical data model for manufacturing events, a content-based routing service, data transformation services as well as event processing workflows. Furthermore, an EAI Process Model is proposed. This model is used by an EAI Process Editor to plan and design the integration processes that enable the exchange of data in the Real-time Factory. In addition to the EAI Process Model, an Adaptation Model for the Real-time Factory is proposed. This model constitutes an adaptability framework for the Real-time Factory that implements the monitor, analyze, plan and execute (MAPE) functions of a self-managing environment and serves as a guideline for the feedback loop established between the execution and the planning environment. The architecture presents self-managing and adaptive mechanisms thanks to the automation of the monitoring and analysis tasks. The monitoring phase is implemented by a mining process that provides real-time domain data evaluation and transforms it into high-level context descriptions that can be processed in the analysis phase. For the analysis of domain context, which comprises the analysis phase of the MAPE-based feedback loop, a Provenance-aware Service Repository is proposed. The Service Repository processes domain recommendations and enables the communication

with the EAI Process Editor and other lifecycle applications in order to react responsively to turbulent scenarios in the domain. The Service Repository manages information about services, processes and their dependencies in a service knowledge base and in a process knowledge base. A semantic data engine in the Repository provides an inference mechanism, based on an algorithm that generates the appropriate corrective actions to attend the recommendations made by the mining process. Both the mining graph and the Service Repository close the MAPE cycle and automate the domain knowledge extraction process, which eases an agile adaptation of EAI processes based on a real-time domain data evaluation. This architecture is capable of managing the life cycle of services and EAI processes in order to achieve the desired agility in an interconnected environment.

A prototype implementation for the integration architecture, the EAI Process Editor, the mining process and the Service Repository are introduced and described in this thesis and serve as a proof of concept. The applicability and validation of the approach are supported by different use cases. The evaluation of the approach has been realized by the examination of different criteria that have been classified in six categories: interoperability, flexibility, mediation, adaptability, agility and integration. These categories are used to evaluate the approach and to compare it with past and current approaches in the EAI domain. Two recent research approaches to integration and context management in the manufacturing domain are also evaluated and compared to the presented approach.