Information Systems Architecture for Collaborative Manufacturing in Virtual Enterprises

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Abstract

Nowadays the concept of collaborative manufacturing in virtual enterprises seems to be an appropriate answer to the actual competitve situation. From the point of view of information processing there are many restrictions coming up with this concept because of the hierarchical and inflexible approach of the traditional information systems. This paper introduces a new framework architecture using a CORBA-based manufacturing approach and building on Web-based manufacturing. Main task of the proposed framework architecture is supporting the communication within a production plant on the one side and the communication among the partners of a virtual enterprise on the other side. The possibilities and benefits of an integration of applications and data within a plant as well as across enterprise boundaries will be discussed with practical examples from the application areas of process control and Web-based simulation.

Keywords

Virtual Enterprise, Collaborative Manufacturing, Web-based Simulation, CORBA

1 INTRODUCTION

The globalisation of the markets and the resulting intensified competitive situation have dramatically altered the basic conditions for today's manufacturing companies. Due to the increasing pressure to satisfy the customer's demands, the

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concentration on core-competencies and the segmentation, many companies break down their inflexible organisations and skip local restrictions. Instead of this, they put on a flexible, virtual, network-shaped and temporally restricted cooperation of decentral competencies. From the point of view of information processing, the shift of coordination tasks from internal coordination within a company to external coordination of several companies working on a common project is critical. In the borderline case of a virtual enterprise the problems arising can be shown exemplarily.

Therefore, on the basis of the common objective of a virtual enterprise, the requirements on the information management will be analysed and the deficits of existing information systems as well as architectures will be discussed. As a result, an information systems architecture will be suggested using a CORBA (Common Object Request Broker Architecture)-based approach and building on Web-based manufacturing. The objective is to restrict the idea of integration not only to the processes within a manufacturing company, but also taking into account the interfaces to external cooperation partners.

2 REQUIREMENTS FOR INFORMATION SYSTEMS

There are many challenges to the information systems architecture when setting up a virtual enterprise. Potential barriers for a cooperation spawning different enterprises are (Hardwick, 1996, Picot, 1996):

- High degree of distribution. Applications and relevant data are highly distributed.
- Highly heterogeneous environment. The environment consists of heterogeneous applications, information systems, communication systems, operating systems, hard- and software, which all have to integrate and operate seamlessly.
- Coordination and cooperation mechanisms. In order to achieve a controlled and coordinated cooperation of different applications, a controlling mechanism spawning the partners of a virtual enterprise is needed.
- Dynamic of reorganisation. Virtual enterprises must be able to form and dissolve quickly. Therefore, communication-links have to be set-up and dissolved quickly.

Insufficient security. Companies participating in a virtual enterprise necessarily offer insights of their own company to the others. A high level of security concerning the access to company specific data has to be guaranteed.

Collaborative manufacturing in virtual enterprises leads in some ways to specific requirements concerning the information management and the respective information systems architecture:

On the one side, an integrated data and process management within the whole production network is a prerequisite to coordinate and supervise the process of fabrication along the whole process chain. Therefore, the access of external cooperation partners has to be restricted to a subset of the process data by means of security mechanisms. On the other side, monitoring, diagnostics and simulation are important applications used at planning level as well as at supervisory level. In order to enable the user at planning level to adapt the processes immediately to changes of production conditions, a seamlessly integration of planning and process level is required.

3 DEFICITS OF CONVENTIONAL INFORMATION SYSTEMS AND ARCHITECTURES

Figure 1 depicts the model of a conventional single production plant. The most relevant data sources are grouped at the bottom, which are (Warneke, 1996):

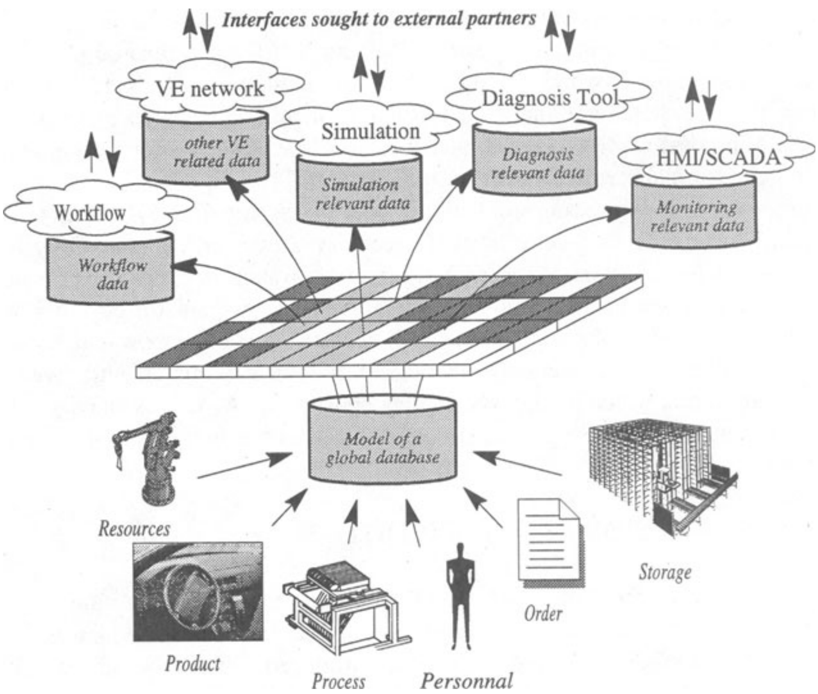

Figure 1: *Production plant relevant data and applications (model).*

- resources data, e.g. machines, performance characteristics, capacities and tools
- product data, e.g. part numbers and names, parts lists, stock
- process data, e.g. structure of the process, process states
- personnal data, e.g. wage group, number of hours working, current work
- order related data, e.g. date, quantity, costs
- storage related data, e.g. subcontractors, minimum stock, actual stock.

Applications typically operate on a subset of the enterprise data. This is expressed by a filter function filtering the global database of the single production plant according to the applications' need. When linking the enterprise with external partners, application interfaces have to be offered.

However, real enterprises do not match this szenario, because the data itself is highly distributed and there is no global database. Therefore, it has to be the task of the information system and the applications to provide the model of a global database and to support interoperability for the applications. Especially across enterprise boundaries this turns out to be extremely difficult, because of different hardware platforms and operating systems.

Moreover, today's information systems lack support for coordinated production within a production network, e.g. the link-up of simulation models of distributed manufacturing systems and the synchronisation of production plans. Considering the task of process management, market-available tools do not offer the possibility to integrate external partners in the enterprises' workflow.

In order to run the linked-up simulation models, transparent access to parts of the operating data of the shop-floor level is necessary. However, the shop-floor level lacks support for an open, connective information system. Vendor-specific hard- and software solutions are dominant, comprising non-standardised interfaces. Thus, isolated applications are the consequence. Exchange of process data between these applications and the planning level therefore results in implementing vendor-specific interfaces, which is time and money consuming. As a consequence, when setting up virtual enterprises, access to process data is becoming one of the major problems.

4 INTRODUCTION OF THE ARCHITECTURE

In consideration of the requirements and deficits of today's information systems architectures, a new architecture, developed at the Institute for Manufacturing Automation and Production Systems, will be introduced. Obviously, this cannot be a completely self-contained architecture, but more a framework, defining the basic mechanisms for integrating data sources, applications and a coordination module.

The framework defining the information systems architecture is centered round the middleware CORBA, which is a distributed object architecture enabling to write object-oriented client/server applications in heterogeneous distributed environments. CORBA ensures transparency concerning the operating system, the communication system and the programming language. In addition, CORBA provides various services, which can be used by applications. These services - among others - cover persistent objects, concurrency, transmission of events, a security framework and services for defining collections and SQL querys (Object Management Group, 1998).

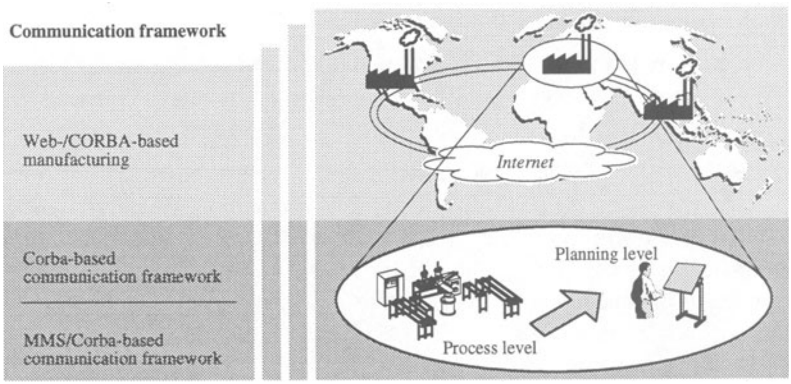

Figure 2: Proposed framework architecture.

Within the communication framework, two communication levels are distinguished (Figure 2): the communication among the partners of a Virtual Enterprise and the communication within a plant among the hierachically structured levels from the top most planning level to the shop-floor level. These aspects will be discussed in more detail in the following chapters showing how to integrate applications at the different levels and giving practical examples.

5 INTEGRATING APPLICATIONS AND DATA

In the following, the integration of applications and data across enterprise boundaries and within a plant in the proposed framework architecture will be discussed.

5.1 Integrating applications at the Web-/CORBA-based manufacturing level

On planning level there are different application areas for Web-based manufacturing like diagnostics, monitoring and simulation. In the following, for the Web-based manufacturing level a Java and CORBA-based architecture will be described exemplarily in the case of Web-based simulation.

Analysing the existing discrete-event simulation software tools with regard to their support for coordinated production within a production network, one can state the following three deficits (Shen, 1998):

- Lack of portability: Simulation models developed using one simulation language or library might not be easily ported to another environment.
- Lack of interoperability: Components of a simulation application cannot be written in different programming languages, or running over different operating systems or hardware platforms.
- Lack of capability to execute the simulation models over the Internet and the Web.

The suggested Java and CORBA-based architecture takes these deficits into consideration and provides the possibility of remote simulation as a prerequisite for collaborative manufacturing in virtual enterprises. Transparent communication between the different production sites is obtained by use of a CORBA ORB that operates the control and data transfer between clients and servers. The implemention of simulation models as Java applets enables the simulation user at a production site A to execute the retrieved model of a production site B with a Java-enabled Web browser.

5.2 Integrating applications within a plant

One of the most important issues when proposing a new framework architecture is the possibility to integrate the existing legacy applications. Conceptually, this can be done by defining the so called CORBA wrappers. This means, CORBA servers have to be defined offering the functionality of the legacy application. This is done by specifying IDL interfaces for the services of the legacy applications. Then, the IDL compiled code is augmented by local calls to the legacy applications using delegation. With this approach, a CORBA wrapper for a commercially available simulation tool was successfully implemented at the Institute for Manufacturing Automation and Production Systems.

5.3 Integrating product data across enterprise boundaries

Communicating product data efficiently among the partners of a Virtual Enterprise is crucial. This need was addressed by the ISO 10303 Standard STEP (Standard for the Exchange of Product Model Data, ISO 10303-1), and its modelling language EXPRESS (ISO 10303-11). Considering a manufacturer's STEP database, a communication architecture has to be provided to grant external partners access to the database. This could be done by either utilising a database-vendor specific type of middleware, e.g. a SQL network driver, or CORBA.

With a CORBA-based approach, queries can be assembled using the Query Service and accessed through the Collection Service. In addition, STEP provides an IDL language binding for access to a STEP database (ISO 10303-26). Thus clients can be programmed in any of the programming languages that have a CORBA language mapping.

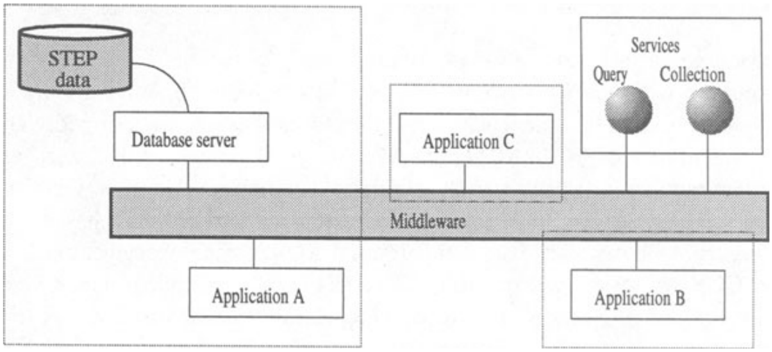

Figure 3: *A STEP/CORBA-based framework architecture as proposed in Hardwick, 1996).*

5.4 Integrating database systems across enterprise boundaries

The CORBA-based integration of database systems can be achieved in general by one of the means already discussed above:

- CORBA wrappers can be used in conjunction with an IDL defined interface
- CORBA's Query and Collection Services can be used if supported by the database system

As there are currently no CORBA 2.2 compliant query and collection services commercially available, at the Institute for Manufacturing Automation and Production Systems the actual work in progress is based on the first approach.

5.5 Integrating manufacturing data within a plant

In order to seamlessly integrate manufacturing data in a virtual enterprise, a CORBA-based approach is presented. It is based on the semantic of the MMS-protocol (Manufacturing Message Specification) for data-exchange between the hierarchically structured levels of an enterprise. MMS was chosen, because of its industrie acceptance and widespread use e.g. in the automotive industrie. Moreover, MMS an ISO standard with products being available from many vendors.

In the proposed information systems architecture, application relevant data is offered enterprise-wide via CORBA interfaces. Thus, a bidirectional mapping of the MMS protocol to equivalent CORBA interfaces has to be defined. The communication model of MMS is client/server. Several objects and classes are defined for communicating with a variety of possible automation devices. First, the mapping of the objects and classes and its correpsonding services has to be specified. Figure 4 shows that except the Journal Management Service, a direct mapping to CORBA services is possible. The Operator Communication Services are best mapped to a Web-based interface, which allows world-wide access to a device, e.g. for teleservice. MMS objects itself are mapped to corresponding IDL interfaces.

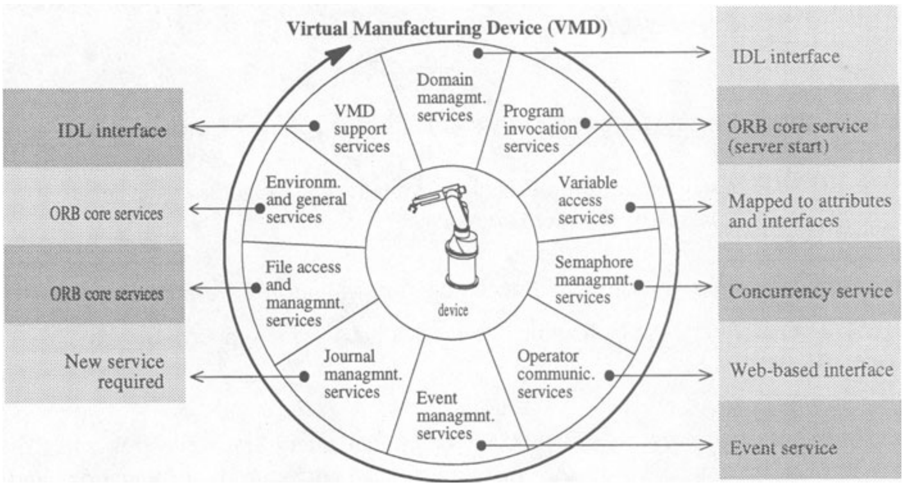

Figure 4: *Mapping of MMS objects to CORBA services and interfaces.*

In order to integrate legacy MMS applications a gateway solution is proposed. Applications based on the CORBA/MMS specifications communicate among themselves via the ORBs core services, whereas MMS legacy use the standard

MMS protocols. In case MMS legacy objects want to communicate with the new CORBA/MMS objects, it is the gateways task to route the corresponding request.

6 EXAMPLES FOR THE APPLICATION AREAS SIMULATION AND PROCESS CONTROL

This chapter details the framework architecture by the two examples of Web-based simulation and process control.

6.1 Example 1: Web-based simulation

Simulation has been shown to be a successful means supporting complex processes of making decisions in the fields of material handling as well as manufacturing and business processes (Feldmann, 1997a). As stated before, the existing discrete-event simulation software tools do not provide almost any support for coordinated production. Therefore, the main task of the suggested Web-based simulation approach is to allow the simulation users the dynamic link-up of models of the distributed production sites in virtual enterprises for simulation purposes.

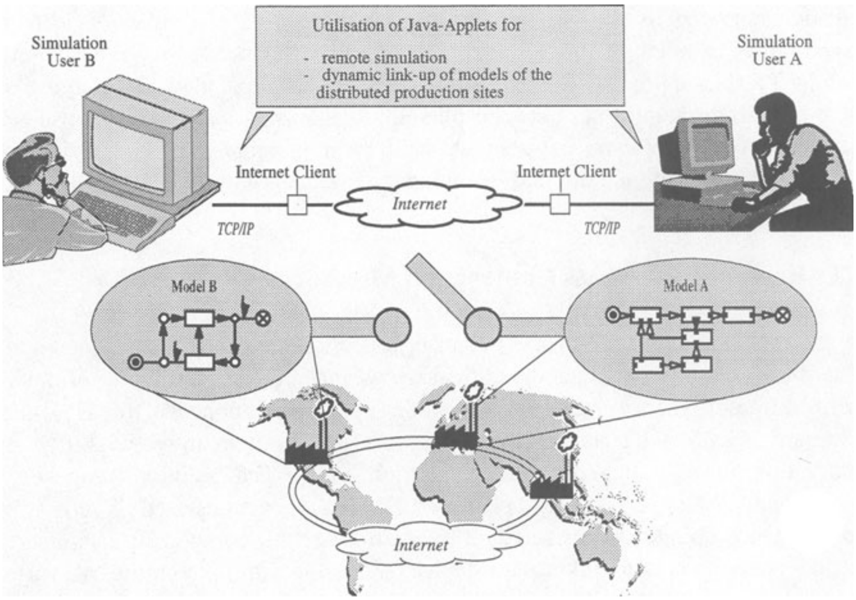

Figure 5: *Link-up of models of the distributed production sites in virtual enterprises for simulation purposes.*

Figure 5 shows the constellation of a virtual enterprise with production sites dispersed throughout the world. In the following, the functionality of the Web-based simulation approach should be explained exemplarily in the case of temporary stoppages due to internal disturbances in the production site A of the virtual enterprise. In order to compensate the resulting production loss and to carry out the promised delivery dates, it might be necessary to partly shift production orders to another production site B in the virtual enterprise or to integrate additional external production capacities in the case of a planned extension of ressources (Feldmann, 1997b). Therefore, the simulation user A must be supported finding out the site with the most favorable production conditions. The implemention of simulation models as Java applets enables the simulation user at the production site A to view and execute the retrieved model of the production site B with a Java-enabled Web browser. After linking-up the models of the production sites A and B, the simulation user A can create a simulation plan according to the necessary production capacities for the achievement of the customers demands. The suggested approach provides the possibility of remote simulation as a prerequisite for collaborative manufacturing in virtual enterprises and has shown to be able to solve issues relating to co-operative manufacturing.

The global availability of simulation models of the distributed production sites is very useful for all partners of a virtual enterprise. On the one hand, in the case of stoppages in a production site the shift of production orders to another production site will be supported, on the other hand additional external production capacities can be integrated in the case of a planned extension of ressources. Due to the exchange of simulation models within the production network via the Internet using FTP this approach reveals a high potential for rapid decision making and enables the communication between planning teams separated by large distances. At present, the prototype environment will be implemented at the Institute for Manufacturing Automation and Production Systems with the simulation tool Simple++.

6.2 Example 2: Process Control and Monitoring

In the application areas of process control, process monitoring and diagnostic, the access to relevant process data is critical. However, the interoperability of devices from different vendors results in vendor-specific components for HMI-tasks (Human Machine Interface), and thus offering limited interoperability and integration in e.g. diagnostic or simulation tools. The solution proposed in (Feldmann, 1997c) is based on Java-based HMI-components stored directly in the device. Once uploaded to a standard Web Browser the component establishes a virtual communication link to its device and allows the executing of various functions, according to the components build-in functionality. According to Figure 6, the communication is performed in two steps: a standard OPC server, independable of a special fieldbus system is used to read/write process variables. A gateway is then used as a CORBA wrapper to the OPC server (OLE for Process Control), thus interfacing to the TCP/IP network which links the higher level of the manufacturing hierarchy. The protocol between the gateway and an Internet-client is then based on CORBA.

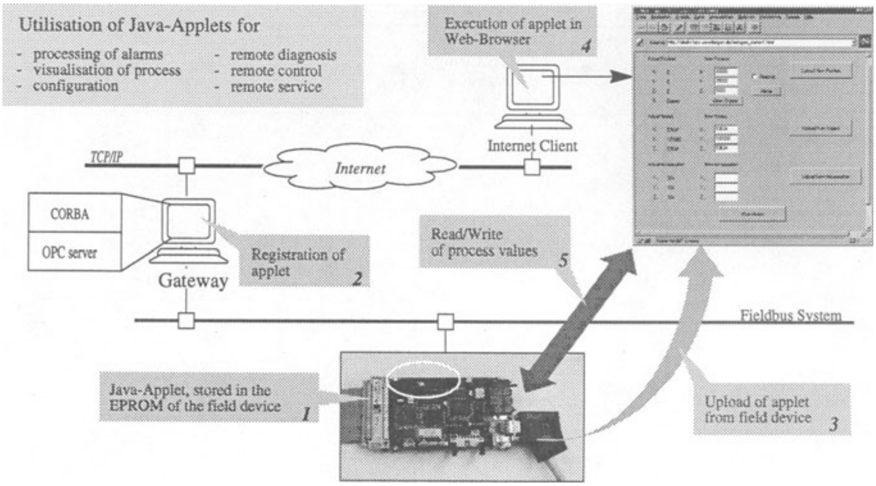

Figure 6: *Access to process data utilising a CORBA-based approach.*

7 SUPPORT FOR DISTRIBUTED COORDINATED WORKFLOWS

The model proposed for the distributed coordination of an virtual enterprise is primarily based on the work of (Schuster, 1997). According to his thesis, coordination and cooperation of the applications within a virtual enterprise is achieved by two means. Firstly, a global workflow, which is made up of subworkflows and which defines the partition of the tasks when setting up the virtual enterprise. Secondly, the subworkflows, which are parts of the internal workflows of the partners. The proposed framework architecture is supposed to provide a basic workflow coordination component, which is integrated in the middleware CORBA as an additional service. The workflow components' task is to offer services to structure and coordinate the control flow of the overall cooperation. In addition services for dynamically (re-)configuring the overall workflow have to be provided. The subworkflows are executed locally and are synchronised through the global workflow. In addition, each partner has access to the state of the overall workflow (see Figure 7).

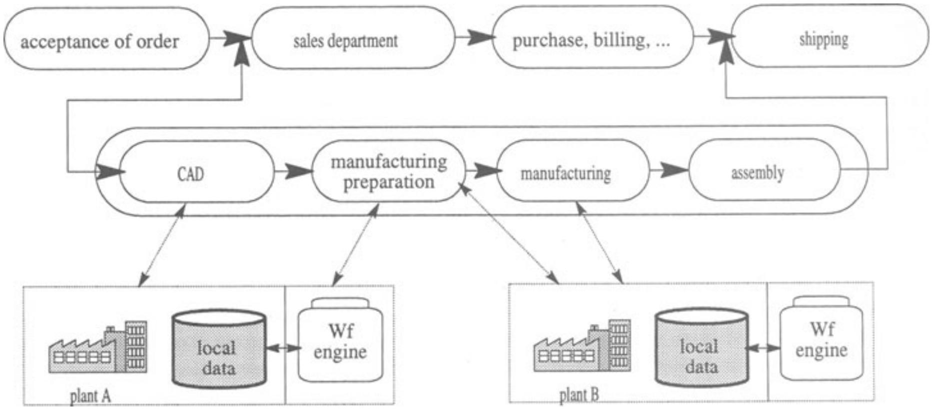

Figure 7: *Distribution of subworkflows.*

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N.N.: ISO 10303-26 *Industrial automation systems and integration - Product Data Representation and Exchange - Part 26: Implementation methods: Standard data access interface - IDL language binding*

9 BIOGRAPHY

Professor Feldmann, born in 1943, graduated Dipl.-Ing. and Dr.-Ing. in productional engineering from the Technical University of Berlin. From 1975 to 1982 Professor Feldmann has had different leading functions at Siemens AG in the field of manufacturing automation and assembly. Since 1982, Professor Feldmann has been a professor in manufacturing automation and production systems and member of the board of the Manufacturing Institute at the University of Erlangen-Nuremberg. Professor Feldmann is a member of the International Institute for Production Engineering Research (CIRP), of the Scientific Society of Production Technology (WGP) and of the Society of German Engineers (VDI).

Harald Rottbauer, born in 1966, completed his master degree in mechanical engineering at the Technical University of Munich in 1992. After participating on a one-year internship-program of the Siemens AG in the US, Mr. Rottbauer completed his studies in business administration at the Technical University of Munich in 1996. Since then he is a colleague of Prof. Feldmann at the Institute for Manufacturing Automation and Production Systems. His research interests are in the fields of global manufacturing and he specialises in electronic production management and simulation-based costing. In this context he is busy within a related national working group of the Society of German Engineers (VDI).

Born in 1971, Thomas Stöckel completed his master degree in Computer Science with first class honours at the University of Erlangen-Nuremberg in 1996. Since then he is a colleague of Prof. Feldmann at the Institute for Manufacturing Automation and Production Systems. He specialises in time-critical communication systems and new control strategies, e.g. Java-applications for remote control, within the CIM (Computer Integrated Manufacturing) environment and is busy within related national standardisation groups (DKE UK 951.3 "Fieldbus"). Also, he is working on a standardised communication model within CIM based on the Common Object Request Broker Architecture (CORBA).