OBJECTIVES OF INTEGRATED DIGITAL PRODUCTION ENGINEERING IN THE AUTOMOTIVE INDUSTRY

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Abstract: To appropriately meet the constantly rising market demands, the innovation topic "digital factory" has taken on key significance in the automotive industry. By means of a new integration concept – integrated production engineering – the three fields mechanics, electrics, and logic are more closely intermeshed using a so-called virtual resource model. In this context, two major challenges have to be mastered: the organizational and the functional integration. The prototypical realization of this integration concept is carried out on the basis of a practical scenario from the commercial vehicle development.

Keywords: Automobile industry, control engineering, industrial production systems, integration, data models, planning, programmable logic controllers, validation

1. INTRODUCTION

Global competition in the automotive industry has led to a considerable increase in the number of vehicle variants. Thus the product creation process from design over production engineering up to production has become a key factor for both economically successful vehicle manufacturing and the fast and flexible adaptation to changing customer demands and dynamic markets. The innovation topic digital factory is geared to support this process through integrated digital production engineering, validation, and start-up and operation of the production facilities (Schiller, 2003). Production engineering, consisting of digital planning and control engineering, is a key component of this new trend. In fact, the goal and result of integrated digital production engineering is the digital factory. Not only the individual processes but also the information streams (from development to the factory information systems) have to be taken into account. Further, the initial situation and the future developments regarding a complete digital integration, organizational and functional will be covered in greater detail.

1.1 Digital Production Engineering

Production engineering projects are typically multidisciplinary, inter-organizational projects. The current situation in digital production engineering is characterized by a large number of different IT tools, both PC based and main frame applications. This leads to the occurrence of redundant data stocks and a lack of standardized processes prescribing the way specific engineering tasks are to be carried out.

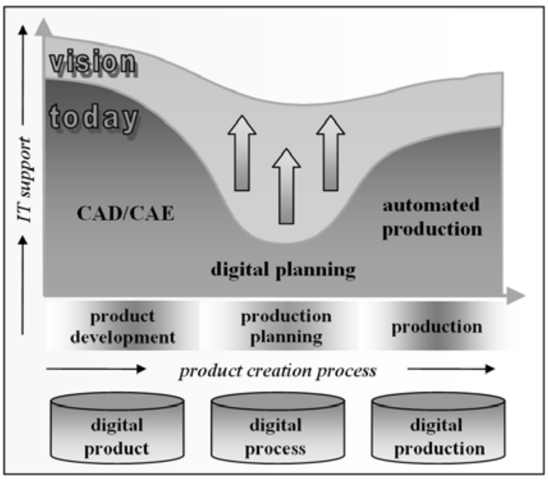

Figure 1: IT support within the product creation process

Due to the historical development, the usage of computer-aided technologies is much higher and has achieved a greater degree of maturity in both product development and production processes than in production engineering (cf. Figure 1). Hence, production engineering is limping behind as regards the introduction of uniform IT tools, standardized processes, and common data management methods. Here the concepts of integrated digital production engineering will allow substantial improvements.

1.2 Organizational and functional integration

Four core phases can be differentiated in production engineering: concept planning, rough planning, detailed planning, and start-up of production (cf. Figure 2). The task distribution usually takes place between the OEM (original equipment manufacturer), the main contractor for the complete system, and, if need be, further engineering service providers. The exact distribution may vary from project to project. Generally speaking, the main task is to link product, process, and resource data with each other by defining which component (product) is to be manufactured using which production steps (process) on which manufacturing equipment (resource). The first phase, concept planning, aims at developing a rough system concept on the basis of the results of the product development phase (e.g. geometrical product description, parts list, engineering bill of materials) and the requirements of the sales department (e.g. quantities, product mix). This is normally the basis for an invitation to tender. In rough planning, generally done by the main contractor, a more detailed system concept considering the production equipment to be deployed is developed. In detailed planning, the specifics of each individual workstation must be worked out, including all the geometrical conditions (e.g. collision analyses, accessibility), capacity planning, time balancing, ergonomic analyses, sequences of operations, and off-line programming for automated components. With this detailed planning, a digital concept validation of the future system takes place by simulation (Strassburger, 2003). Afterwards the OEM grants approval for the subsequent realization by the main contractor and the following start-up phase for the overall system. Looking at solely the IT systems deployed in production, i.e. primarily factory information systems and controls, we can state that, for the design of these systems, we need more than just the mechanical information (e.g. geometry, kinetics): further information about electrical connections (e.g. wiring, circuit diagrams, input/output) and the logic of the system (operational sequences, statuses, and switching conditions) is necessary. Currently, the tools of digital planning cover exclusively the mechanics. Yet for an integrated production engineering, it is practical and necessary that the three system views mechanics, electrics, and logic are regarded, developed, and evaluated in a holistic manner.

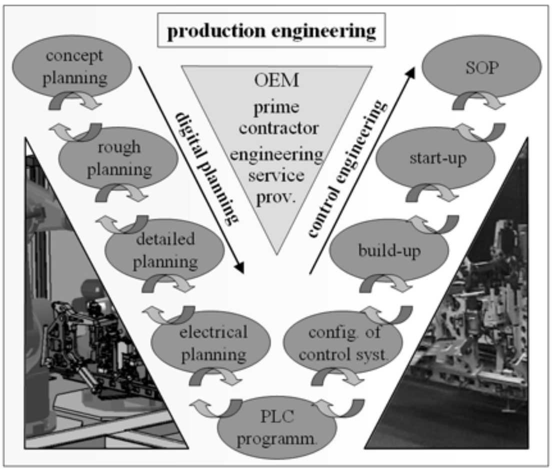

Figure 2: Key aspects of production engineering

As set out above, we are presently confronted by two major challenges in integrated digital production engineering: 1) the organizational integration and 2) the functional integration. The organizational integration requires the solution of the problem of heterogeneous IT structures in inter-organizational production engineering projects. A key component for this is the creation of a common terminology and semantics. They are the foundation for interpersonal communication, understandable man-machine interfaces, and IT-supported information transfer. Fundamental ideas for this are documented in chapter 2.1 of this article. Similarly, the functional integration is based on an integrated data management, as far as engineering and/or modeling tasks are concerned. In contrast, the validation phase during start-up is based on the on-line coupling of the factory information and control systems with the digital mechanical model of the relevant resource. Details of this are set out in chapter 2.2.

2. DEVELOPMENT OF AN INTEGRATED ENGINEERING ENVIRONMENT

The problem of heterogeneous IT structures in geographically distributed applications can generally be solved in two ways. One alternative is the deployment of a single large, usually commercial system with sufficient functionality which covers all the relevant aspects. For the area of digital production engineering in the automotive industry there are currently two major software providers for such solutions: Tecnomatix (Tecnomatix, 2004) and DELMIA (DELMIA, 2004). The alternative is to use an integration layer that connects all geographically distributed, heterogeneous IT systems so that they can communicate with one another. It is, however, difficult to force all the enterprises taking part in the production engineering process to utilize one uniform IT system environment and is not desirable under consideration of economical aspects in the mid-term. For this reason, the following focuses on the integration of relatively autonomous IT applications.

2.1 Inter-organizational and cross-functional data management

Before the production engineering process starts, one key prerequisite must be ensured: all the partners in the undertaking must employed a common terminology and semantics. This is significant for the information exchange on the interpersonal level as well as for the computer communication itself (Berner-Lee, 2001). For example: partners of different areas of expertise use their own vocabularies to describe real world objects. These different views finally result in various data models which are not compatible. Actual, this is the main reason for the lack of interoperability in the digital world.

Figure 3 depicts the rough sequence for the semantic harmonization. The prerequisite above is met by each partner providing a glossary of the terms used in all the technical disciplines enriched with definitions and made accessible for all partners. This documentation forms the basis for the technical communication during the harmonization process. The single steps in Figure 3 are designated A to E. During step A, each partner creates a component ontology from the data schema of its IT systems, using an ontology editor such as KAON, FZI Karlsruhe, for example. This ontology is the explicit machine-processable representation of the relevant semantics. Step B merges these isolated component ontologies to an initial global ontology. Afterwards the global ontology is cleared of semantic conflicts (e.g. homonyms, synonyms), with standardization of the structure and the terms of the global ontology taking place in step C. This result can serve as input for standardization committees or as a template for the modeling of initial data schemas (e.g. for organizations wanting to start with digital production engineering for the first time or wishing to join a running project). In step D those portions (and/or branches) which are required for the implementation of a specific project, e.g. body-in-white production engineering of the Mercedes light truck ATEGO, are selected from the standardized global ontology. We assume that there is a need for information exchange in every production engineering project, and that this cannot be fully considered in advance through the standardization process. Therefore Figure 3 fictitiously shows that a share of approx. 80 % corresponds to the standardized ontology, while the balance of about 20 % is not standardized and the data are added separately.

This 20 % of the data may even contribute to a further iteration of the harmonization process for the next version of the global ontology. If required, in the last step E, relevant data schemas can be derived from the project-specific ontology for the IT systems involved and/or appropriate interfacing modules such as wrappers.

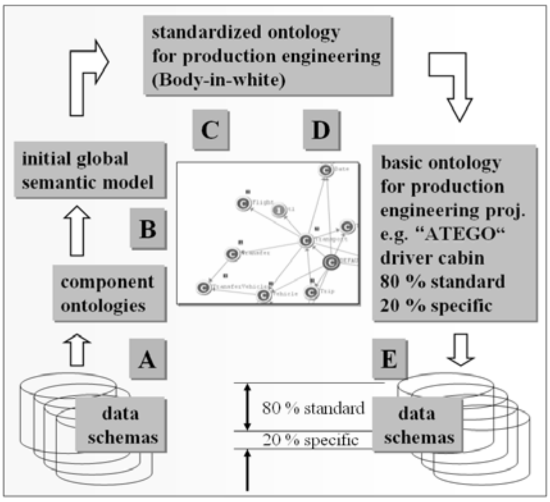

Figure 3: Semantic integration process

The basic ontology developed during the semantic harmonization process for digital planning is a linchpin for the data exchange between the project partners involved in joint production engineering projects. The requests of individual partners for specific data elements and the data transfer are enabled by a so-called reference model, which contains the basic ontology as a core component (cf. Figure 4). In addition, the reference model provides the overall infrastructure and functionality necessary for user interactions, e.g. retrieval queries, or for the data exchange and the general ontology management (further details: Assmann, 2005).

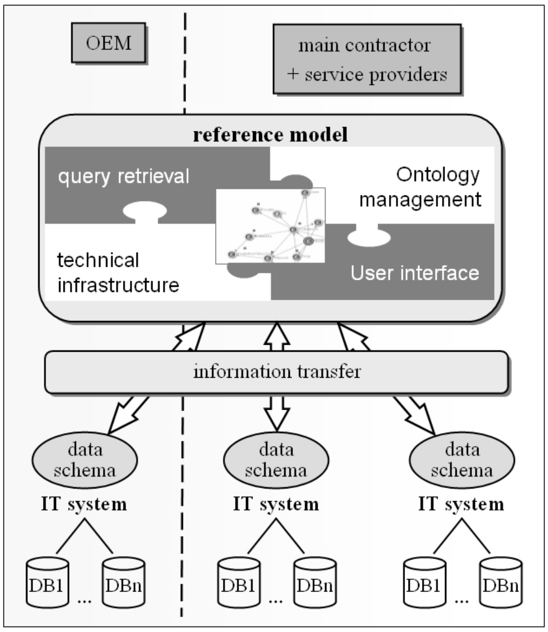

Figure 4: Reference model for inter-organizational information transfer

2.2 Multidisciplinary collaboration - Integration of digital planning and control engineering

As stated in chapter 1.2, a variety of departments (both engineering and organizational) are invariably involved during a production engineering process. As a rule, the mechanical concept planning is accomplished by the OEM itself. Performance of all other tasks concerning the production engineering process, e.g. the electrical planning or the PLC programming, is typically awarded to external suppliers.

Today all the partners involved in a production engineering project carry out their special working tasks independent of each other to the greatest possible extent. Moreover, both the data generated in the various organizational units and the processes and methods employed are typically not at all compatible in most cases. Inevitably, this unsatisfactory situation leads to data leakage during the exchange of planning data between the different project partners. Therefore, the actual data exchange often occurs in a file-based way, by means of some diagrams and pictures or even using some pieces of paper. To sum up, today, an integrated digital production engineering process between the OEM, the prime contractor, and the various service providers who are involved in the planning project does not exist.

With the implementation of integrated digital production engineering, the mechanical, electrical, and the control engineers could work simultaneously and networked, using up-to-date, complete, and consistent data sets. Thanks to the integrated collaboration between the different departments, positive synergy effects could be extracted. Additionally, both the real start-up of the line and real start of production will be accelerated dramatically.

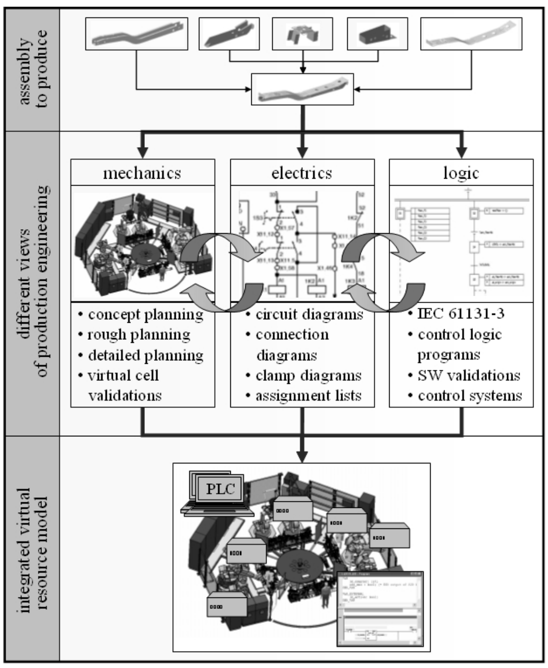

Figure 5: Integrated digital production engineering

To accomplish an inter-organizational and cross-functional integrated digital production engineering, all the work contents of the three topics mechanics, electrics, and logic have to become more closely integrated. Figure 5 portrays the target integration of the different views of production engineering in the form of a so-called virtual resource model.

This virtual resource model encompasses all the information about the mechanical and the automation components of a manufacturing cell. Based on process sequence descriptions (Pert/Gantt chart), rough PLC programs could be generated from the virtual resource model off line. In subsequent steps, the control engineers expand the rough PLC programs in their working systems. Finally, they develop detailed and compiled PLC programs. Based on these compiled control programs, the project managers responsible for the control technology could tailor their control systems to the demands of the OEM. This integrated production engineering concept yields manifold benefits:

- Enabled simultaneous and networked cooperation between mechanical and automation engineers.
- Non-redundant data management.
- Continuous availability of up-to-date, consistent data sets.

More information concerning this cross-functional integration concept and the resultant benefits can be taken from (Diedrich, 2005).

Many automotive manufacturers and prime contractors have recognized the outstanding significance and the great use potentials of this integrated digital production engineering concept. This becomes evident when we consider the current trend: at the Hanover fair 2004 and during the Digital Factory congress (Ludwigsburg), the OEM DaimlerChrysler (Bär, 2004), the software vendor DELMIA (Menges, 2004), the automotive suppliers Siemens Automotive (Horn, 2004) and KUKA Schweißanlagen (Fedrowitz, 2004), and the control system developer PSI (Adams, 2004) introduced initial integration concepts.

2.3 PLC software validation

At present, employing CAD and CAP applications allows product, manufacturing, and resource validations to be effected in upstream stages of engineering and production planning. For example, process planners can now utilize the software tools of the digital factory to designate the optimal positions for the welding robots so that they can execute their tasks as quickly as possible without any collisions.

Not only does this integration approach of digital planning and control engineering enable digitized optimizations of product, process, and layout. This targeted linking of the virtual resource model and the respective PLC programs will enable the logic control to be validated against the virtual resource model long before the production line is laid out. This virtual start-up enables faults in the logic of real

PLC programs to be detected and eliminated at a very early stage. Based on this, the PLC programs can be optimized with respect to an improved behavior of the manufacturing cell without the necessity of its being physically available. Another benefit of a virtual start-up is that operators can be trained at the real control panel on the basis of the virtual resource model, allowing them to become familiar with the behavior, the functions, and the operation of the manufacturing cell beforehand, i.e. without its real existence in the line. Usage of such a training panel substantially cuts training time while ensuring operator performance.

With this integration approach the various functionalities of a control system coupled with the real PLC can be checked using the virtual resource model, thereby implementing a virtual start-up of the real control system. Figure 6 shows the interaction between the virtual resource model, the real PLC(s), the training panel, and the control system for the implementation of a virtual start-up.

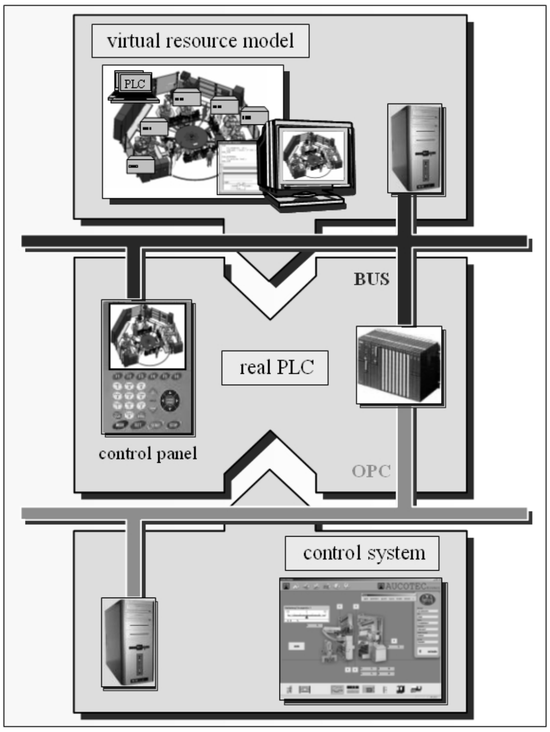

Figure 6: Concept for the implementation of a virtual start-up

Relocating the test and start-up processes from the factory to the control engineer's PC speeds up the planning and engineering process. Furthermore, the complete process of a real start-up is considerably accelerated and, with it, the real start of production. Finally all these benefits are reflected in higher degrees of maturity at the start of production, resulting in fewer problems and faster ramp-ups.

2.4 Practical scenario

The practical scenario used exemplarily for the prototypical implementation of the integrated digital planning approach in the BMBF project MODALE and especially for the virtual start-up is a manufacturing cell taken from the commercial vehicle division (Modale, 2004). Figure 7 depicts this manufacturing cell as a virtual 3D cell model. In this practical scenario, the various planning steps for creating a virtual resource model and the subsequent virtual start-up are defined in the form of three different use cases. These use cases are fundamental components of the production engineering process (cf. Figure 2). In this context, the inter-organizational aspect is considered.

- As a main focus of Use Case No. 1, the most important planning steps for a cell reengineering together with their constraints are specified. Before executing the actual planning steps comprising the concept, rough, and detailed planning, it is essential to first achieve a uniform understanding between all the engineering partners in the form of a semantic harmonization of the particular component ontologies. Starting from these various component ontologies, both a standardized and a global ontology are developed in later steps (cf. chapter 2.1). The global ontology forms the foundation for the necessary data exchange processes in the further course of the planning. Once the homogenization process of the terminology has been completed, the actual cell reengineering can be started. As the OEM typically carries out the mechanical concept planning itself, the prime contractor and other engineering service providers usually handle the work contents of the rough and the detailed planning.

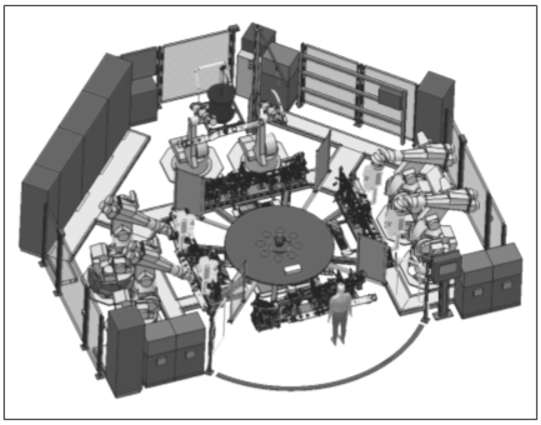

Figure 7: Manufacturing cell for the practical scenario

- Since the seamless digital planning process up to the IT systems deployed in production are considered in MODALE, the main focus of Use Case No. 2 is the line start-up. Within this use case, the real PLC is developed, configured, and then checked for potential faults using the virtual resource model and, if need be, the cell behavior improved. In this context both the engineering process and its integration in the overall production engineering process are taken into account. Yet, the online interlinking of the real PLC (in MODALE, usage of a soft PLC) and the virtual resource model are also core elements of Use Case No. 2.

- Use Case No. 3 deals with the issue of innovative services. In this context, innovative services are services that can be realized by means of the virtual resource model, i.e. without availability of the physical manufacturing cell. Hence different diagnostic cases are considered: for instance, alerts due to a failure or even maintenance work after a default number of maximal operating cycles (e.g. weld guns, clamping devices). One part of this use case targets the diagnostic configuration and its integration into the production engineering process. Furthermore, a diagnostic simulation in the form of an online linking between control system, PLC, and virtual resource model (cf. Figure 6) is implemented exemplarily in the Innovative Services Use Case.

3. SUMMARY AND OUTLOOK

The digital factory is the goal and the result of the integrated digital production engineering process. The enabling technology is an integrated engineering environment for the overall product creation process from the initial design studies to the virtual validation of the start-up of production based on an integrated virtual resource model. Two questions remain: What are the next steps from here and what must be taken into account for the future? Another key process chain for an OEM is the customer ordering process. The point of intersection of these two core processes is production: in other words, the real factory.

Figure 8: Seamless digital process chain from the digital product to the real factory (Bär, 2004)

In fragmented markets with dynamic changes, the relationship and interdependencies between the product creation process and the customer ordering process are very close. From the digital perspective, the IT systems and methods deployed in both process chains must be integrated more effectively in the near future. These efforts are summarized under the notion of the digital enterprise. The most important future role of the digital factory in this scenario is to integrate the digital product as a result of the digital product development and the real factory developed as a result of the digital production engineering process (cf. Figure 8). Together, this will generate a closed loop between the real and digital worlds in automotive production with significant contributions toward higher quality, lower costs, and faster cycle times.

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