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DIGITAL FACTORY – SIMULATION ENHANCING THE PRODUCT AND PRODUCTION ENGINEERING PROCESS

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ABSTRACT

The digital factory concept offers an integrated approach to enhance the product and production engineering processes and simulation is a key technology within this concept. Different types of simulation, such as discrete event or 3D-motion simulation can be applied in virtual models on various planning levels and stages to improve the product and process planning on all levels. The focus and key factor is the integration of the various planning and simulation processes. In an advanced stage simulation technology can be applied in the digital factory concept to enhance the operative production planning and control as an integrated process from the top level to the factory floor control.

1 VISION

The vision of the digital factory concept focuses on the integration of methods and tools available on different levels for planning and testing the product and the related production and operative control of the factory. (VDI 4499) and integrates the following processes:

- Product development, test and optimization.
- Production process development and optimization.
- Plant design and improvement.
- Operative production planning and control.

The digital factory concept can be also seen as an enterprise and information strategy managing and collaborating processes of factories in global networks, as illustrated in Fig. 1. It offers methods and software solutions for product and portfolio planning, digital product development, digital manufacturing, sales and support that deliver faster time-to-value, as shown in Fig. 2. Collaborative solutions support people and processes involved in each major phase of the product and production phase (Constantinescu et al. 2006). Therefore the digital factory concept, Fig.3, integrates databases for product, process and factory modelling and advanced visualisation, simulation and documentation in order to improve the quality and dynamic of the product and production processes involved.

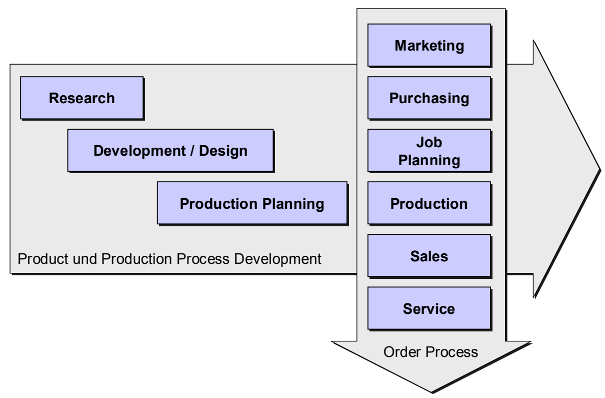

Figure 1: Digital Factory Processes

2 PRODUCT ENGINEERING

In the digital factory concept the engineering process has to gain competitive advantage through optimized performance. Innovative engineering allows collaborating teams to streamline the engineering of the product and of the production process engineering. The digital factory concept enables:

- Integration of CAD designs and CAE information.
- Synchronization of the engineering processes that require the participation of the entire value chain accessing all product information needed.
- All product-related teams to work together effectively without regard to physical location.
- Acceleration of product delivery; design teams to seamlessly collaborate with manufacturing teams.
- Establishment of reusable product configurations across an entire product lifecycle and multiple products.

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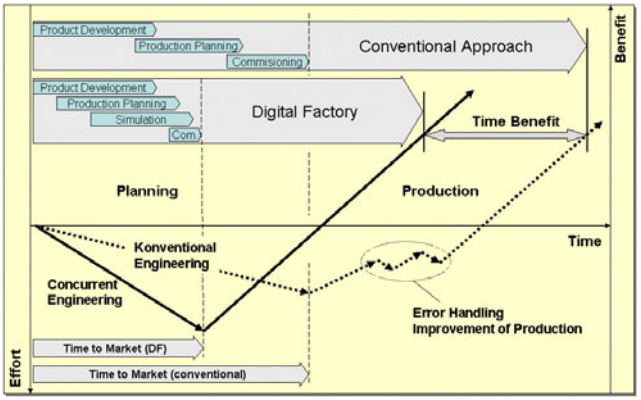

Figure 2: Digital Factory - Benefit and Effort

The digital factory requires a full engineering process management for multi-site product teams using a variety of CAD authoring applications and to manage a product structure with all product information, not just CAD files (Fig. 3). All of the relevant CAD, CAM, and CAE information have to be managed, as well as design specifications, documents, requirements, and other types of product related information:

- CAD Integration connecting multiple, dissimilar CAD systems, including CATIA, Pro/Engineering SolidWorks, Unigraphics NX Series, Solid Edge, AutoCAD etc..
- Visual product collaboration for integrated visualization capabilities and workflow management improve communications among team members.
- Multi-site collaboration to participate in design, automated engineering and manufacturing processes.

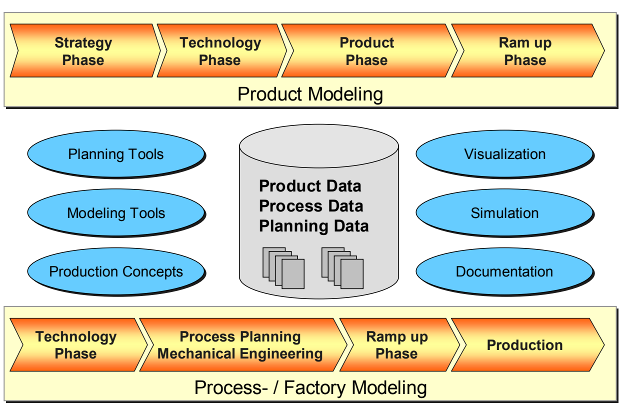

Figure 3: Digital Factory Concept

Process management capabilities enable to define engineering workflows that enforce company specific business rules and efficiently execute automated product-related processes (Bley et al. 2005). The benefits of an advanced engineering process management are:

- Increase product innovation and flexibility.
- Increase design and manufacturing concurrency.
- Catch costly design mistakes up front in the product lifecycle.
- Enable team members to securely access all related information.
- Improve communication among OEMs, suppliers, and allied partners.
- Synchronizes activities of globally dispersed teams.
- Integrate current CAD, CAM, and CAE technology into new integrated processes.

In the digital factory environment many software solutions based on CA-technologies are available for the product related processes. In the field of plant design and optimization the integration is not really state of the art. Especially for operative planning and control the market is relatively new and open integration tools have to be developed to connect the planning levels directly with the factory floor.

2.1 Product Lifecycle Management

Product lifecycle management (PLM) is an integrated, information driven approach to all aspects of a product from its design inception through its manufacture, deployment and maintenance, culminating in its removal from service and final disposal. The PLM approach requires at once an information strategy, an enterprise strategy and ultimately a transformational business strategy. It can be seen as a comprehensive approach to innovation built on enterprise wide access to a common repository of product information and processes.

PLM represents a transformational business strategy for global manufacturers - a strategy built on common access to a single repository of all knowledge, data and processes related to the product.

PLM builds a coherent data structure that enables real-time, virtual collaboration and global data sharing. It lets companies consolidate systems while leveraging existing investments. Through open APIs and adherence to standards, it minimizes data translation issues while providing information to make effective decisions at every stage of the product and production.

3 PLANT DESIGN AND OPTIMIZATION

Plant design and optimization focuses on the optimization of material flow, resource utilization and logistics for all levels of plant planning from global production networks, through local plants down to specific lines with the objectives:

- Shorten new product introduction, time-to-market, and time-to-volume.
- Improve production layout and minimize investments.
- Machines and equipment are in the right place.
- Sufficient material handling equipment available.
- Optimized buffer dimensions.
- Product handling is kept to a minimum.

Modeling and simulation techniques enable dynamic analysis to ensure that plant design problems and waste are discovered before the company ramps up for production. Further simulation technology ensures in advance of the start of production, that the factory hits the demands for efficient operations.

3.1 Resource Data Base

A resource data base provides a library to manage a wide range of manufacturing resource data. This includes machine resources, machine tools, cutting tools and gages, robots, welding guns and manufacturing process templates. Parametric search query technology allows to retrieve the data from a comprehensive structure.

3.2 Factory Design and Layout

There are CAD tools factory layout planning available that provide predefined modules for creating detailed, factory models. These layout tools allow to work with predefined objects that represent virtually the resources used in a factory, from floor and overhead conveyors, mezzanines and cranes to material handling containers and operators. With these predefined objects a layout model can be implemented in 3D quickly and efficiently without drawing the equipment in details (Fig. 4).

Virtual reality factory models enable to move through factory mock-ups, walk through, inspect, and animate motion in a rendered 3D-factory model. This design and communication technology also provides design collaboration activities in order to view, measure, analysis, and inspect for clearance in a 3D-virtual factory model.

3.3 Optimizing the Factory Flow

Factory layouts can be analyzed in a first step by using part routing information, material storage requirements, material handling equipment specifications, and part packaging information. The shortest distance between any two points the closest incoming dock and storage area to a part's point of use have to be identified.

Material flow studies have to be performed on alternate layout configurations and layout options compared in order to find the best layout und to improve production efficiency.

Enhancing the factory layout based on material flow distances, frequency and cost is a first step towards more efficient factory layouts, which directly result in reduced material handling and improved production outputs.

Figure 4: 3D-Factory Layout Using Predefined Objects (UGS)

3.4 Plant, Line and Process Simulation

Plant, line and process simulation can be performed by use of discrete event simulation tools. These tools allow analyzing systems and processes in order to optimize material flow, resource utilization and logistics for all levels of plant planning (Kapp et al. 2005). This includes planning of global production facilities, through local plants, to specific lines. Discrete event simulation technology allows to:

- Minimize the investment cost for production lines while meeting the required production demands.
- Detect and eliminate problems that otherwise would require cost- and time-consuming correction measures during production ramp-up.
- Improve the performance of existing production systems by implementing measures that have been verified in a simulation environment prior to implementation.

Simulation models enable to run experiments and what-if scenarios without disturbing an existing production system. Also it is possible to explore system characteristics and optimize performance of planed systems long before the real system is installed.

3.5 Dynamic Line Balancing

Line balancing and machining planning requires to calculate operating cycle times and to generate a respective NC tool path. Discrete event simulation models provide a dynamic perspective of the balanced production line. It allows to analyze throughput, work-in-process, resource utilization and buffer sizes in order to improve the line balancing.

3.6 Part Manufacturing

Part manufacturing applications link the tasks of the manufacturing engineer, NC programmer, tool designer and tooling manager, while extending access to the shop floor. It features the ability to create operations in both a hierarchical structure and a process sequence using graphical editing and displays.

The 3D-simulation of the NC path, shown in Fig. 5, enables to detect collisions, analyze material removal and optimize cycle times. Further specific detailed process information can be delivered to the shop floor, and an NC tool path can be created taking into account cycle times for each set of features and operations.

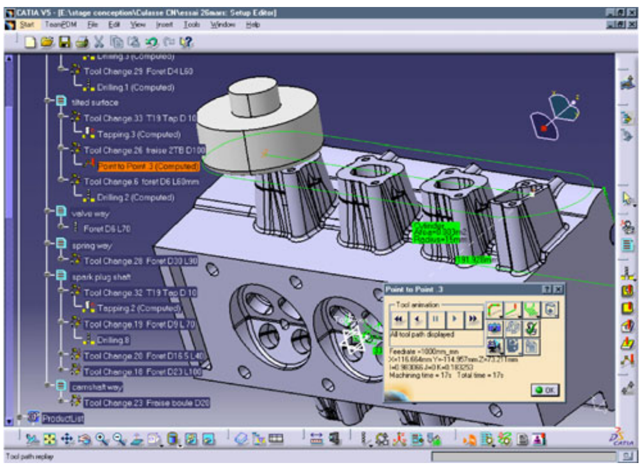

Figure 5: 3D-Technology for Integrated NC Planning, Simulation, and Offline Programming (Delmia)

3.7 Simulation of Robotic Workcells

Digital manufacturing and simulation of robotic workcells focuses on the design, simulation, optimization, analysis and offline programming of robotic workcells and automated manufacturing processes in the context of product and production resource information. This requires a concurrent engineering platform to model the mock-ups of manufacturing cells on 3D graphics to optimize processes and calculate cycle times.

Motion simulation and synchronization of several robots and mechanisms including 3D path definition is required to perform reachability checks, collisions detection and optimization of cycle time for. Typical features are:

- Workcell layout design and modelling from 3D-CAD-Data.
- Robots, machines, tools, equipment libraries.
- Modelling of complex kinematics of robots and other mechanisms.
- Robot calibration for improving accuracy.
- Automatic path planning.
- Collision detection.
- Sequence of operations (SOP).
- Offline programming (OLP).

Models, which shall be used for offline programming, have to implement the physical and control characteristics of robots and other automated devices. Robot offline programming requires accurate simulations of robot motion sequences in order to download machine programs to the real controller on the shop floor (Eberst et al. 2004). Controller specific information, including motion and process attributes have to be added to the generated robot paths.

A typical application in the robotic field addresses the entire spot-welding design and programming process (see Fig. 6). Designing a spot-welding cell layout by accessing CAD models directly, optimizing robot placement and path and selecting the best welding gun are required features. Critical factors such as space constriction, geometric limitations and welding cycle times have to be taken into account. Features in this kind of application are gun search, automatic robot placement, path cycle-time optimizers, and weld point management tools. These enable to create virtual cells, simulations, and programs that accurately reflect the physical cell and robot behaviour. Finally robot programs and the sequence of operations can be generated for the application, verified and the PLC programs can be created automatically.

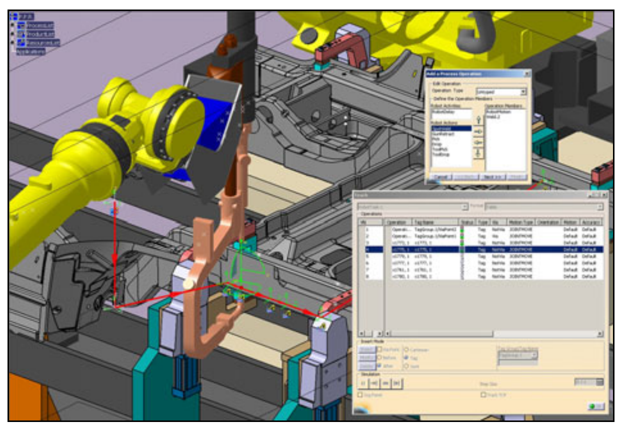

Figure 6: Robot Motion Planning, Simulation, and Offline Programming for a Spot Welding Process (Delmia)

3.8 Model Based PLC Offline Programming

With time and cost pressure on introducing new products and production changes, the PLC programming shall not be handled as an isolated, independent function on the shop floor level. The PLC program generation integration in a 3D-integrated virtual environment, Fig. 7, allows working in parallel and sharing information from both mechanical design and control departments.

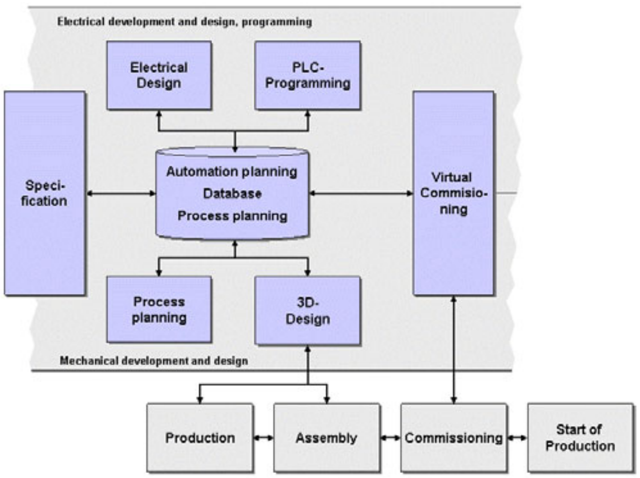

Figure 7: Integrated Engineering in the Digital Factory Includes Mechanical and Electrical Related Processes

This enables an automatic generation of PLC programs directly from the virtual manufacturing model and allows for virtual commissioning prior to building the equipment on the shop floor with benefits, such as:

- Visualize and optimize functionality and behaviour early in the production engineering phase.
- Increase the speed, consistency and reliability of design processes.
- Prove of feasibility of the control logic.
- Correcting logic errors well before ramp-up.
- Cut time and cost by creating shop-floor documentation off line.
- Evaluate PLC program changes on a virtual model instead of taking risks on real equipment.

The integration of model based automatic offline programming including simulation and verification by use of a virtual manufacturing model using real automation data can optimize the engineering process and help to cut ramp-up times significantly (Schloegl 2006).

3.9 Human Resource Simulation

An accurate modelling, simulation and analysis of manual assembly designs, manual workplaces and human operations with detailed 3D virtual human models, Fig. 8, can optimize execution times and prevent work-related health problems. Human resource simulation focuses on:

- Detailed design of manual operations.
- Checking the feasibility of tasks.
- Ergonomic analysis.
- Time analysis.
- Generating work instructions.

Figure 8: Visualisation and Simulation of a Wing Assembly Workplace (Delmia)

Human resource simulation improves workplace ergonomics, optimized assembly cycle times, improve communication of planning results, increase productivity of production facilities, generate a comprehensive documentation of human operations and reuse of best-practices. The evaluation and effective design of manual workplaces can help to raise the motivation of workers on the shop floor and therefore increase profitability.

4 MULTICRITERIA DECISION MAKING

The optimization of flexible production systems is in many cases a very complex tasks, which can be classified in the areas:

- Parameter optimization
- Optimization of control strategies
- Layout optimization

In order to improve factory and system layouts, parameter settings and control strategies it is required to run a multicriteria decision making processes. Optimization in this sense does not assume, that a global optimum exists which has to be reached, but that a system configuration is searched, which provides very good or at least reasonable sub-optimal results. The parameter optimization is related to production parameters, such as number of AGV’s or number of workpiece carriers in a transfer system. In most cases the Realization of parameter changes is possible with a relatively small effort even during operating the production.

The optimization of control strategies shall improve the distribution of orders (mapping) and the time related coordination (scheduling). It can be varied the service strategy or particular priorities, and decisions, which order to be produced on which machine. A change of control strategies needs more effort and requires mostly software changes of the control software during the ramp up or operational period.

The layout optimization deals with the positioning of various production equipments. However in most cases the solution space is already limited through existing resources and boundary conditions. Big changes of the layout structure need a high effort and are often only considerable in case of planning new systems or complete reorganisation of existing production areas.

In the integrated optimization concept shown in Fig. 9, all these levels are interconnected and changes on one level have nearly always an impact on the connected levels. If an optimization is performed on one level only, this is much faster. However it may lead not to a sufficient solution.

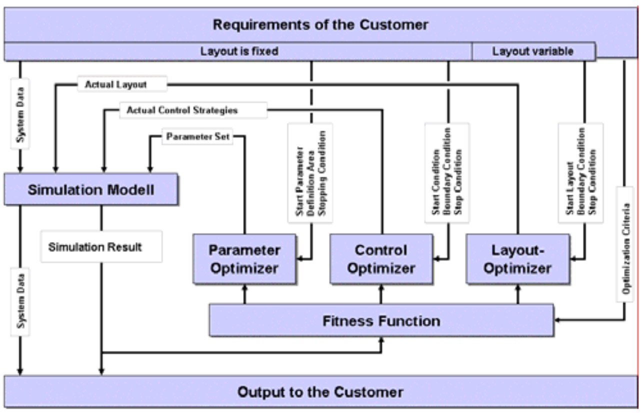

Figure 9: Optimization of Parameter Settings, Control Strategies, and Layout Variants by Use of Simulation Models

5 OPERATIVE CONTROL AND OPTIMIZATION

The digital factory approach using simulation for operative production planning and control extends the one for plant design and optimization. The following objectives shall be reached:

- Improve collaboration between production planning and execution.
- Improve process control and variance reduction capability.
- Adjust schedules and production processes in real.
- Deliver customer orders accurately with good quality on time.
- Improve quality and reduce cost of errors.
- Reduce inventory, work in progress and scrap costs.
- Improve visibility of the production processes to supply chain planning.

This simulation based approach requires a steady feedback loop for operative controls and optimization of production processes from the factory floor (Fig. 10). This is needed to update general data, model structure and model parameter with the actual situation from the factory. In order to deliver accurate results a model has always to be started with the actual WIP (work in process) and actual status of the resources.

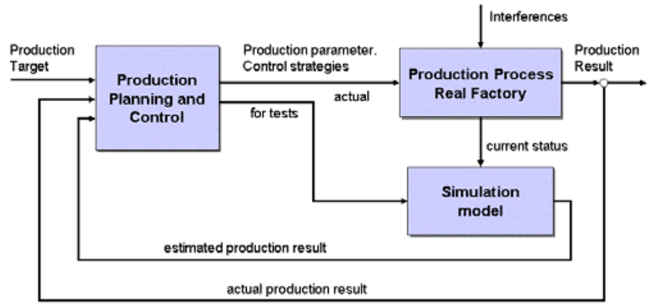

Figure 10: Simulation Integrated Feedback Loop

5.1 Production Management

A production management solution requires a complete and scalable shop floor environment that enables manufacturing organizations to improve agility, capture operational knowledge and to increase efficiency. The integration has to connect the process planning level with the control level from manufacturing execution systems (MES) to real-time process monitoring and control (SCADA/HMI).

5.2 Sequence Optimization for Production Planning

Operative production planning requires sequencing, scheduling and routing orders to production resources. Allocating orders to the factory floor on single lines, parallel lines, multiple lines, as well as splitting and merging lines requires detailed information and partly complex rules and strategies. Especially, if many different products and variants have to be produced, and sequencing of orders is restricted by a large number of rules, software support is mandatory. A simulation based sequencer tool can assist in reducing the manual effort for producing feasible schedules improving the schedule quality. Modern systems are using state of the art optimization such as genetic algorithms and enable the production planner to quickly generate optimized schedules.

5.3 Product and Production Tracking

Product and production tracking tools capture and communicate real-time manufacturing data automatically from the shop floor and give a real-time view into the production environment. The product and production tracking provides the ability to view the data from several different perspectives, such as by product, work in process, route, tools, equipment, material, and labour. This ability helps to meet the requirements of diverse users in the organization.

The product and production tracking complements the ERP and SCM systems by capturing manufacturing data to a level of detail and precision that ERP and SCM systems don't match. The resulting information allows rapid identification of the cause of problems with fast reaction to limit the impact of these problems.

5.4 Product and Production Quality

The growing adoption of six sigma and lean manufacturing initiatives highlights the importance manufacturers place on improving product and production quality. The digital factory concept enhances the six sigma and lean initiatives by providing an environment to analyze dimensional variation; generate complete, verifiable CAD-based machine inspection programs for measuring equipments and machines by sharing quality data in a digital environment.

5.5 Digital Factory Architecture

The digital factory concept requires the integration of tools for design, engineering, planning, simulation, communication, and control on all planning and factory levels. Each of the particular tools requests specific algorithms and specific data. The digital factory approach is an approach towards using common data for all applications in order to enable collaboration with virtual models for different purposes and different level of detail (Zäh 2004). Therefore an open architecture is an important issue of the digital factory concept. Openness and interoperability is the key factor for implementing digital manufacturing concepts (Kühn 2006). Conversely, the lack of open standards within a digital factory environment creates significant integration and implementation effort for customers trying to deploy digital manufacturing.

5.6 Open Factory Backbone

An open factory backbone (OFB) is a scalable digital enterprise backbone to transform the process of digital manufacturing (Fig. 11). It provides an open platform for integration of independent software solutions that seamlessly interoperate with one another in a digital factory environment. Open XML technology gives a platform that factory wide data exchange. An open factory backbone provides a technology platform that benefits manufacturers as well as application developers from different areas to independently create specialised applications that plug into an integrated digital factory environment and to offer a fully mature, open and integrated environment.

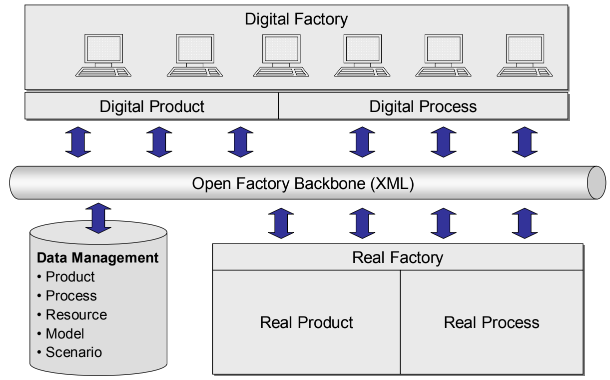

Figure 11: Open Factory Backbone for Open Communication and Integration in the Digital Factory

5.7 Linking the Factory Floor

For the operative production planning and control a link to the factory floor is mandatory. Open interfaces based on industry standards are required to integrate the various control levels with the planning level. A multi-tier architecture design enables to deploy a wide array of flexible architectures. These can be used to build up virtually applications, from the Human-Machine Interface (HMI) systems to complex and demanding Supervisory Control and Data Acquisition (SCADA) systems.

5.8 Linking the ERP System

In a digital factory environment the operative production planning and control also requires a link to the enterprise resource planning level. An ERP connector shall:

- Provide an import and export of data such as routes, consumptions, equipment and users.
- Connect HMI, SCADA, and product management systems to the ERP-systems.
- Update the ERP with real-time plant floor data.

A state of the art ERP connector should be based on the ISA-95 standard.

5.9 Factory Data Management

Manufacturing planning and execution involves a variety of complex and interconnected activities from part and assembly process planning to plant design, ergonomic analysis and quality planning. Information and data from product design, manufacturing engineering and production management have to be handled transparent for all applications in the digital factory environment.

5.10 Factory Process Management

Factory Process Management (FPM) tools establishes the relationships and associations between product, process, plant and resource, which are the basis for the creation of a manufacturing plan. The over all goal is to provide all users to quickly assess the impact of their decisions on product, process, plant and resource requirements. Software tools are required for simulation, workflow, change management, integrated visualization, configuration management and integration tools. These tools are using the open factory backbone and the factory data management.

6 CONCLUSION

The digital factory concept is an integrated approach to enhance the product and production engineering processes. Simulation is a very important key technology in the over all concept and can be applied in virtual models on various planning levels and stages to improve the product and process planning. UGS and Delmia offer software solutions towards this approach.

In the first phase of the digital factory concept the focus is on integrated product engineering. For this area many tools are already available in the market. The second phase includes the plant design and optimization in a collaborative environment concurrently with the product engineering. Many tools are available for certain purposes. However there is still a lack of open integration possibilities between tools and planning levels and optimization on a multicriteria level is required. The third phase of the digital factory concept is focussing on operative production planning and control down to the factory floor. This approach requires an extremely high effort and future research is needed to developed methods and tools for this approach.

REFERENCES

Bley, H. C. Zenner. 2005. Handling of process and resource variants in the digital factory. CIRP Journal of Manufacturing Systems, No 34 H. 2, p. 187-194.

Cai, J., M. Weyrich, and U. Berger. 2004 Digital factory triggered virtual machining process planning for powertrain production in extended enterprise. MechRob, Mechatronics and Robotics, (2004) p. 1072-1077.

Constantinescu, C., V. Hummel, and E. Westkämper. 2006. Fabrik Life Cycle Management. wt Werkstattstechnik online 96 (2006) H. 4, p. 178-182.

Constantinescu, C., V. Hummel, E. Westkämper. 2006. New paradigms in Manufacturing Engineering: Factory Life Cycle. Annals of the Academic Society for Production Engineering. Research and Develop ment, XIII/1, Volume XIII, Issue 1.

Eberst, C., H. Bauer, J. Minichberger, H. Nöhmayer, and A. Pichler. 2004. Self-programming robotized cells for flexible paint-jobs. MechRob, Mechatronics and Robotics, (2004) p. 1089-1093.

ISA-SP95. 2006. Enterprise-Control System Integration, ISA. Available via <www.isa.org> .

Kapp, R., B. Löffler, H.-P. Wiendahl, and E. Westkämper. 2005. The logistics bench: Scalable logistics simulation from the supply chain to the production process. CIRP Journal of Manufacturing Systems, 34 H. 1, p. 45-54

Kühn, W. 2006. Digitale Fabrik, Fabriksimulation für Produktionsplaner, Hanser Verlag. München

Schloegl, W. 2005. Bringing the digital factory into reality - virtual manufacturing with real automation data. CARV, International Conference on Changeable, Agile, Reconfigurable and Virtual Production, p. 187-192

VDI 4499 Blatt 1. 2006.. Digital factory – Fundamentals Available via <http://www.vdi.de>

Zäh, M., and G. Reinhart. 2004. Virtuelle Produktionssystem-Planung. Virtuelle Inbetriebnahme und Digitale Fabrik. Utz Verlag, München.

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