

DIGITAL FACTORY - INTEGRATION OF SIMULATION FROM PRODUCT AND PRODUCTION PLANNING TOWARDS OPERATIVE CONTROL

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ABSTRACT

The digital factory concept is an integrated approach to enhance the product and production engineering processes and simulation is a key technology in digital factory concepts. Different types of simulation can be applied in virtual models on various planning levels and stages to improve the product and process planning. In an advanced stage simulation can be used in the digital factory concept to enhance the operative production planning and control processes from the management level to the factory floor also.

DIGITAL FACTORY - 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). Therefore the digital factory concept integrates the following aspects

- 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.

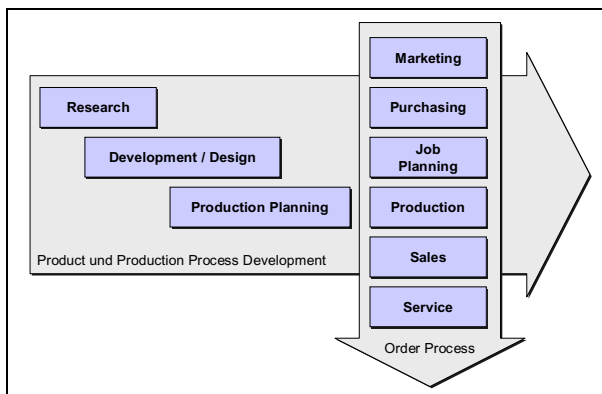


Figure 1: Digital Factory Processes

The digital factory concept 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 figure 2 (Walter 2002). These solutions support people and processes involved in each major phase of the product and production phase.

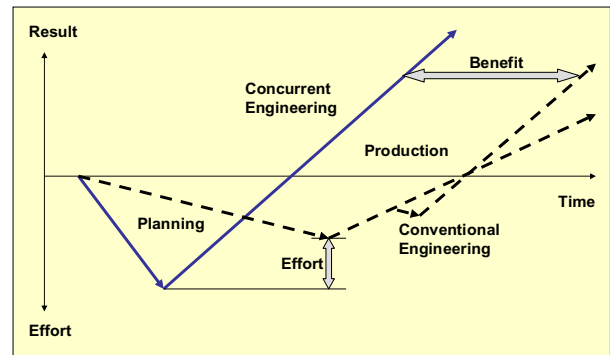


Figure 2: Digital Factory Concept

Simulation is a key technology for enhancing the product and production engineering processes in digital factory environments. Virtual models can be defined on different levels of detail depending on the actual demand. Further different types of simulation, such as

- FEM-Simulation
- Motion simulation
- Discrete-event simulation

can be applied. In digital factory concepts it is important to share data between models on different levels.

DIGITAL FACTORY – PRODUCT ENGINEERING

In the digital factory concept the engineering process has to gain competitive advantage through optimized engineering performance. Innovative engineering accelerates the product and production process engineering by enabling collaborating teams to streamline the engineering processes. The digital factory concept requires

- Integrating CAD designs and CAE information
- Synchronize the engineering processes that require the participation of the entire value chain and their access to all of the product information needed.

- Enable all of product-related teams to work together effectively without regard to physical location.
- Accelerate product delivery by enabling design teams to seamlessly collaborate with manufacturing teams.
- Establish product configurations re-useable across an entire product lifecycle and multiple products

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. 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-centric information.

- Multi-CAD Integration integrating multiple, dissimilar CAD systems, including CATIA, Pro/Engineering SolidWorks, Unigraphics NX Series, Solid Edge and AutoCAD.
- 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

Process management capabilities enable to define engineering workflows that enforce company specific business rules and efficiently execute automated product-related processes. 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 processes

In the digital factory environment many products for these CA-technologies are available in the market. 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.

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

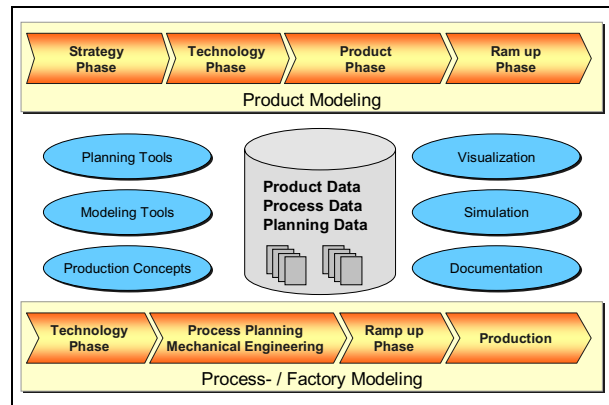


Figure 3: Digital Factory Concept

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 stage.

DIGITAL FACTORY - 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.

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

Modelling 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.

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 queries retrieve the data from a comprehensive structure.

Factory Design and Layout

There are factory layout CAD tools 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 fast and efficiently without drawing the equipment in details.

Virtual reality factory models enable to fly through factory mockups, 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.

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 and 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, figure 4, which directly result in reduced material handling and improved production outputs.

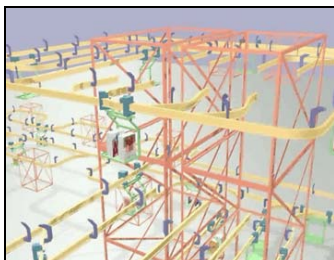


Figure 4: Discrete event simulation of a mono rail production system

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. This includes planning of global production facilities, through local plants, to specific lines. 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 planned systems long before the real system is installed.

Discrete Event Simulation offers:

- 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

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.

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 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.

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. Controller specific information, including motion and process attributes have to be added to the generated robot paths.

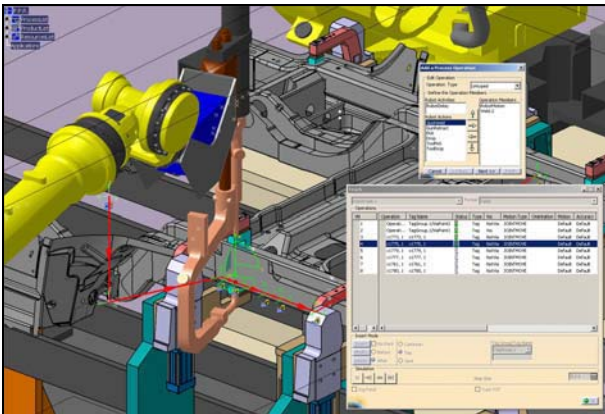


Figure 5: Robot offline programming (Delmia)

A typical application in the robotic field addresses the entire spot-welding design and programming process. 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.

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 allows working in parallel and sharing information from both mechanical design and control departments. 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 of Programmable Logic Controllers including simulation and verification by use of a virtual manufacturing model can optimize the engineering process and help to cut ramp-up times significantly.

Human Resource Simulation

An accurate modelling, simulation and analysis of manual assembly designs, manual workplaces and human operations with detailed 3D virtual human models 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

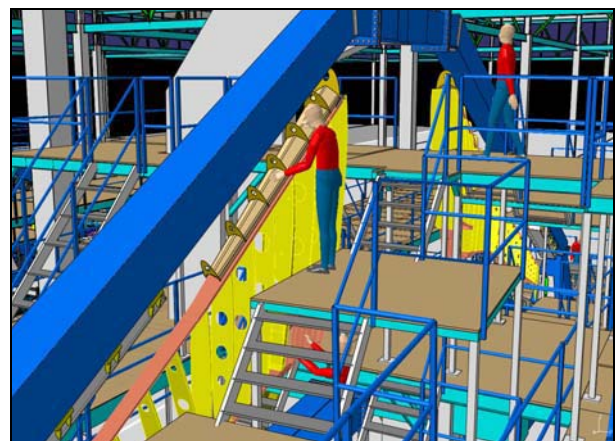


Figure 6: Visualisation and simulation of a wing assembly workplace (Delmia)

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.

DIGITAL FACTORY - OPERATIVE CONTROL AND OPTIMIZATION

The digital factory approach for operative production planning and control extends the one for plant design and optimization. This approach requires a steady feedback loop from the factory floor, in order to update general data, model structure and model parameter with the actual situation from the factory.

Objectives

- 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

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).

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 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.

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 the 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.

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 helps to enhance the six sigma and lean initiatives by providing a graphical 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.

DIGITAL FACTORY - ARCHITECTURE

The digital factory concept requires the integration of design-, engineering-, planning-, simulation-, communication- and control-tools 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.

Open Factory Backbone

An open factory backbone (OFB) is a scalable digital enterprise backbone to transform the process of digital manufacturing. 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

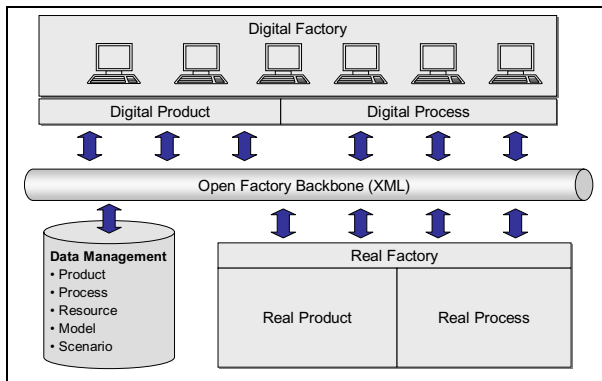


Figure 7: Open Factory Backbone

from different areas to independently create specialised applications that plug in to an integrated digital factory environment and to offer a fully mature, open and integrated environment

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.

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.

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.

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.

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. 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.

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BIOGRAPHY



WOLFGANG KUEHN studied mechanical engineering at the University of Brunswick, Germany. Then he worked with Blaupunkt for two years. At the University of Bremen he got his PhD in production engineering in 1991, and his habilitation in the area of simulation of production systems in 1997. From 1993 to 1995 he worked as Associate Professor at the Asian Institute of Technology in Bangkok. In 1996 he founded the SIPOC Simulation based Planning, Optimization and Control GmbH in Bremen. Since 1997 he has been working as a professor for production planning and control in the department of Electrical, Information and Media Engineering at the University of Wuppertal.