DIGITAL FACTORY – INTEGRATION OF SIMULATION ENHANCING THE PRODUCT AND PRODUCTION PROCESS TOWARDS OPERATIVE CONTROL AND OPTIMISATION

WOLFGANG KUEHN

Faculty E – Electrical, Information and Media Engineering, University of Wuppertal
Rainer-Gruenter-Str. 21, 42119 Wuppertal, Germany
E-mail: wkuehn@uni-wuppertal.de

Abstract: The digital factory concept offers an integrated approach to enhance products and production engineering processes. 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 to various planning tasks and stages to improve the product and process planning at 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. Further, the combination of simulation and optimisation techniques will offer advanced approaches for planning and improving the product development and production planning processes.

Keywords: Digital factory, Virtual Factory, Discrete Event Simulation, Robot simulation, Data Integration

1 INTRODUCTION

The vision of the digital factory concept focuses on the integration of methods and tools available on different levels to plan and test the product and the related production process from the early design phase to the operative control of the factory [VDI 4499, 2006]. The digital factory integrates the following processes:

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

Digital factory is a concept including a network of digital models, methods and tools such as simulation and 3D-visualisation, which are integrated through a comprehensive data and flexible modules management [Westkämper et al, 2005]. Products, processes and resources are modelled based on actual data, in a virtual factory. Based on the actual data and models the planned products and production processes can be improved by use of virtual models until the processes are fully developed, extensively tested and mostly error free for their use in the real factory.

Digital factory is a comprehensive approach, which consists of the virtual factory and its integration in the real factory as well (figure 1). The clearance for the real production start takes place based on digitally proven concurrent engineering [Zäh and Reinhart. 2004]. Therewith the start-up period for production can be significantly reduced (Time-to-Volume) and the competitive position of the company can be improved. Further digital factory shortens Time-to-Market and Time-to-Customer. Product development and production planning have to be in direct interaction, in order to plan and produce as efficiently and as cost-effectively as possible.

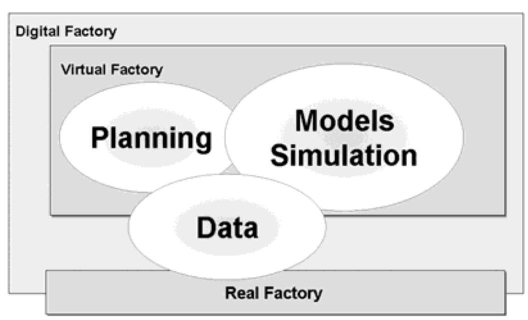

Figure 1: The digital factory integrates the virtual and the real factory

The digital factory exceeds the sum of the entire planning tools and focuses on:

- Integration of product development and production planning, examination and optimisation of planning regarding economic efficiency, flexibility and reduction of planning period (Time-to-Market)
- Reduction of planning costs through actual planning data, error avoidance, etc.
- Fast and safe start of production (Time-to-Volume)

- Reduction of production costs and change costs through the standardisation of solutions and increase of productivity
- Integral examination of production and optimisation of the supply chain (Time-to-Customer)

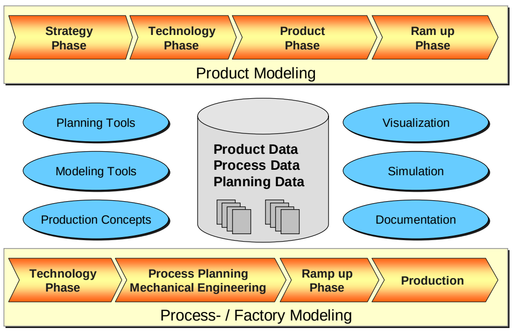

Figure 2: Digital factory concept

The digital factory concept shown in figure 2, can be also seen as an enterprise including an information strategy to manage and integrate the processes of multiple factories in global networks. 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 figure 3. Collaborative solutions support people and processes involved in each major phase of the product and production phase [Constantinescu et al. 2006] and the digital factory based methodology can be applied even in SMEs [Spath and Potinecke 2005].

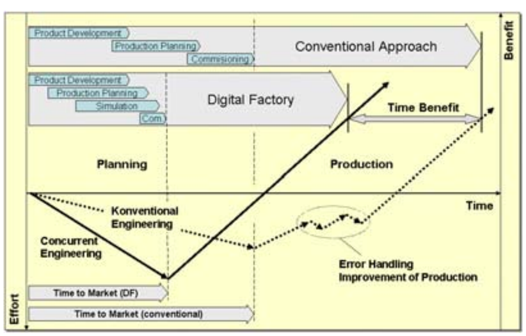

Figure 3: Digital factory - benefit and effort

Therefore, the digital factory concept integrates databases for product, process and factory modelling and advanced visualisation, simulation and documentation to improve the quality of the product and the quality and dynamics of the production processes involved. With the digital factory organisational, technical and economic goals shall be reached, such as:

- Improvement of profitability
- Improvement of planning quality
- Shorter product launch time
- Transparent communication
- Standardisation of planning processes
- Competent knowledge management

Some aspects of the digital factory regarding the integration of simulation to enhance the product and the production process are discussed in the following. The discussion will cover the steps from the product engineering process to the operative production control and optimisation.

2 PRODUCT ENGINEERING

In the digital factory concept the engineering process has to achieve competitive advantage for the firm through improved engineering performance. Innovative engineering accelerates the design of the product and production process, as shown in figure 4, by enabling team collaboration to streamline the engineering processes. The digital factory concept requires to:

- Integrate CAD designs and CAE information.
- Synchronize the engineering processes that require the participation of the entire value chain accessing all the product information needed.
- Enable all of the product related teams to work together effectively without regard to their physical location.
- Accelerate product delivery by enabling design teams to seamlessly collaborate with manufacturing teams.
- Establish re-useable product configurations across an entire product lifecycle and multiple products.

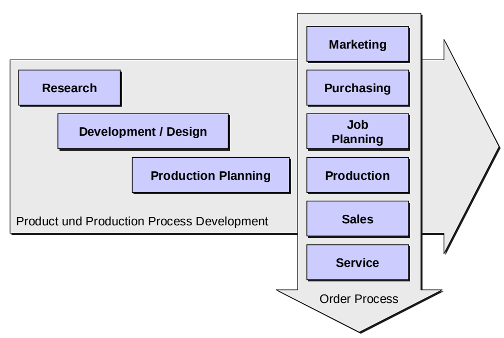

Figure 4: Digital factory processes

The digital factory requires a full engineering process management for multi-site product teams using a variety of CAD applications in order to manage a product structure with all the product information, not just CAD files [Gausemeier and Stollt, 2006]. All of the relevant CAD, CAM, and CAE information have to be managed (see figure 5), 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 the communication among team members.
- Multi-site collaboration to participate in design, automated engineering and manufacturing processes.

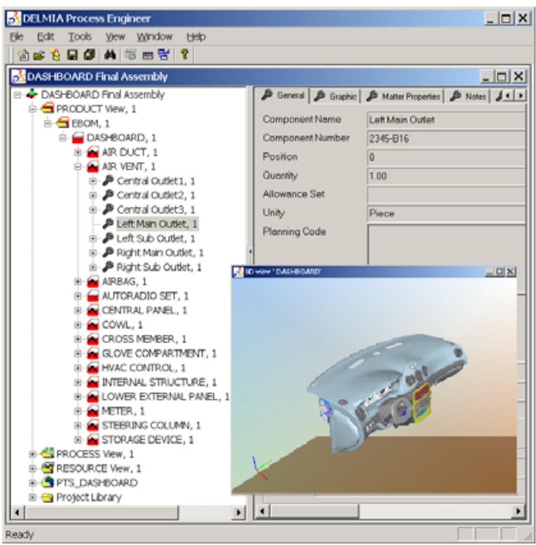

Figure 5: Product and process definition (Delmia)

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 the relevant information.
- Improve communication among OEMs, suppliers, and allied partners.
- Synchronize activities of globally distributed teams.
- Integrate current CAD, CAM, and CAE technology into integrated reference processes.

2.1 Product Lifecycle Management

Product lifecycle management (PLM) is an integrated, information driven approach to all aspects of a product from its conceptual design 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 OPTIMISATION

Plant design and optimisation focuses on the optimisation 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 following objectives:

- Shorten new product introduction, time-to-market, and time-to-volume.
- Improve production layout and minimize investments.
- Ensure that machines and equipment are in the right place.
- Ensure that sufficient material handling equipment is available.
- Optimize buffer sizes.
- Ensure that product handling is kept to a minimum.

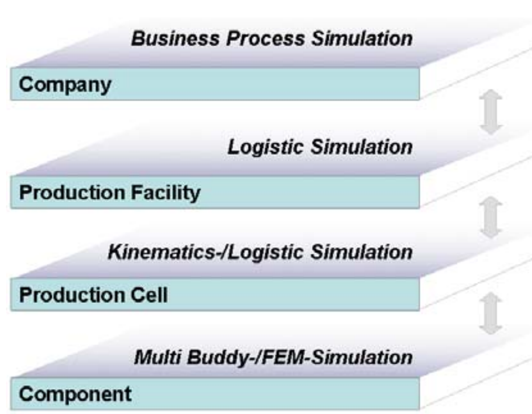

Figure 6: Establishing a 3D-factory layout by use of predefined objects (UGS)

Depending on the particular goals different levels of detail are required. For complex simulation tasks in the digital factory it is advisable to define manageable subtasks and to model these separately, rather than using a single simulation model for all purposes. For example, the motion paths and processes of robots in a complex production cell can be modeled and programmed by use of a detailed model, considering detailed motion control parameters and strategies. On the next level only selected results of this detailed model, such as handling times, may be used for the logistic model of the production flow.

Specifically, in the digital factory simulation can be performed on several levels by use of hierarchical models (figure 5). In some applications such as robotics or NC-processing, motion simulation with geometric and kinematic models dominates. In other fields such as production flow planning and control, mainly discrete event simulation is applied.

The digital factory approach requires data consistency among these levels and subtasks. 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 ahead of the start of production, that the factory will be able to meet the demands for efficient operations. Typical simulation applications in the digital factory are:

- Layout planning and simulation for layout validation and optimisation
- Static analysis and dynamic simulation of logistic and production flows
- Line balancing of assembly processes
- Simulation of complex material handling
- Robotics and complex motion
- Simulation of part manufacturing
- Simulation of human resources
- Ergonomic simulation
- Simulation of production logistics
- Simulation for control software testing
- Simulation for operative production control

The integration concept of the digital factory requires powerful interfaces and database systems for the joint use of actual data and modules between different complexity levels (vertical integration) and between the operational function areas (horizontal integration).

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. Query technology based on parametric search allows to retrieve data from a comprehensive structure.

3.2 Factory Design and Layout

CAD tools for factory layout planning are available that provide predefined modules for creating detailed factory models. These layout tools allow to work with predefined objects that virtually represent the resources used in a factory, from floor and overhead conveyors, mezzanines and cranes to material handling containers and operators. With these modular objects a layout model, such as the one shown in figure 7, can be implemented in 3D in a fast and efficient way without drawing the equipment in detail.

Figure 7: Establishing a 3D-factory layout by use of predefined objects (UGS)

Virtual reality models enable to move through factory mock-ups, walk through factories, 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, analyse, 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 can be identified. Material flow studies can be performed on alternative layout configurations and layout options can be compared in order to find the best layout and to improve production efficiency.

Enhancing the factory layout based on a method considering material flow distances, frequencies and costs is a first step towards more efficient factory layouts, which directly result in reduced material handling and improved production output.

3.4 Plant, Line and Process Simulation

Plant, line and process simulation can be performed by means of discrete event simulation tools. These tools allow to analyse systems and processes in order to improve 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.

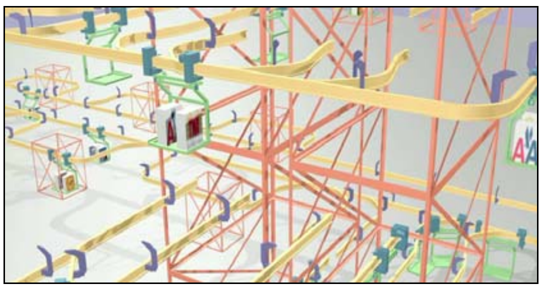

Figure 8a: Discrete event simulation of a JIT production system for the dynamic analysis a highly automated monorail transportation system (SIPOC)

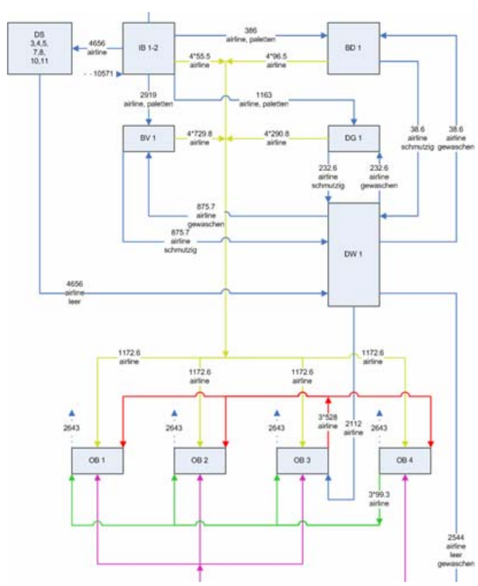

Figure 8b: Transport structure (part section) of the JIT production system shown above (SIPOC)

Simulation models enable to run experiments and what-if scenarios without disturbing an existing production system. It is also possible to explore system characteristics and optimise the performance of the planned production and logistic systems long before the actual systems are installed. Especially for production systems with complex system dynamics (as shown in figure 8), JIT requirements and extreme peek loads and there are large benefits for the production planner. Furthermore simulation offers a powerful platform to improve open and transparent communication between all departments and persons involved in the planning and operating process. Critical issues can be discussed and checked in advance. The planning reliability obtained saves time and money.

3.5 Part Manufacturing

Part manufacturing applications require to 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 display.

The 3D-simulation of the NC path, shown in figure 9, enables to detect collisions, analyze material removal and reduce cycle times. Further detailed process information can be delivered to the shop floor, and NC tool paths can be created taking into account cycle times for each set of features and operations.

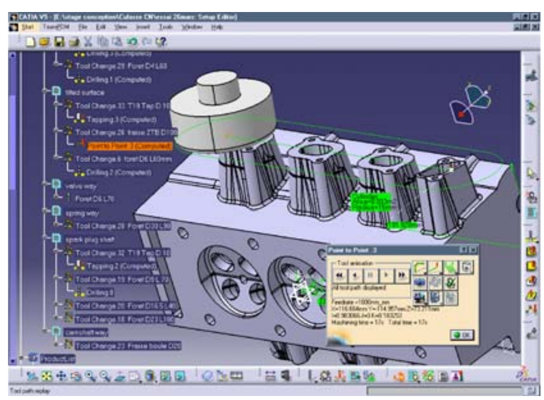

Figure 9: 3D-Technology for integrated NC planning and simulation and offline programming (Delmia)

3.6 Simulation of Robotic Workcells

Digital manufacturing and simulation of robotic workcells, as shown in figure 10, focus on the design, simulation, optimisation, 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 optimise processes and calculate cycle times.

Figure 10: 3D-Robotic workcell simulation (Delmia)

Motion simulation and synchronization of several robots and mechanisms including 3D path definition are required to perform accessibility checks, collision detection and optimisation of cycle time. Typical features are:

- Workcell layout design and modelling from 3D-CAD-Data.
- Robots, machines, tools and equipment libraries.
- Modelling of complex kinematics of robots and other mechanisms.
- Robot calibration to improve accuracy.
- Automatic path planning.
- Collision detection.
- Sequencing 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 simulation 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, has to be added to the generated robot paths.

3.7 Realistic Robot Simulation (RRS)

In order to improve modelling, simulation and offline programming of robot applications regarding the dynamic and absolute position accuracy a virtual Robot Controller (VRC) interface has been introduced as shown in figure 11. This interface enables to integrate the original software of controllers for industrial robots almost completely into simulation systems in a standard manner. RRS I focuses on motion control only, RRS II offers extended possibilities by additionally including programming capabilities, technology control and a user interface.

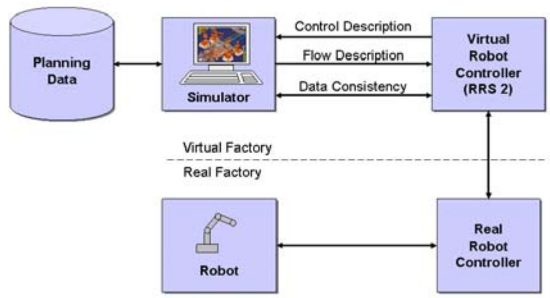

Figure 11: RRS (Realistic Robot Simulation) enables to use the real control algorithms in simulation.

A typical application in the robotic field addresses the entire spot-welding design and programming process. Designing a spot-welding cell layout by directly accessing CAD models, optimizing robot placement and path and selecting the best welding gun are required features.

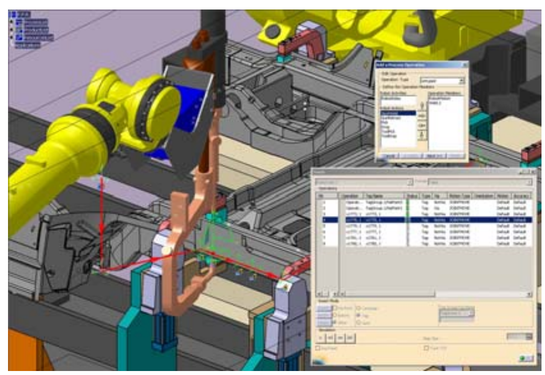

Figure 12: Robot motion planning, simulation and offline programming for a spot welding process (Delmia)

Critical factors such as spatial constraints, geometric limitations and welding cycle times have to be taken into account. The main 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 (figure 12). Finally, robot programs and the sequence of operations can be generated and verified for the application, and the PLC programs can be created automatically.

3.8 Model Based PLC Offline Programming

For production ramp ups with time and cost pressure as well as for 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 can be part of a 3D-integrated virtual environment (figure 13) which allows to work in parallel and share information from both the mechanical design and the control departments.

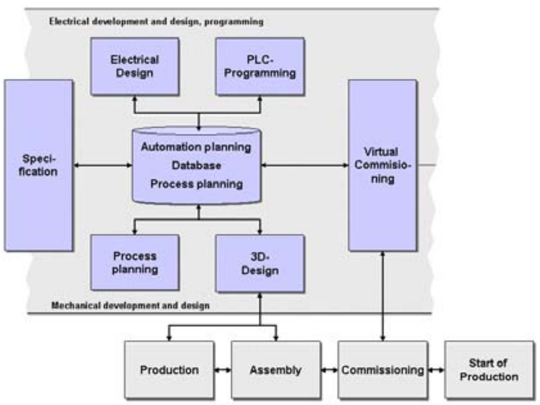

Figure 13: Integrated engineering in the digital factory includes mechanical and electrical related processes

This enables an automatic generation of PLC programs directly from the virtual manufacturing model, e.g. as shown in figure 14, and allows for extensive virtual tests prior to building the equipment on the shop floor. Benefits include:

- Visualize and optimise functionality and behaviour early in the production engineering phase.
- Increase the speed, consistency and reliability of design processes.
- Prove the feasibility of the control logic.
- Correct logical errors well before ramp-up.

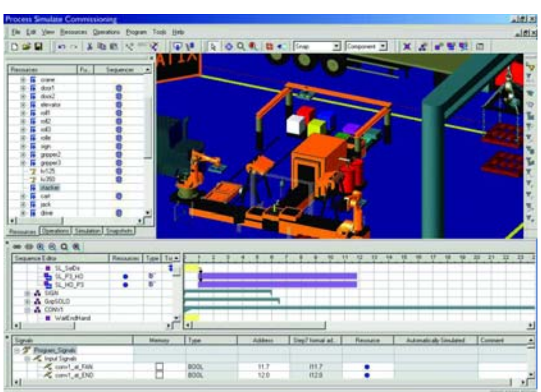

Figure 14: “Process simulate” for simulation of production processes (UGS)

- 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 and applying real automation data can optimise the engineering process and help to significantly cut ramp-up times [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 (figure 15) can reduce 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 15: Visualisation and simulation of a wing assembly workplace (Delmia)

Human resource simulation improves workplace ergonomics, assembly cycle times, and communication of planning results, increases productivity of production facilities, generates a comprehensive documentation of human operations and promotes the 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.

3.10 Dynamic Line Balancing

Line balancing and machining planning require to calculate operating cycle times and to generate for instance a corresponding NC tool path. Discrete event simulation models provide a dynamic perspective of the balanced production line (figure 16). They allow to analyze throughput, work-in-process, resource utilization and buffer sizes in order to improve the line balancing.

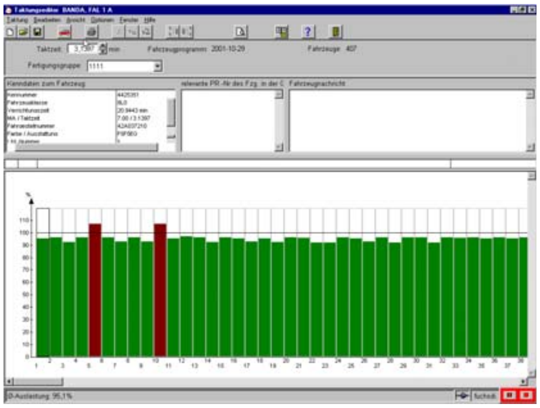

Figure 16: Line balancing (Delmia)

4 OPERATIVE PRODUCTION CONTROL

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

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

This simulation based approach requires a steady feedback loop from the factory floor (figure 17) in order to update general data, model structure and model parameters with the actual situation from the factory. To deliver accurate results a model has always to be initialised with the actual WIP (work in process) and actual status of the resources.

In order for models to be used for operative production planning and control there are special requirements such as:

- Model parameterisation
  Automated model parameterisation by use of standardised interfaces (Database Interface, XML …)
- Fast simulation runtime
  Simulation models have to run fast to provide operative production planning with timely results.
- Modularity
  A consistent hierarchical structure and modularisation enables to flexibly assemble models by use of pretested modules.
- Automated model generation
  For the operative use it is useful to generate models automatically from actual data.
- Accuracy
  The accuracy of an operative model has to be adapted to the particular case of operation.
- WIP
  Initialization of models with actual WIP (Work in Process) from the real production. Direct start of the Models with the initialized WIP.
- Switching
  Seamless switching between operative processing and simulation mode

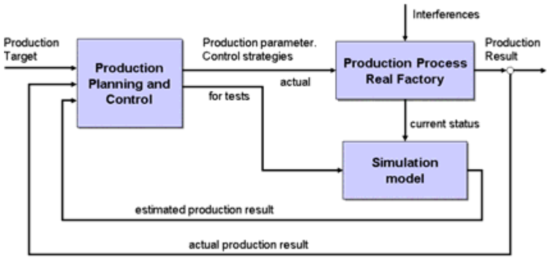

Figure 17: Simulation integrated feedback loop for operative control and improvement of production processes

Reference models are important elements of the digital factory, especially in the area of operative control and optimisation, because they considerably support efficient planning. Reference models are tested and validated models, which offer a general reference for defined solutions and common practice or best practice processes. Reference models shall be comprehensible, universally valid and offer paradigm characteristics and independence from a particular software implementation [Wenzel et al, 2005]. Additionally, a modular and open structure shall offer the possibility to easily adapt these models to new areas of application.

Generally two alternative ways for model building can be used, in order to keep the modelling effort in acceptable limits:

- Predefined, tested and validated modules, which have to be parameterised from actual data for operative use
- Automated model generation and parameterisation at runtime from actual data.

The future concept of flexible and adaptable factories the model generation directly from actual data is the better (forward-looking) approach.

4.1 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 to the control level from manufacturing execution systems (MES) to real-time process monitoring and control (SCADA/HMI).

4.2 Sequence Optimisation for Production Planning

Operative production planning requires the sequencing, scheduling and routing of 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. In particular, if many different products and variations have to be produced, and the 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 to produce feasible schedules and improve the schedule quality. Modern systems use state of the art optimisation technologies and enable the production planner to quickly generate optimised schedules.

4.3 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 of 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 organisation.

The product and production tracking complement the ERP and SCM systems by capturing manufacturing data to a level of detail and precision that ERP and SCM systems cannot match. The resulting information allows for the rapid identification of problem causes and fast reaction to limit their impact.

4.4 Product and Production Quality

The growing adoption of six sigma and lean manufacturing initiatives highlights the importance that 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 the dimensional variation of production data; generate complete, verifiable CAD-based machine inspection programs to measure equipment and machines by sharing quality data in a digital environment.

5 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 requires specific algorithms and specific data.

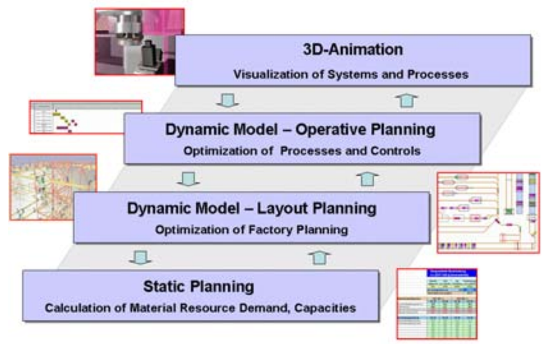

Figure 18: Models on different levels in the digital factory

The digital factory approach aims at using common data for all applications on different modelling levels (figure 18) in order to enable collaboration with virtual models for different purposes and different levels of detail [Zäh, 2004]. Therefore an open architecture is an important feature of the digital factory concept. In practical use digital factory applications require the use of diverse software components. For the integration of suppliers into development and supplier networks, open interfaces need to be developed with the exclusion of the proprietary ones. [Wagner and Blumenau, 2003]. Open interfaces and interoperability are the key factors 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.

5.1 Open Factory Backbone

An open factory backbone (OFB) is a scalable digital enterprise backbone to transform the process of digital manufacturing (figure 19). It provides an open platform for the integration of independent software solutions that seamlessly interoperate with one another in a digital factory environment. Open XML technology gives a platform for 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.

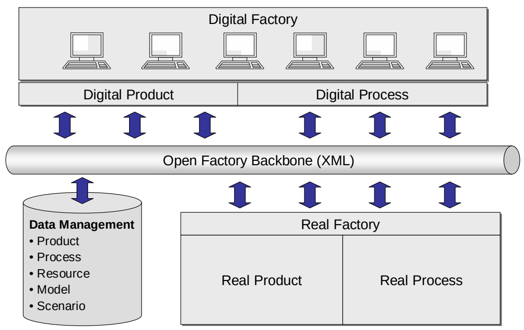

Figure 19: Open factory backbone for open communication ant integration in the digital factory

5.2 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. [Blumenau and Wuttke, 2005]. A multi-tier architecture design enables to deploy a wide array of flexible architectures. These can be used to build up virtual applications, from the Human-Machine Interface (HMI) system to complex and demanding Supervisory Control and Data Acquisition (SCADA) systems.

5.3 Linking the ERP System

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

- Provide data import and export facilities for routes, consumptions, equipment and users.
- Connect HMI, SCADA, and product management systems to the ERP-systems.
- Update the ERP with real-time floor data.

A state of the art ERP connector should be based on the ISA-95 standard. [ISA-SP95, 2006].

5.4 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. An example for a possible factory data management structure is shown in figure 20. Information and data from product design, manufacturing engineering and production management have to be transparently handled for all applications in the digital factory environment.

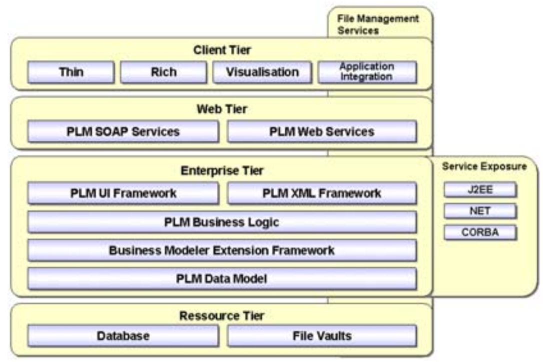

Figure 20: Factory data management architecture (UGS)

5.5 Factory Process Management

Factory Process Management (FPM) tools establish the relationships and associations between product, process, plants and resources, which are the basis for the creation of a manufacturing plan. The overall goal is to allow 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, and configuration management as well as integration tools. These tools are using the open factory backbone and the factory data management.

6 CONCLUSION AND FUTURE WORK

The digital factory concept is an integrated approach to enhance the product and production engineering processes. Within this concept Simulation is a key technology and can be applied in virtual models on various planning levels and stages to improve the product and process planning. Software vendors such as UGS and Delmia offer software solutions to implement this approach.

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

Future work will focus on open standard interfaces available for integration of various tools from different software vendors into the digital factory system architecture. The realisation of the digital factory concept needs various software components such as design and planning software or simulation tools. All these have to function closely together. A single software system cannot cover the complete range of required functionalities: this can be achieved with the use of specialised software systems and their integration. Therefore, the requirements for each system include:

- Networked system and data architecture with integration of processes and product development process.
- Open system architecture with standard interfaces.
- Modular architecture for expandability.
- Efficient data management.
- Consistent 3D-visualisation platform
- Advanced documentation and change management.

An open integration of the diverse software components in a joint system architecture is recommended, which enables flexibility in the future integration of software modules from various suppliers.

Further future work will combine the methods and tools available today and advanced optimisation features. The optimisation of complex systems in the digital factory requires multi criteria decision support to improve flexible production systems, complex design and planning tasks. The optimisation of these can be classified in the following categories:

- Parameter optimisation.
- Layout optimisation.
- Optimisation of control strategies.

Parameter optimisation is related to the production parameters, such as number of AGVs or number of work piece carriers in a transfer system. In most cases the implementation of parameter changes is possible with a relatively small effort even during production.

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

The layout optimisation deals with the positioning of various production equipment. In many cases the solution space is already limited by existing resources and existing boundary conditions. Major changes of the layout structure need significant effort: considerable changes are often needed when planning new systems or completely reorganising existing production areas.

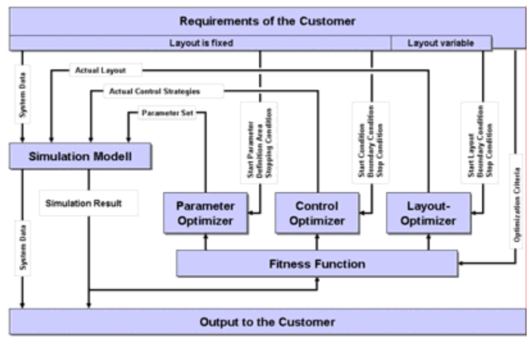

Figure 21: Optimisation of parameter settings, control strategies and layout variants by use of simulation models

In order to improve factory and systems layout, parameter settings and control strategies multi criteria decision making processes are required (figure 21). Optimisation in this sense does not assume that a global optimum has to be reached. A system configuration has to be found, which provides very good or at least satisfactory results, to suit customer demand. If the optimisation is performed on one level only, the process is much faster. However, it may lead to an inadequate solution.

Performing a simulation run means testing one scenario by use of a model with one defined set of parameters. In most cases a number of simulation runs are required in order to gain an improvement of the production planning. By use of optimisation algorithms this procedure can be systematically automated, e.g. with genetic algorithms (figure 22).

The biological evolution has the ability to adapt complex structures and organisms to different environmental and living condition by use of variation of the genetic material and applied selection mechanisms. For technical optimisation purposes a mathematical model using stochastic variation, recombination and selection mechanisms can be successfully applied. The biological variation of the phenotypes and genotypes, change of information and use of information in a different sequence, is modelled by mathematical algorithms using random processes. Similar to biological selection mechanism, where the best adapted individuals will survive, in mathematical models the solution which fits the fitness functions at the best will be selected and can be used for a next variation step until a suitable solution for the optimisation problem is reached. In combination with simulation, genetic algorithms offer a very promising approach for the use on several levels and applications in the digital factory.

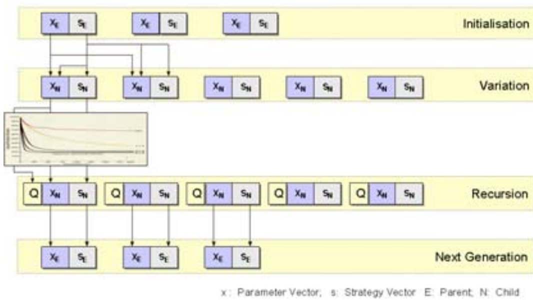

Figure 22: Optimisation by use of genetic algorithms

In summary, it can be stated that the methods and instruments of the digital factory realise a complete digital processing of product development and production planning up to the virtual ramp up and operation. The early parallelisation of these processes significantly reduces development and ramp-up times. The early interference and integration of product development and production planning improves planning reliability and offers considerable savings, because a larger part of product costs is determined in the early phases of the product development.

In the digital factory environment many software solutions based on CA-technologies are already available for product related processes such as product design and engineering. In the fields of plant design, operative control, and optimisation integration is not really state of the art. Today it is partly available for selected software products and selected industrial areas. Especially for operative planning and control the market is relatively new and open interfaces and integration tools have to be developed to link the planning levels directly to the factory floor.

REFERENCES:

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

Bley, H.; Fritz, J; Zenner, C. 2006, Digital factory in automobile industry, ZWF, vol 101, no 1-2, p 19-23

Blumenau, J.-C.; Wuttke, C.-C. 2005, Application of the digital factory in the ramp up of production systems by using online-data. CIRP Journal of Manufacturing Systems, no 34(3), p. 241-245

Bracht, U.; Masurat, T. 2005, The Digital Factory between vision and reality, Computers in Industry, Netherlands vol 56 (May 2005), no 4, p. 325-33

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

Cai, J.; Weyrich, M.; Berger, U. 2004, Supplier integrated powertrain machining process planning in digital factory, ICMA, Internat. Conf. on Manufacturing Automation, no: 4, p. 565-572

Constantinescu, C.; Hummel, V.; Westkämper, E. 2006. Factory Life Cycle Management. wt online 96 (2006) no. 4, p. 178-182

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

Gausemeier, J.; Stollt, G. 2006, Digital factory and virtual production, ZWF, vol 101, no 1-2, p. 28-34

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

Kapp, R,; Löffler, B.; Wiendahl, H.-P. 2005. Westkämper, E.: The logistics bench: Scalable logistics simulation from the supply chain to the production process. CIRP Journal of Manufacturing Systems, 34 no. 1, p. 45-54

Kühn, W. 2006. Digitale Fabrik, Simulation 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

Spath, D.; Potinecke, T. 2005, Virtual product development - Digital factory based methodology for SMEs. CIRP Journal of Manufacturing Systems, no. 34(6), p 539-548

Schraft, R.-D.; Kuhlmann, T. 2006, Systematic introduction to the digital factory, ZWF, vol 101, no 1-2, p. 15-18

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

Wagner, T.; Blumenau, J.-C. 2003, The digital factory, more than a planning environment. Schriftenreihe Produktionstechnik, Univ. d. Saarlandes no. 29(2003), p. 7-12

Wenzel, S.; Jessen, U.; Bernhard, J. 2005, Classifications and conventions structure the handling of models within the Digital Factory, Computers in Industry, Netherlands, vol 56, no 4, p. 334-46

Westkämper, E.; Gottwald, B.; Fisser, F. 2005, Migration of the digital and virtual factory to reality. CIRP Journal of Manufacturing Systems, no 34(5), p. 391-396

Zäh, M.-F., Reinhart, G.. 2004. Virtuelle Produktionssystem-Planung. Virtuelle Inbetriebnahme und Digital Factory. Utz Verlag, München.

Zah M.-F.; Carnevale, M.; Schack, R.; Muller, S. 2005, Approach to the implementation of the digital factory in the aircraft industry, Industrie Management, vol 21, no 2, p. 15-18

AUTHOR BIOGRAPHY

WOLFGANG KUEHN studied mechanical engineering at the University of Brunswick, Germany, and later 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, Optimisation and Control GmbH in Bremen. Business areas are simulation for various industries, further digital factory concepts and advanced controls for aircraft production. 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. Research areas are production networks and digital factory concept.