Virtual Production - The connection of the modules through the Virtual Production Intelligence

Daniel Schilberg, Tobias Meisen and Rudolf Reinhard

***Abstract* —Virtual production is a main contribution to keep high-wage countries competitive in producing high quality goods. To use the Virtual Production effectively in this context, a base that allows a holistic, integrated view of IT tools used in the process has to be created. The aim of such an analysis is the increase of product quality, production efficiency and performance. In this paper, an integrative approach which represents the integration, analysis and visualization of data generated along simulated processes within the production technology a basic building block to achieve the goal of virtual production is introduced. The system is developed for the application domain production technology. It provides a context-sensitive information analysis to gain more detailed knowledge of production processes. The introduced system is called Virtual Production Intelligence.**

***Index Terms* — Virtual Production, Virtual Production Intelligence, VPI, Digital Factory**

I. Introduction

The market for industrially manufactured goods is changing more and more rapidly. Therefore companies must confront the challenges of on the one hand rising individual customer requirements and on the other hand low obtainable prices for the product – despite an increasing expenditure. This applies in particular companies, which act in high-wage countries, because of the by the BRICS (Brasilia, Russia, India, China, South Africa) dominated global competition for less customized products. Considering the individualization and increasing performance of products the complexity of products and production processes in mechanical and automatic processing is constantly growing. This, in turn, results in new challenges concerning the designing as well as the production itself. In order to face these challenges, measures are required to meet the demands which are based on higher complexity. One measure to face this challenge is a more detailed planning of the design and manufacturing of the products by the massive use of simulations and other IT tools which enable the user to fulfill the various demands on the product and its manufacturing. To a further improvement of simulations and IT tools it is important not to evaluate them separately but in their usage context: which tool is used to which planning or manufacturing process. It has to be fathomed which information on which effort between the tools are exchanged.

To formulate and execute an appropriate measure, it is necessary to create a basis which allows a holistic, integrative examination of deployed tools in the process. Aim of such an examination is an increasing product quality, efficiency and performance. Due to the rapid development of high-performance computers, the use of simulations in product design and manufacturing processes has already been well-established and enables users to map relations more and more detailed virtually. This has led to a change concerning the way to perform preparatory and manufacturing activities. Instead of an early development of physical existent prototypes, the object of observation is developed as a digital model which represents an abstraction of essential characteristics or practices. The subsequent simulation the digital model is used to derive statements concerning practices and properties of systems to be examined. The use of digital models in production processes is described by the term of virtual production which specifies a “mainstreaming, experimental planning, evaluation and controlling of production processes and plant by means of digital models” [4,5].

This paper will introduce an integrative concept which describes an important component to achieve the objective of a virtual production by the integration and visualization of data, produced on simulated processes within the production technology. Taking account of the application domain of production technology and used context-sensitive information analysis, with the aim of an increasing improvement of knowledge concerning the examined processes, this concept is called Virtual Production Intelligence. To illustrate this measurement, initially the problem will be specified more precisely to present the vision of a digital factory afterwards and to create an understanding for the difficulty of IT tools. The aim of this paper is to present how the Virtual Production contributes to

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the facing of the addressed challenges.

II. Problem

As a central issue of the virtual production the heterogeneous IT landscape can be identified. As indicated in the introduction, a variety of software tools to support various processes are used. Within these software tools data cannot be exchanged without effort. The automation pyramid offers a good possibility to demonstrate this difficulty. The automation pyramid is depicted in Figure 1. It shows the different levels of the automation pyramid with the corresponding IT tools and the flow of information between the levels. The level related processes are supported by the mentioned IT tools very good or at least sufficient. At the top level command and control decisions for the company management are supported by Enterprise Resource Planning (ERP) systems. Therefore, these systems allow the decision-makers in the management to monitor any enterprise-wide resources like employees, machinery or materials.

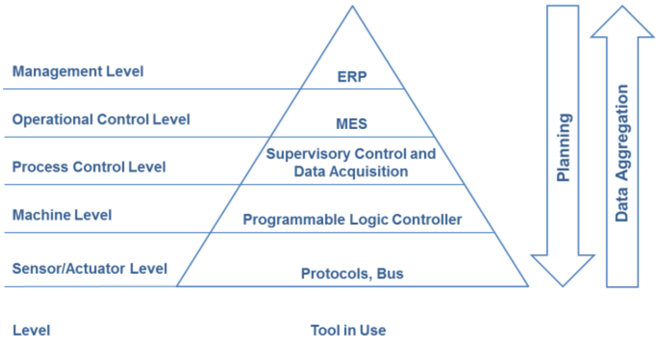

Fig. 1 automation pyramid [6]

At the lower levels, the Manufacturing Execution Systems (MES), the data acquisition (Supervisory Control and Data Acquisition SCADA) and programmable logic controllers (PLC) are arranged according to the increasing complexity. The field level is the lowest level. Corresponding to protocols the data exchange is organized on this level. The used software tools are developed very well to support the corresponding processes on the appropriate level. The Association of German Engineers (VDI) addressed for the virtual production a unified data management as a way to use data and information across all levels, but this is not realized yet. Without a unified data management the data exchange from a PLC via the SCADA and MES up to the ERP system requires a great effort for conversions and aggregating. The goal is that the ERP can support decisions on the base down to the PLC Data and changes in the ERP system will change the input for the PLC. Currently most companies only exchange data between different levels instead of a flow of information across all levels. This is why a holistic picture of production and manufacturing process is not possible [7].

At present, a continuous flow of information is available only with the application of customized architectures and adapters to overcome the problem of heterogeneity. This involves high costs, why usually small and medium-sized enterprises (SMEs) have no integration of all available data into a system.

There are a high number of different IT tools for virtual production. These enable the simulation of various processes, such as in manufacturing technology, the realistic simulation of heat treatment and rolling process or the digital viewing of complex machinery such as laser cutting machines. At this juncture various independent data formats and structures have developed for a representation of the digital models. Whereas an independent simulation of certain aspects of product and manufacturing planning is possible, the integrative simulation of complex manufacturing processes involves high costs as well as an high expenditure of time because in general an interoperability between heterogeneous IT tools along the automation pyramid is not given. One approach to overcome the heterogeneity is the homogenization with the help of a definition of unified data standards. In this context a transfer of the data formats into a standardization of data by the use of specific adapters as mentioned above. However, this approach is not practical for the considered scenario for two reasons. Firstly, the diversity of possible IT tools that are used lead to a complex data standard. This is why its understanding, care and use are time and cost intensive.. Secondly, the compatibility issues for individual versions of the standard are to be addressed (see STEP [8]). Therefore the standard must be compatible with older versions and enhanced constantly to reflect current developments of IT tools and to correspond to the progressive development through research [9, 10].

Another approach, which is chosen as basic in this paper, includes the use of concepts of the data and application integration, which do not require a unified standard. The interoperability of IT applications must be ensured in a different way so that no standard data format is necessary. This is done by mapping the various aspects of the data formats and structures on a so-called integrated data model or ¬ canonical data model [10, 11]. In current approaches to these concepts are extended to the use of semantic technologies. The semantic technologies enable a context-sensitive behavior of the integration system. The continuation of this approach enables the so-called adaptive application and data integration [12, 13].

The integration of all data collected in the process in a consolidated data management is only the first step to solving the problem. The major challenge that must be overcome is the further processing of the integrated data along a production process to achieve a combination of IT tools across all levels of the automation pyramid. The question of the analysis of data from heterogeneous sources is addressed in the analysis of corporate data for some time. The applications that enable integration and analysis of data are grouped under the term "Business Intelligence" (BI). BI applications have in common that they provide the identification and collection of data that arise in business processes, as well as their extraction and analysis [14, 15].

The problem in the application of BI on virtual production is that the implementation of the BI integration challenges of heterogeneous data and information conceptually solves in the first place which causes significant problems in the implementation of functional systems. Thus, in concept, for example, a translation of the data into a common data format and context-sensitive annotation is provided. A translation

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may not be achieved because it is proprietary information which meaning is not known to the annotation. This is also the reason why so many BI integrations have failed so far [16].

The following shows that the previously addressed problems should be solved by the vision of the digital factory. Because this vision is not realized yet, the section heterogeneity of simulations and solution: Virtual Production Intelligence will outline next steps towards the realization of a digital factory. The term "Virtual Production Intelligence" was selected in reference to the problem introduced in the term "business intelligence", which has become popular in early to mid-1990s. It called "business intelligence" methods and processes for a systematic analysis (collection, analysis and presentation) of a company's data in electronic form. Based on gained findings, it aims at improved operative or strategic decisions with respect to various business goals "Intelligence". In this context “Intelligence” does not refer to intelligence in terms of a cognitive size but describes the insights which are provided by collecting and preparing information.

. This corresponds to the use of the word "intelligence" as used in context of intelligence activities in the English language (e.g. Central Intelligence Agency - CIA).

III. Digital Factory

The digital factory (Figure 2) is defined by the working group VDI in the VDI guideline [4] as:

"*the generic term for a comprehensive network of digital models, methods and tools – including simulation and 3D visualization – integrated by a continuous data management system. Its aim is the holistic planning, evaluation and ongoing improvement of all the main structures, processes and resources of the real factory in conjunction with the product* ".

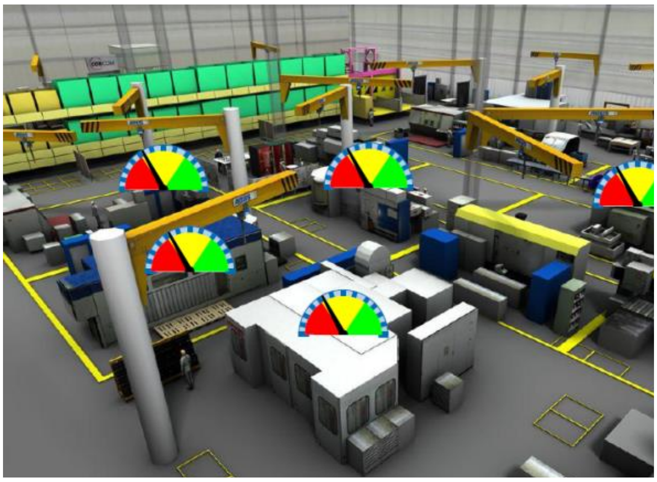

Fig. 2 displays the digital factory with indicators if a process is running

According to the VDI guideline 4499 the concept of the digital factory does not include individual aspects of the planning or production but the entire product life cycle (PLC) (Figure 3). All processes from the onset to the point of decommissioning shall be modeled. Therefore the observation starts with the collection of market requirement, the design stages including all the required documents, project management, prototypes (digital mock-ups), the necessary internal and external logistic processes, planning the assembly and manufacturing, the planning of appropriate manufacturing facilities, installation and commissioning of production facilities, the start-up management (ramp up), series production, sales to maintenance and ends with the recycling or disposal of the product all these points should be part of the Digital Factory. Currently there is no platform which complies with this integration task. But there are already implemented some elements of the digital factory at different levels of the automation pyramid or in phases of the PLC.

Existing PLC Software products help companies to plan, monitor and control the product life cycle in parts. However, these applications are usually only isolated solutions and enable the integration of IT tools that have the same interfaces for data exchange and are provided by the same manufacturer. The detail of the images of individual phases of the product life cycle does not reach this high spatial resolution of special applications to the description of individual phases of the product life cycle or of IT tools that focus on aspects of individual phases. Therefore the recommendation of the VDI to design data management and exchange as homogeneous as possible can only be considered for new developments. Besides there is still no approach about how to implement a standard for such a homogeneous data exchange and how to prevent or avoid the known issues of a standardization process. Therefore even a project that wants to realize the homogenization of the flow of information cannot succeed, because it is not defined what such a condition has to look like. Moreover there is no standard or efforts to standardize as for example the Standard for the Exchange of Product Model Data (STEP) compete with proprietary formats. It must be considered that the proprietary formats were also used to protect the knowledge and skills of the software provider.

With view to a visualization of the digital factory there are tools of Virtual and Augmented Reality which enable users to realize 3D models of factories with or without people as well as to interact with it and to annotate information. A real time-control of a physical existent plant via virtual representation, at which data from the operation in virtual installation are illustrated and further processed for analysis, is right now not possible. The running times of individual simulations do not meet the real-time requirement. With the present techniques, its developments and innovations the goal of digital manufacturing is to be achieved.

The Virtual Production Intelligence serves as a basic building block for the digital factory. To achieve this goal, it is not necessary to address the overall vision of the digital factory, but rather it is sufficient to focus the area of simulation-based virtual production (see Figure 4). Again, the VDI guideline 4499 is cited to the definition of virtual production:

"is the simulated networked planning and control of production processes with the aid of digital models. It serves to optimize production systems and allows a flexible adaptation of the process design prior to prototype realization."

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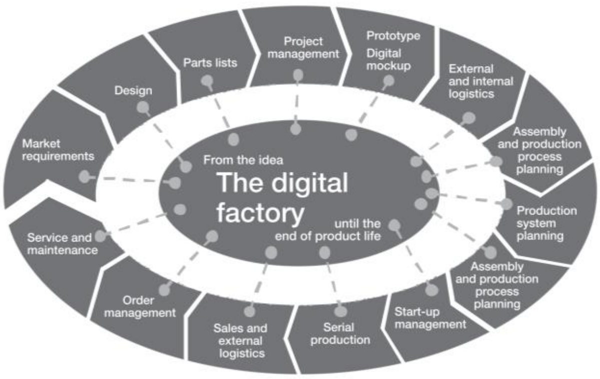

Fig. 3 Product Life Cycle (VDI 4499)

The production processes are here divided into individual process steps, which are described by simulations. The simulation of the individual process steps is done using modern simulation tools which can represent complex production processes accurately. Despite the high accuracy of individual simulations the central challenge in virtual manufacturing is the sum of individual process steps in a value chain.

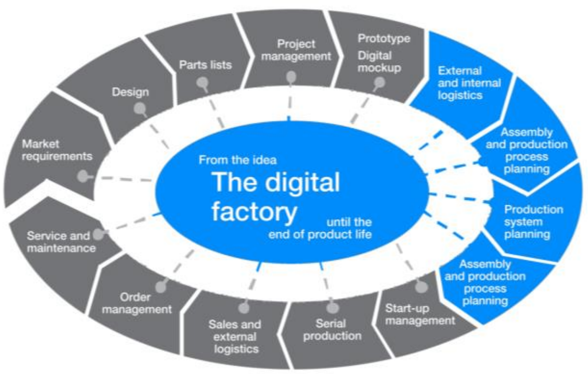

Fig. 4 localization of virtual production within the product life cycle in accordance with VDI Directive 4499

The Virtual Production Intelligence (VPI) is developed to set the interoperability of IT tools in a first step with distinctly less effort than using tailored solutions mentioned above. In a second step the integrated data is consolidated, analyzed and processed. The VPI is a holistic, integrative approach to support the implementation of collaborative technology and product development and factory and production planning. Thereby enabling optimization potentials are identified and made available for the purpose of early identification and elimination of errors in processes. To better understand the terms holistic, integrative and collaborative will be defined as follows:

- Holistic: all parts of the addressed processes will be taken into consideration.
- Integrative: use and integration of existing solutions.
- Collaborative: consideration of all processes addressed in involved roles as well as their communication

In the next section, the above-mentioned heterogeneities that should be overcome by the use of the VPI, a closer look.

IV. Heterogeneity of Simulations

Regarding ISO / IEC 2382-01 [17] interoperability between software applications is realized when the ability exists to communicate, to run programs, or to transfer data between functional units is possible in such a way that the user need no information about the properties of the application. Figure 5 summarizes the heterogeneities, which contribute significantly to the fact that no interoperability is achieved without using customized adapters [18, 19, 20].

Fig. 5 types of heterogeneity of simulations

Technical heterogeneity describes differences in the way how to access data or applications by users or other applications. The syntactic heterogeneity describes the differences in the technical description of data, for example different coding standards such as ASCII or binary encoding, or the use of floating-point numbers as float or double. These two types of heterogeneity can be overcome relatively easy by the use of adapters. Therefore a generic approach should be applied, so that the implemented adapters are reusable. Existing libraries and solutions are available to address the problem of technical heterogeneity. Most modern programming concepts contain methods for implicit type adjustments and controlling explicit conversion of data [18, 19, 20].

Overcoming the structural and semantic heterogeneity is the much greater challenge. Structural heterogeneity differences specify the representation of information. Semantic heterogeneity describes the differences in the importance of domain specific entities and concepts used for their award. E.g. the concept of ambient temperature is used by two simulations, simulation A, usesthe concept to define the room temperature of the site where the heating furnace is located. Simulation B uses the concept to define the temperature inside the heating furnace so the temperature in the immediate vicinity of the object to be heated is specified.

In the following section, the VPI is presented, which provides methods to overcome of the mentioned heterogeneity and to facilitate interoperability between applications [18, 19, 20].

V. Virtual Production Intelligence

The main objective for the use of the "Virtual Production Intelligence" is to gather results of a simulation process, to analyze and visualize them in order to generate insights that enable a holistic assessment of the individual simulation results and aggregated simulation results. The analysis is based on experts know how and physical and mathematical models. Through an immersive visualization requirements for a "Virtual Production Intelligence" are completely covered.

The integration of result data from a simulation process in a uniform data model is the first step to gain knowledge from these data and to realize the extraction of hidden, valid, useful and actionable information. This information includes, for example, the quality of the results of a simulation process or in concrete cases, the causes for the emergence of inconsistencies. Right now the user who has to identify such aspects has currently limited options to do so. With the realization of an integration solution a uniform view to the data gets possible. This includes on the one hand

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the visualization of the entire simulation process in a visualization component and on the other hand, the analysis of the data over the entire simulation process. For this purpose, different exploration methods can be used.

First, the data along the simulation process is integrated into a canonical data model. This is implemented as a relational data model, so that a consistent and consolidated view of the data is possible. Subsequently, the data is analyzed on the analysis level by the user. The user can interact in an immersive environment to explore and analyze the data. With the ability to provide feedback to the analysis component, the user can selectively influence the exploration process and make parameterizations during runtime.

In addition to a retrospective analysis by experts, it is also useful to monitor the data during the simulation process. Such a process monitoring assures compliance with parameter corridors or other boundary conditions. Therefore, if a simulation provides parameter values outside the defined parameter corridors the simulation process will be terminated. Then experts can analyze the current results in order to subsequently perform a specific adaptation of the simulation parameters. A process monitoring could also enable the extraction of point-of-interests (POI) on the basis of features that would be highlighted by the visualization.

Figure 6 shows the components of the "Virtual Production Intelligence". The application layer includes the simulations that are needed along a defined process. These are interconnected through a middleware that implements the data exchange. The middleware ensures the data integration and data extraction during the process. An integration server is deployed, which provides a service-oriented approach. It provides integration and extraction services. The database server tracks the central data model and serves as a central repository for all data generated during the process.

The following example illustrates the possibility of using the VPI in supporting the factory planning process. Figure 7 depict the functionality according to the example.

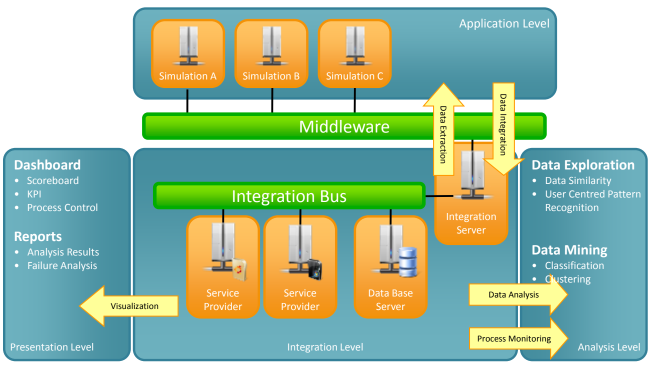

Fig. 6 Components of the Virtual Production Intelligence

The VPI is used for platform-optimized factory layout and process chain analysis. The factory design in the example is based on the principles of Condition Based Factory Planning (CBFP) [10]. This approach represents a modularization of the planning process of factories. The approach is carried out in dedicated planning modules. The data collection and analysis in the planning stages is carried out by the use of common office applications. The main issue is to copy the data correctly from one module to the next, right now this is done manually. Therefore it is associated with high costs in terms of data transfer consistency, and continuity. In particular, the realization of a factory model for varied production scenarios is not readily feasible, because there is no consolidated data. To show the present situation individual planning modules have to be linked by an operator.

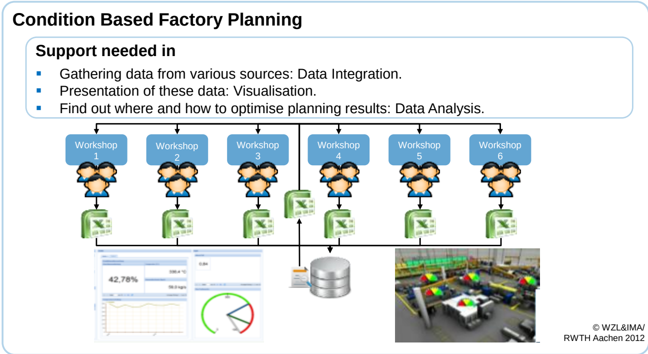

Fig. 7 support in factory planning

By applying the VPI concept to the CBFP many opportunities for an innovative production planning process became possible. All the CBFP modules can be interconnected by the use of the common information model. New possibilities for analyzing and visualizing can be realized based on a central data management. Simulation results of different factory planning scenarios can easily be compared. To ensure a comprehensive and compact presentation of results and planning parameters of the various simulation modules, the VPI-platform has a web 2.0 module extension that enables the user to analyzes, interact and optimize the factory planning process. The web application can be run in any modern browser. The application supports the people involved in the planning process with current process variables from the database. Thus, it is guaranteed that the web app data is always synchronized with the server data. The user has the ability to send queries to the data base, perform manipulations on the inputs and outputs of the simulation and make changes to their presentation. It is possible to conduct a comprehensive process chain analysis, taking the particular dependencies with capacity planning and production planning structure into account. An effective optimization of different structures of production, such as determining the number of process chains and production segment is made possible only by mapping the interdependencies of different planning modules.

VI. Conclusion

With the VPI an essential contribution to the realization of the vision of the digital factory can be achieved. The VPI is an integration platform that enables heterogeneous IT tools in the phase of product and production planning to interoperate with each other. Based on information processing concepts it supports the analysis and evaluation of cause-effect relationships. Since product and production planning is the core area of virtual production as part of the digital factory the contribution focused on this part. The VPI is the basis to establish interoperability, the functionality of the VPI was presented and illustrated by using the example of factory planning. The use of the VPI allows a significant reduction in engineering effort to create tailored integration and analysis tools, since the VPI is an adaptive solution. Now it is possible to start with a process-oriented and so contextual information processing. Information is now not only based on a single process step, it is related to the overall process, so that the importance and validity of information can be considered.

The future work concerning the VPI will be the interactive data exploration based analysis. It is important to evaluate what cause-effect relationships can be identified through the exploration process. Furthermore, it must be examined how this information can be presented to the user in an immersive environment, and how can context information understandable and comprehensible be presented. For this purpose, there are various feedback-based techniques in which experts assess results of analysis and optimization. A bidirectional communication is needed, the user gives feedback and this feedback will be used to correct the displayed information. The system will store this feedback to avoid imprecise or erroneous statements.

References

[1] Chandler, A. D. (2004): Scale and Scope. The Dynamics of Industrial Capitalization. In: Belknap Press of Harvard University Press. Cambridge, Mass., London.

[2] Schuh, G.; Aghassi, S.; Orilski, S.; Schubert, J.; Bambach, M.; Freudenberg, R. et al. (2011): Technology roadmapping for the production in high-wage countries. In: Prod. Eng. Res. Devel. (Production Engineering), Bd. 5, S. 463–473.

[3] Brecher, C. (2011): Integrative Produktionstechnik für Hochlohnländer: Springer Verlag (Vdi-buch).

[4] VDI Guidline 4499, Blatt 1, 2008: Digitale Fabrik.

[5] VDI Guideline 4499, Blatt 2, 2011: Digitale Fabrik.

[6] Lauber, R.; Göhner, P. (1999): Prozessautomatisierung 1. 3. Auflage, Springer, Berlin.

[7] Kagermann, H.; Wahlster, W.; Helbig, J.: Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 – Ab-schlussbericht des Arbeitskreises Industrie 4.0.Forschungsunion im Stifterverband für die Deutsche Wissenschaft. Berlin 2012.

[8] DIN EN ISO 10303

[9] Nagl, M.; Westfechtel, B. (2003): Modelle, Werkzeuge und Infrastrukturen zur Unterstützung von Entwicklungsprozessen. Symposium (Forschungsbericht (DFG)). 1. Aufl.: Wiley-VCH. S. 331-332.

[10] Horstmann, C. (2011): Integration und Flexibilitat der Organisation Durch Informationstechnologie. 1. Aufl.: Gabler Verlag. , S. 156-162.

[11] Daniel Schilberg (2010): Architektur eines Datenintegrators zur durchgängigen Kopplung von verteilten numerischen Simulationen. Aachen: VDI-Verlag.

[12] Meisen, T.; Meisen, P.; Schilberg, D.; Jeschke, S. (2011): Application Integration of Simulation Tools Considering Domain Specific Knowledge. In: Proceedings of the 13th International Conference on Enterprise Information Systems.

[13] Reinhard, R.; Meisen, T.; Beer, T.; Schilberg, D.; Jeschke, S. (2012): A Framework Enabling Data Integration for Virtual Production. In: Enabling Manufacturing Competitiveness and Economic Sustainability; Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2011), Montreal, Canada, 2-5 October 2011. Hrsg. v. Hoda A. ElMaraghy: Berlin Heidelberg, S. 275-280.

[14] Byrne, B.; Kling, J.; McCarty, D.; Sauter, G.; Worcester, P. (2008): The Value of Applying the Canonical Modeling Pattern in SOA. IBM (The information perspective of SOA design, 4).

[15] West, M. (2011): Developing High Quality Data Models. 1. Aufl. Burlington, MA: Morgan Kaufmann

[16] Yeoh, W.; Koronios, A. (2010). Critical success factors for business intelligence systems. Journal of computer information systems, 50(3), 23.

[17] ISO/IEC 2382-01

[18] Daconta, M.; Obrst, L.; Smith, K. (2003): The Semantic Web: The Future of XML, Web Services, and Knowledge Management.

[19] Schilberg, D., Gramatke, A., Henning, K. (2008): Semantic Interconnection of Distributed Numerical Simulations Via SOA. In: Proceedings World Congress on Engineering and Computer Science 2008. Hrsg. v. International Association of Engineers: Hong Kong: Newswood Limited, S. 894-897.

[20] Schilberg, D.; Meisen, T.; Reinhard, R.; Jeschke, S.(2011): Simulation and Interoperability in The Planning Phase of Production Processes. In: ASME 2011 International Mechanical Engineering Congress & Exposition. Hrsg. v. ASME: Denver.

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