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# ADVANCED MODELING OF NETWORKED PRINT PRODUCTION BY USE OF XML-BASED JOB DEFINITION AND JOB MESSAGING COMMUNICATION

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## ABSTRACT

Networked production gains increasing importance in many industries. In print media industries networked production requires advanced print and media specific job definitions and the communication of job relevant information along the complete production chain. The relatively young XML based communication standard JDF/JMF allows to specify workflow models and data exchange. Based on an object-oriented approach a simulation and modeling framework is proposed, which implements modules for the resources and controls applied in this particular industry. For this framework the available JavaSim-simulation library shall be extended to enable modeling of networked print production using the same JDF-/JMF-communication algorithms as applied in real-world system communication. This leads towards integration of simulation for factory planning and operative planning and control of networked print production in a digital factory environment.

## 1 INTRODUCTION

The print media industry is facing tough competition. Overcapacity and sluggish demand are cutting margins. At the same time, customers' expectations regarding flexibility, quality, speed and reliability have never been higher. The various machines and processes have already been widely optimized in the past. Now the situation calls for processes to be reviewed, organization to be optimized and manufacturing costs to be cut even further. Process integration and networked production are the leading directions for the next years. Simulation technology enables to analyze and improve the planning even of complex production networks.

In various industries there are already many simulation approaches (Dangelmaier et al. 2006, Kapp et al. 2005, Mönch 2007, Yalcin and Namballa 2004) of networked production systems even in digital factory environments (Bley et al. 2005, Schloegl 2005, Wenzel et al. 2005, Westkämper et al. 2005). So what is especial in print production networks. In print media industries there are mainly small and medium businesses, large companies are exceptional and the production planning and control differs from other industries. The main difference compared to other industries is that production planning performed is mainly job related and not product related. Often with start of planning a production job the product is not completely defined. Further in printing industries often the argument is used that there are no standardized products and each job differs from others. Print products are often not defined with a product structure containing a bill of material.

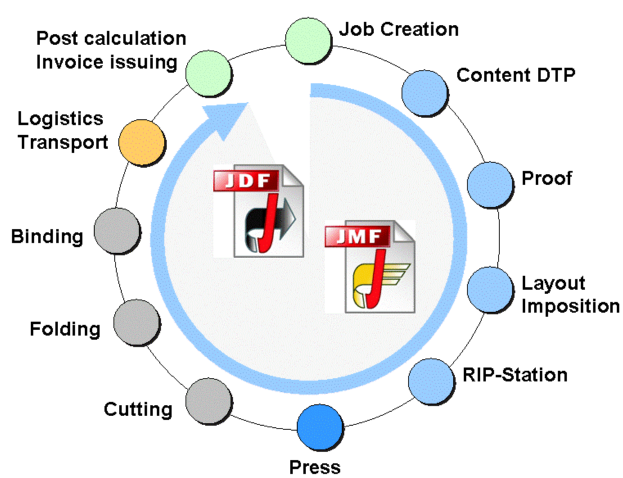


Figure 1: Processes in print production

In print media industry the communication technology is changing. The newly developed vendor independent Job Definition Format (JDF) and Job Messaging Format (JMF) are established as a new industrial communication standard to networked print production (Kühn and Grell 2005). Supported by the PDF document format a new generation of full integrated network workflow solutions can be developed that enable process integration along the entire value added chain (Figure 1) Faster job preparation, clear job tracking and enhanced cost transparency are the goals. All job-relevant information can be distributed to the various production areas and all production data can be transfers to central control system. The fact that the production system has one general interface cuts the technical implementation workload and eases the maintenance outlay for networked print production considerably.

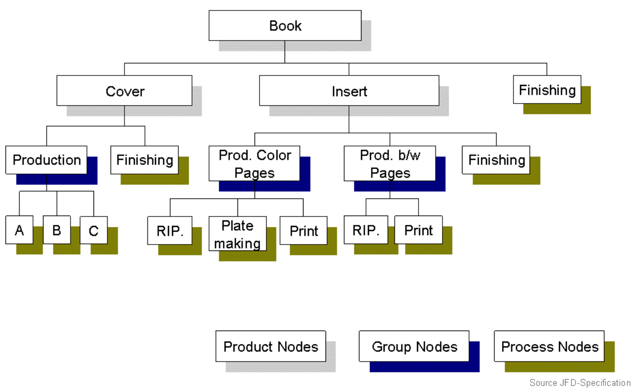


Figure 2: JDF-Structure

Due to the job related approach the JDF-structure (Figure 2) contends product nodes, process group nodes and process nodes in the same structure (CIP4 2005a). A JDF-node requires input resources, such as machines, material, data etc. and produces output resources, such as goods in process, data etc. (Figure32). These output resources are again input resources for the next JDF-node.

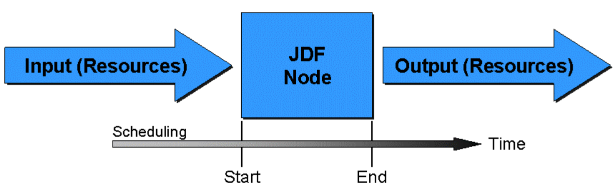


Figure 3: JDF-Node

Discrete event simulation technologies enables to test, analyze and optimize networked production in advance. The use of discrete event simulation for modeling process in a print production workflow is not new (Bäck et al., 1997) (Nordqvist and Fällström 1996). Heidelberger Druckmaschinen AG has developed BizModel, a simulation software for printshop planning (Heidelberg 2008). BizModel takes the actual situation within a print shop and delivers options for optimized print shop development with regard to technical and business-management but the software doesn't cover detailed networked production aspects.

For networked print productions and new communication standards the demand has changed and an advanced approach for simulation is mandatory (Buckwalter 2005a/b). This paper presents a concept for a simulation framework focused on networked print production. The important feature of this framework is the use of JDF-/JMF-communication algorithms in simulation, which is compatible to the real system communication.

## 2 SIMULATION OF NETWORKED PRINT PRODUCTION

Networked print production projects are very complex. These projects don't focus on one particular area of a company only; all areas and levels of a company and even the network between companies have to be involved. A company can't just buy a network. To establish a networked production requires to analyze and standardize most of the processes in a company or respectively in all involved companies. This is an enormous effort. In practice it takes nearly two years to establish a network production project in a medium size printing company with 100 people. The experience shows that there are a lot of problems in detail, which are seen first during the praxis test at the customer's place.

Simulation is a powerful tool to improve decision-making on a reliable base. Simulation shall enable to model print production networks in advance, to identify good process strategies and to find problems at an early state. This improves and accelerates the benefits available in networked production systems. The customer requirements for simulation of networked print production can be classified in the following categories:

- Simulation of networked job preparation
- Simulation of networked machine presetting
- Simulation of networked production planning and control
- Simulation of networked operating data logging and actual costing
- Simulation of the networked colour workflow
- Simulation of customer networks
- Evaluation of the investment decision

Each of these positions has specific requirements and not all of these has to be reached immediately in a project. The priority depends on the customers requirements in the actual project and the investment amount available for the project. However a full integration will provide most benefit. The benefits of each category are described in the following.

### 2.1 Simulation of Networked Job Preparation

Simulation of networking job preparation shall improve benefits such as:

- Reduce job throughput times,
- Eliminate inefficiencies due to duplicated data capture in different software applications,

- Reduce costs incurred due to errors by means of standardized designations, up-to-date order information and previews.

### 2.2 Simulation of Networked Machine Presetting

The presetting produced digitally in order management or prepress can be used to set up electronically controllable machine components. Simulation helps to test and improve the networking machine presetting operations:

- Reduction in setup times,
- Reduction in waste, improvement in production reliability and quality,
- Reassignment of the work to just a few specialists.

### 2.3 Simulation of Networked Production Planning and Control

Simulating the networking production planning and control shall improve benefits, such as:

- Eliminating duplicated inputs,
- Eliminating follow-up questions on the production status,
- Reducing the effort required for planning meetings,
- Increasing the reliability of production by ensuring that paper, ink and plates are available when needed at the correct press,
- Increasing efficiency by a feedback loop based on actual data.

### 2.4 Simulation of Networked Operating Data Logging and Actual Costing

Simulation offers to check and analyze networking operating data logging and actual costing:

- Eliminating duplicated inputs and checks,
- Providing prompt status messages and high-quality management information,
- Recording the actual costs.

### 2.5 Simulation of the Networked Colour Workflow

Networking the colour workflow can be checked and improved by simulation:

- More productivity from the first step to the finished print,
- Increased reliability and consistency in the print quality, true-colour proofs,
- Shorter setup time and less waste.

### 2.6 Simulation of Customer Networks

In print production the integration of the customer in networked solutions has a lot of benefits. By use of simulation these networks can be tested and improved:

- The customer's project members have a complete overview of the project information they need. This includes the product description, the time and place of delivery for order tracking and access to the stock system for requisitioning preprinted materials.
- Accelerated communication thanks to digitalization of ordering processes with agencies and print service providers.
- Deliver management information for customers covering inquiries, print orders issued, etc. This represents a source of quick data for checking budgets.

### 2.7 Evaluation of the Investment Decision

Process integration based on the Job Definition Format shall help to eliminate inefficiencies in the production process. This benefit is achieved at the cost of investments in software, hardware and services. In addition, management and the staff undergoing training are tied up to a significant degree during the introductory phase of networking. The benefits and cost of networking must be weighed against one another depending on the order and operating structure. Discrete event simulation can support the decision-making process.

For the implementation of production networks the technical and commercial aspects have to be considered. Simulation allows to analyze technical aspects, such as resource layout and communication architecture. Further input data for the cost calculation can be validated. The payback period is determined by considering two areas separately. These are, on the one hand, networking of job preparation, production planning and control and operating data logging and actual costing – grouped under the term operational data networking – and, on the other, networking of machine presetting and colour workflow.

## 3 THE INTEGRATION CONCEPT

In order to enable models with acceptable effort and sufficient level of detail a concept for an applied simulation framework shall be introduced. A simulation framework focusing on print production networks has to fit the specific requirements. Goal of the Java-based simulation framework is to model the production and information flow including production planning and control in detail.

In order to obtain usable results the communication between the resources shall be compatible with the real-world communication. Figure 4 shows an overview of the principal communication structure between the job management system and the simulation modules. The job management system takes a job, a JDF instance, from the job queue. It simulates the execution of the job in the particular area, consuming input resources and producing

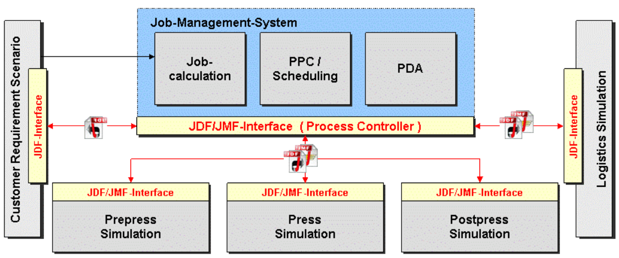


Figure 4: Simulation Communication Structure

output resources accordingly and then sends the updated JDF instance for further processing in the workflow. During process execution, all state changes within the simulation model are sent to the production planning and control systems monitoring the process or tracking the job. In the first approach the production processes, such as printing, cutting, folding or needle stitching have not been modelled in detail. The simulation framework concept is baed on the JavaSim library developed at the University of Wuppertal (Kuehn 2002) and the Java-based JDF Communication Library available at CIP4 (CIP4 2006).

## 3.1 Simulation Framework Concept

In the proposed framework concept all modules of resources shall be seen as an object containing modeling the physical behavior of the resource including the low level control and an object containing the communication interface. The communication with the resource is performed through the communication interface only and the communication interface has to be compatible with the real-world communication, at least on a certain level.

The clear separation of modeling the material flow, the controls and the communication will lead to a better integration of simulation into the planning and implementation processes. For the integration of simulation in digital factory environments this is very important. Compatible interfaces between simulation modules and the control systems enable to switch between simulation modules and system components.

By use of compatible communication it is also possible to build an entire print production workflow using only simulated processes, but use a real production planning and control systems to track and control the processes in the workflow. Such a setup allows to experiment with configurations of production systems very realistically because the real control logic of the real production planning software is applied. Further in simulation the effort can be reduced significantly, because the control system need not be emulated in the simulation model itself.

This framework concept can be applied in the digital factory environment to plan and to evaluate complex networked print production systems. In a second stage it even offers the possibility to enhance the operative production planning and control as an integrated process from the top level to the factory floor control.

## 3.2 JDF/JMF Communication

The definition of JDF is based on the idea of creating a standardized, manufacturer independent and comprehensive data format for the print media industry to standardize information exchange between different applications and systems in and around the graphic arts industry. The concept for this industry standard originally was presented by Adobe, Agfa, Heidelberger Druckmaschinen and MAN Roland. In between it is maintained and developed by the International Cooperation for the Integration of Processes in Prepress, Press and Postpress Organization (CIP4), a not-for-profit association, which currently consists of more than 300 manufacturers, organizations and print service providers. Details are available at www.cip4.org. The CIP4 reference model is shown in Figure 5.

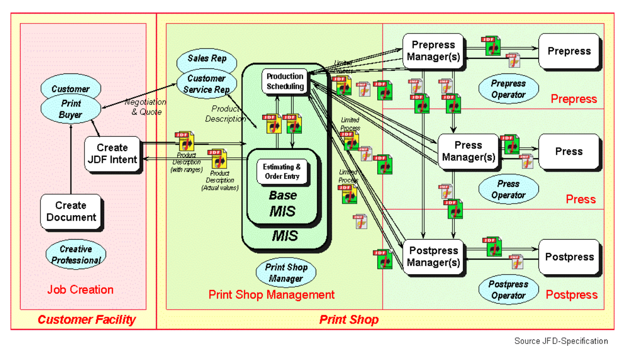


Figure 5: CIP4 Reference Model

- JDF is a comprehensive XML-based file format for job ticket specifications combined with a message description standard and message interchange protocol,
- JDF enables the integration of commercial and planning applications into the technical workflow,
- JDF provides a clear, full-integrated structure for the entire workflow including the relevant target and actual data,
- JDF enables end-to-end production control, even across corporate boundaries,
- JDF enables both the horizontal and the vertical integration between order management, produc-

tion planning and control, and production resources.

- JDF has become an accepted and requested standard in the industry among suppliers and customers.

JDF also has an integrating effect on the different market segments of the print media industry. In the future, messages in both newspaper printing and commercial printing will be transmitted via a common standard. The establishment of a uniform, comprehensive standard significantly reduces the effort required to develop and implement networking solutions. Print service providers are able to deploy software applications from different manufacturers without having to make any compromises when it comes to networking. However, because the JDF specification (CIP4 2005a) is very comprehensive (more than 900 pages) it is not very useful for each single device to implement the complete JDF-specification in all details. Therefore subsets are designed.

### 3.2.1 Interoperability Conformance Specification (ICS)

For a simplified and clear communication Interoperability Conformance Specifications (ICS) are defined. (CIP4 2005c/d) These are well-specified subsets of JDF, each defining an interface between pairs of communication partners in the workflow.

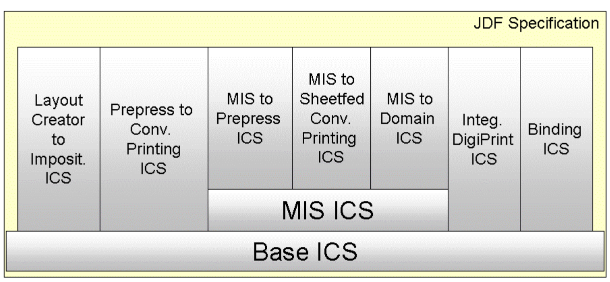


Figure 6: Interoperability Conformance Specifications

The ICS documents provide communication standards for individual classes of devices. ICS documents do not add to the JDF specification, but provide additional constraints and are specific to the particular interface. The ICS specification follows an hierarchical concept (Figure 6). In addition to a base ICS document that applies to all JDF-enabled devices, ICS documents have been published to cover a variety of interfaces, including:

- Binding
- MIS to Prepress
- Prepress to Conventional Printing
- MIS to Conventional Printing - Sheetfed
- Integrated Digital Printing
- Layout Creator to Imposition

ICS documents look at the interface between the “manager” of a job, such as a production planning system or a pressroom management system and the “worker”, the system or software that will perform the desired process. The ICS documents define the roles of the “manager” and “worker”, including their ability to read and write JDF, minimum support for JMF options. Additionally it is defining how job files are to be exchanged or identified, and how support for particular JDF processes and resources is required. When a JDF-enabled product meets the “manager conformance requirement” of a particular ICS, it achieves interoperability with other JDF-enabled products that meet the corresponding “worker conformance requirements” of the same ICS. The discrete event simulation of networked print production systems has to apply this ICS approach in order to be compatible with the real-world communication.

### 3.2.2 Job Messaging Format (JMF)

The Job Messaging Format (JMF) complements the Job Definition Format and is used to transfer messages. Up-to-the-minute information defined using JMF can be exchanged while production processes are in progress. Job lists are created using JMF to report on device capabilities (resolution, formats, etc.) and transmit status messages (CIP4 2005a). JMF uses the http transfer protocol.

### 3.2.3 JDF/JMF-Networking Architecture

The Job Definition Format is a comprehensive standard for data exchange. But the JDF specification does not describe what information is to be maintained where, nor who has the right to access and, where necessary, modify it. Basically, the following logical components are provided in a JDF-based networking system:

- Agents are tasked with writing a JDF or extending or modifying an existing one,
- Controllers route a JDF to the specified location,
- Devices form the interface between software applications and machines. Devices interpret the JDF at their specific nodes and control the relevant machines,
- Machines are components of the workflow that are controlled by a device and carry out the processes.

The agents, controllers and devices should not just be able to process JDF though. They should also provide a JMF interface with a bidirectional communication mechanism for messaging. Figure 7 shows a JDF-/JMF-Device. The input for the job to be performed is communicated via JDF. JMF messages are sent and received during the process. After processing the JDF is sent back containing the actual data of particular job processing.

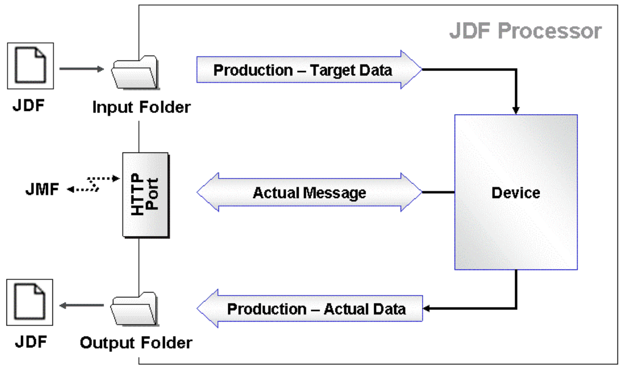


Figure 7: JDF-/JMF-Device

Due to the complexity of production it is not very useful to transfer the JDF-File as a job ticket just from one resource to another. The following production scenario illustrates quite clearly a typical example in networked production: In a particular production workflow, a print job is to be split over three different presses, two of which are located within the company and a third at a cooperating print service provider. Finishing is to be carried out with batches overlapping on two different production lines, i.e. finishing work is to start before all the sheets have been printed. Due to deadline problems, the decision to use a second line for finishing is taken at short notice and leads to a revision in planning after printing has started. This situation shows that a sequential transfer of a job ticket can't be an effective solution. In fact on the control level there is a powerful software required, dealing safely with all these cases. Figure 8 shows a JDF/JMF pipe mechanisms which deals with overlapping production e.g. if one part of job is still produced on the press and another part is already in the postpress area for cutting and folding.

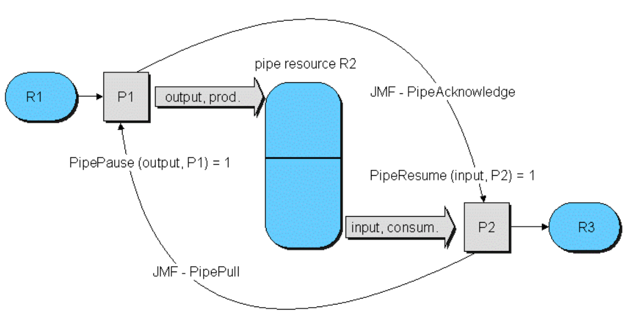


Figure 8: JDF/JMF Pipe mechanism

The networking architecture must comply with the following requirements, among others:

- Secure and unambiguous regulation of data transfer and data management
- Data consistency must be maintained,
- Fast data transfer and short reaction times must be guaranteed,
- Unnecessary data transfer must be avoided,
- The entire system must function without error, even when products from different manufacturers are integrated in a workflow,
- The system should include robust mechanisms to make sure that processes are not aborted if problems arise.

## 4 FRAMEWORK IMPLEMENTATION

The implementation shall be based on the JavaSim library and the Java CIP4 Software Development Kit. Specific Classes and Interfaces have to be implemented.

### 4.1 JavaSim Library

The JavaSim library is an advanced simulation library, developed for the simulation of discrete event processes (Kuehn 2002). The library contains central classes such as the *GeneralSimModel* with the *SimController* and the ModelStructure, the *CtrlObject* or the *InterfaceObject* (Figure 9).

| | |
|---|---|
| General Simulation Objects | Simulation Controller |
| | General Simulation Model |
| | Module |
| Simulation Event Objects | Process Generator, Disruption Object |
| | Shift Calendar, Shift Object |
| | Scheduler |
| Material Flow Objects | Place oriented Material Flow Objects |
| | Length oriented Material Flow Objects |
| | Mobile Material Flow Elements |
| Information Flow Objects | Storing Data |
| | Controls |
| | Random Distributions |
| Decision Making Objects | Connecting and Routing Control |
| | Objects for Managing Services |
| Interface Objects | File, XML, Database, Process Interface |

Figure 9: Structure of the JavaSim library

The JavaSim Library follows an object-oriented design and offers general simulation objects, material flow objects, information flow objects, decision-making objects and applied material flow objects. The core object of each simulation model is the *SimController* which has to handle all events correctly. From the general class *GeneralSimModel* applied models such as a *SimModelPress* or a *SimModelPrePress* can be derived. An hierarchical model structure can be established using the class *Modul*.

The JavaSim library is not fixed on a certain simulation level like many simulation tools in the market. With its object-oriented approach it is open and modular. The library offers features similar to the flexibility of a simulation language, over the level of general building blocks, such as workstations and assembly stations, up to the efficiency of simulators with special building blocks. The JavaSimLibrary strictly follows an object-oriented design. It contains public simulation classes, made available for the user of the simulation library, and internal simulation classes and utility classes for internal use in the library only. The library offers general simulation objects, material flow objects, information flow objects, decision-making objects and applied material flow objects. The internal class *InfFlowObject* is used to implement information flow. Special information flow elements may be derived from this class. The class *SimEventObject* is based on the class *GeneralObject* and contains the additional functionality for creating simulation events. From this class the general classes *EventGenerator* and *MathFlowObject* and *MathFlowObjecExt* are derived. Again from these the detailed material flow classes such as *Buffer*, *BufferFifo*, *BufferLifo* etc. are derived. For all simulation classes there are some general class features available, e.g. such as create object, delete object, constructor control and destructor control.

This JavaSim library with general material flow and control objects is available at the institute. It can be applied as a base for the simulation framework. Objects specific to print production networks have to be inherited from the general objects available.

## 4.2 CIP4 Software Development Kit (SDK).

The CIP4 Consortium makes free open source libraries for the programming languages C++ and Java available (CIP4 2006) These libraries are intended to make it easier for software developers to write JDF applications, reducing development times and therefore cutting costs. However in practice the use of the common libraries doesn't guarantee that JDF is always interpreted consistently. Due to the complexity of JDF the communication allows different XML's even using the specification correctly. A CIP4-certificate for tested communication interfaces is not available yet.

## 4.3 JDF-/JMF-Communication

The communication between modules in the networked print production simulation framework shall be compatible with the real word communication. Modeling of the network communication devices, such as resources, machines, etc. requires compatible JDF-/JMF communication structures. Therefore the JavaSim library shall be extended by use of an JDF-/JMF-communication library. This communication library is available as open source at CIP4 (CIP4 2006). In order to be compatible with the real-world communication the simulation of networked print production systems has not only to apply just the JDF-/JMF library but even the complete ICS approach. However these ICS modules can be implemented stepwise.

Figure 10 shows the principal structure of a simulation module which performs a MIS to … communication. Based on the simulation of the production process and the material flow, the control level links the physical behavior of the module to the communication level with Base ICS, MIS ICS and MIS to … ICS.

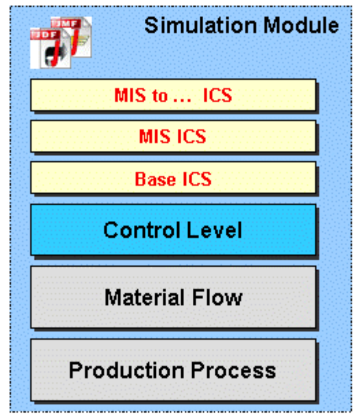


Figure 10: ICS-Module

This concept using compatible communication structures, by applying JDF-/JMF- communication to simulation modules and real production environments as well, allows even to integrate and simulate heterogeneous systems in the print production workflow.

## 4.4 Level of Detail

In the framework the modeling level of detail regarding communication is high in order to be compatible with the real word communication. The level of detail regarding material flow simulation shall be very flexible. If the simulation focus is on communication and controls the material flow model level of detail can be on a relatively low level. In this case resources are just time-consuming objects, errors are produced in a deterministic sequence or randomly in order to enable the test of communication error messaging. For certain modules within a model this level of detail might be increased step by step. With a next level of detail it might be even possible to divide the physical behavior and the low level control for certain resource module. Principally the framework concept is open for these kind of approaches, however the focus here is on communication and not on detailed processes or detailed process controls.

The advantage of the applied hierarchical framework concept is, that a simulation can be performed on a very low level of detail first in order to test the communication flow. In a second step the level of detail can be increased in order to check the dynamic of the modeled production network. And with a next step it is possible to increase the level of detail for bottleneck areas again in order to make really sure that these critical areas fulfill the demand sufficiently.

## 5 SUMMARY

In print media industries networked production gains increasing importance. The relatively young XML based communication standard JDF/JMF allows to specify workflow models and data exchange for print and media specific jobs and the communication of job relevant information along the complete production chain. The proposed simulation framework concept is based on an object-oriented approach. For this framework the available Java-Sim-simulation library shall be extended to enable modeling of networked print production using the same JDF-/JMF-communication algorithms as applied in real-world system communication. The proposed simulation and modeling framework shall implement modules for the resources and controls applied in this particular industry.

The use of compatible communication structures has the advantage that simulation and real-world modules can be combined in a test environment. This approach allows to integrate the framework in a digital factory concept using simulation not only in a factory planning phase but also for the operative planning and control of networked print production.

The simulation framework shall be realized platform-independent in Java. The existing JavaSim simulation library from the University of Wuppertal and the open source JDF-/JMF communication library available from CIP4 are the base for the implementation.

At this state the research is still in a preliminary phase. The libraries are available. First tests have been performed and the result shows that the described approach is possible. The next steps for research and development are to complete and detail the concept and to implement and validate the specific objects of the framework and to extend the functionality and levels of detail stepwise. On each level detailed tests with specific scenarios of networked print production have to be performed in order to validate the framework modules and to test if the concept meets the required demands.

## REFERENCES


Bäck, A., T. Lehtonen, A. Karttunen, M. Kuusisto, and R. Launonen. 1997. Evaluation of Printing Production in Networks by Means of Computer Simulation Models. *Advances in Printing Science and Technology* 24: 177–190.

Bley, H., and C. Zenner. 2005. Coupling of Assembly Process Planning and Material Flow Simulation. In *Proceedings of the 2005 IEEE International Symposium on Assembly and Task Planning* (ISATP2005), Montréal, Canada.

Bley, H., C. Franke, and C. Zenner. 2003. Integrated Data Management and Variant Management – Milestones on the Way to the Digital Factory. Production Engineering, Volume X/1 (2003), *Annals of the German Academic Society for Production Engineering*, 105-108

Bley, H., and C. Zenner. 2005. Handling of Process and Resource Variants in the Digital Factory. *CIRP Journal of Manufacturing Systems* 34 (2):187-194.

Bley, H.; C. Franke, and C. Zenner. 2005. Variant Management in Production Planning. *CIRP Journal of Manufacturing Systems* 34 (1, 1-8).

Buckwalter, C. 2005a. A JDF-enabled Workflow Simulation Tool. In *Proceedings, TAGA 2005, 57th Annual Technical Conference*, 271-281, Toronto, Canada.

Buckwalter, C. 2005b. A Tool for Testing Compliance with CIP4's Interoperability Conformance Specifications. In *Proceedings of 2005 International Conference on Digital Production Printing and Industrial Applications*, 83-84

CIP4 2005a. JDF Specification Version 1.3, <www.cip4.org/documents/jdf_specifications/JDF1.3.pdf> [accessed February 9, 2008].

CIP4 2005b. XML Schema for JDF Version 1.3 <www.cip4.org/Schema/JDFSchema_1_3/JDF.xsd> [accessed February 9, 2008].

CIP4 2005c. "Base Interoperability Conformance Specification" (Base ICS) <www.cip4.org/document_archive/documents/ICSBase-1.0.pdf> [accessed February 9, 2008].

CIP4 2005d. ICS Registry <www.cip4.org/document_archive/ics.php> [accessed February 9, 2008].

CIP4 2006. Java SDK. <www.cip4.org/open_source/index.> [accessed February 9, 2008].

Dangelmaier, W., M. Aufenanger, K. Mahajan, C. Laroque, and D. Huber. 2006. Event simulation of supply chain networks - Dynamic detailing in the material flow simulator d3FACT insight. In *Proceedings ESM, European Simulation and Modelling Conference*, 50-54.

Fritz, J., and G. Hellener. 2006. Planning data preparation - Key requirement for automated simulation modeling. *CIRP International Seminar on Manufacturing Systems*.

George, L., A. Kovacs, and P. Paganelli. 2003. A planning and management infrastructure for large, complex, distributed projects beyond ERP and SCM. *Computers in Industry* 51 (2):165-183.

Heidelberger Druckmaschinen AG. 2008. Print Shop Planning: Optimizing Business Processes Through Simulation. <www.heidelberg.com> [accessed February 10, 2008].

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

Kühn, W. 2002. JAVA-Sim - An advanced Discrete Event Simulation Library. In *Proceedings SCSC 2002, Summer Computer Simulation Conference*, 393-397, San Diego, USA.

Kühn, W., and M. Grell. 2005. *JDF, Process Integration, Technology, Product Description*. Springer, ISBN 3-540-23560-4.

Mönch L. 2007. Simulation-based benchmarking of production control schemes for complex manufacturing systems. *Control Engineering Practice* 15 (11): 1381-1393.

Niemann, J., and E. Westkämper. 2006. Dynamic life cycle performance simulation of production systems. In *IPP, CIRP International on Life Cycle Engineering Conference* 12:419-428

Nordqvist, S., and F. Fällström. 1996. Simulation of Newspaper Production Processes - Decision and Management Support Tools. In *TAGA 1996 Conference Proceedings*, 299–317

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

Vancza, J., T. Kis, and A. Kovacs. 2004. Aggregation - the key to integrating production planning and scheduling. *CIRP Annals - Manufacturing Technology* 53(1):377-380.

Venkateswaran, J., Y.-J. Son, and A. Jones. 2004. Hierarchical Production Planning Using a Hybrid System Dynamic-Discrete Event Simulation Architecture. In *Proceedings of the 2004 Winter Simulation Conference*, 1094–1102.

Wenzel, S., U. Jessen, and J. Bernhard. 2005. Classifications and conventions structure the handling of models within the Digital Factory. *Computers in Industry* 56(4):334-46.

Westkämper, E., B. Gottwald; and F. Fisser. 2005. Migration of the digital and virtual factory to reality. *CIRP Journal of Manufacturing Systems* 34(5):391-396

Yalcin, A., and R. K. Namballa. 2004. An object-oriented simulation framework for real-time control of automated flexible manufacturing systems. *Computers & Industrial Engineering* 48:111–127.

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