A Study about Architecture Development for Grid-based Engineering Service

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1. Introduction

As products have become complex and customers' demand has been diversified, the enterprises' quick responses to a rapidly changing market environment are required. Enterprises attempt to respond quickly to external market influences through diverse ways to reduce production cost and lead time by establishing fast production plans and removing problematic factors through process analysis.

Particularly in Korea, there are big differences in the size of firms between large companies and small to medium-sized enterprises. In smaller enterprises, it is difficult to exchange information among enterprises and to respond quickly to the demand of prime contractor companies. As solutions to these problems, the manufacturing information systems such as the manufacturing execution system (MES), enterprise resource planning (ERP), manufacturing simulation and statistical quality control (SQC) have been used in Korea. However, the usability of these systems is low since they are used in part by enterprises or they are difficult systems in the process of exchanging information among the adopted information systems.

As one of the solutions to these problems, we propose "A Networked Smart Digital Factory Platform Based on Grid Engineering Platform" so the smooth exchange of information among manufacturing companies and among manufacturing information systems is possible. This project will conduct a feasibility study on the proposed platform.

2. Requirements analysis

To produce PCB products, the inner layer should be made, as shown in Figure 1. The inner layer goes through either a drilling process or the process of mounting the devices by drilling through the multi-layer.

The manufacturing companies in charge of each process exist. The applicable manufacturing companies have either vertical relations or horizontal relations that use various solutions to produce a PCB.

Each manufacturing company has its factories located in spatially separated places. The production plans and marketing are done in Korea, while the production and production management are done in China. By the nature of electronic products, the product life cycle is short while the amount of demand and delivery

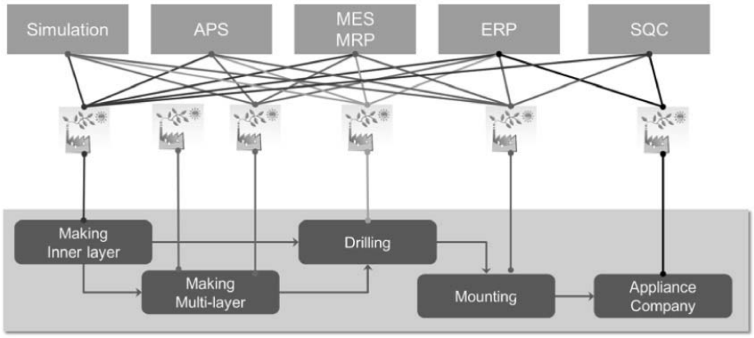


Figure 1. Processes and Solutions for PCB production

due date are irregular and rapidly changing.

Because of this, a manufacturing company can have over demand or cannot meet its manufacturing schedule and due date, bringing about serious situations in the company's business operation.

Expected Services:

The final purpose of networked smart digital factory platform is to enable factories and enterprises in distant places to have smooth utilization of information systems and exchange of information. The following are examples of utilizing networked smart digital factory platform.

The case in which one company has its factories in China and its headquarters in Korea

The production plans are established in Korea, using solutions such as ERP, simulation, and APS. The production instruction is sent to China where the factories perform production management using solutions such as MES and SQC.

In this case, each solution exists in every management organization and manufacturing organization sharing the same information. Alternatively, all the solutions may be in Korea, while they can have access to solutions through the Internet and utilize similar information in China.

The case in which an ordering organization wants to share information with many suppliers

An ordering enterprise may want to know the current state of production and product quality of suppliers. In this case, the suppliers should be able to disclose their information to the particular user.

The case in which component manufacturers want to share the information systems and production information among them

In the case in which a manufacturer cannot operate all the information systems, the various information systems can be utilized through the server located at the center in the form of a group.

Topics to be addressed by the Grid Platform:

Operation of the information system

- Small and medium-sized manufacturing enterprises lack specialized manpower and data processing room that can operate computer systems.

- The systems and tools for product design, planning, or process designs are heterogeneous and geographically distributed, but used only individually by the users/planners who reside in each physical site.

Connection with information systems

- Information is not shared among the information systems that are being operated, so it is used separately.

Collection of data

- It is impossible to collect integrated information about separately located factories and lines.

The case in which the ordering organization wants to check and search for information about current state of production and defective products of subcontractors

- When there are requests from the ordering organization, the data are organized and sent via email.

The case in which many enterprises share the use of the information system

- There is no support.

Information security

- Since it is the internal system, there is no need to consider information security.

Production instruction to factories located in distant places

- Since information is not shared among factories located in distant places, production instruction is impossible.

Overall working process plans and monitoring on the enterprise's production plans

- It is difficult in the physically distant environment.

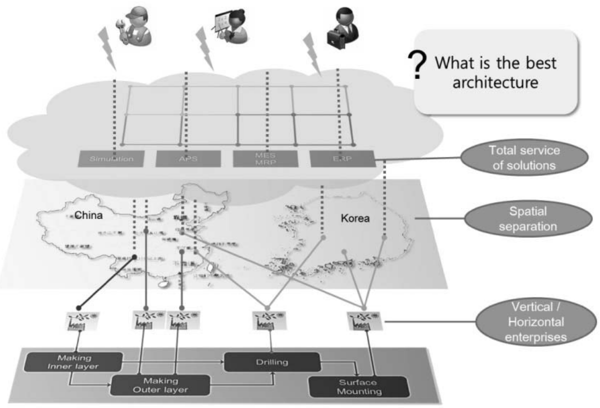


Figure 2. The best structure for the expected service

Grasping each process in current conditions of detailed production in the entire working process

- In the spatially separated case, it is difficult to grasp current conditions of a detailed production.

Simulation, APS

- It is impossible to utilize data on the spot.

Connection with SCM

- No connection

3. Smart Digital Factory Platform based on Grid Engineering for manufacturing concepts

The Smart Digital Factory Platform concept consists of three logic structures in order to address the specified challenges. The Workflows and Roles defining the reference Workflows and Roles of different stakeholders and are implemented in the platform. Stakeholders in this context are different operators, planners, departments, sites or enterprises and the corresponding Digital Tools. The Factory Data Model specifies the information model and objects for the information exchange and is the second logic foundation for the Smart Digital Factory Platform. The third part of the concept is the Smart Digital Factory Platform Architecture, which details the required technical components. In the following sections these three logic structures are further detailed.

3.1 Workflows and roles

Every Engineering Platform requires logic foundations, which are implemented through workflows and specific roles. Therefore, these terms will be explained shortly:

A workflow is a semi-automated realization of a planning or optimization process on the basis of schemes, reference models and management systems. It defines the sequence of processes which have to be performed and which information or document has to be used in which phase of the production design, process development, factory planning and operation activities. A workflow has a clear start, structured activities and a defined end. It possesses a coordinative character through sequencing and parallelizing of work steps. Ideally the interdependencies between the processes are modeled, thus the end of a process clearly determines the next processes to be performed. Figure 3 depicts a small example of a simplified workflow.

The defined workflows have to be implemented in a workflow system. These systems organize and monitor the processes which have to be performed in the workflows. The implementation mechanisms of workflows into the Smart Digital Factory Platform are described in detail in Section 3.2.3 Workflow System.

Role models or role concepts are used particularly in the area of software development and application engineering service. In computing this kind of concepts is used for administration and is known as Role-Based Access Control. Thus, access rights to data, doc-

Figure 3. Example of a Workflow

uments and applications for each role can be regulated. A role concept can be seen as a draft and bundling of multiple roles, that the stakeholders has to take in order to achieve the existing objectives in any given context. A role is dedicated to the process organization. If a stakeholder takes a role, it has to fulfill a specific function.

A role consists of pre-defined activities which a stakeholder can perform, specific characteristics and provides different access rights on data, information and functions. Thereby, a role can be defined once, e.g. PCB Mounting Company has the access rights for Production Order Information but not for Financial Data, and can be assigned to different stakeholders, departments or enterprises. Roles are the advancement of user groups. The advantage of roles is that a stakeholder can possess different roles. Thus, the access rights result in the characteristics of all the allocated roles. Today every stakeholder has his own graphical user interface (GUI) regarding his roles. Figure 3 depicts a

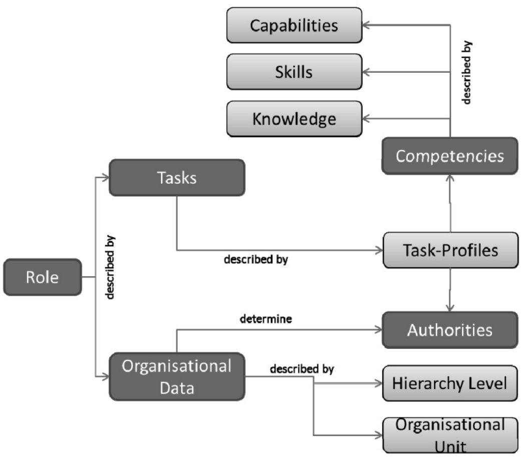


Figure 4. Composition of a Role Description

small example of simple role models.

In order to assure the filling of a role by an individual or several individuals/stakeholders who have the necessary skills, it requires a clear description of the required knowledge and skills to this role.

The task determines the necessary activities, and therefore there are different requirements regarding the competencies of the role-owner/stakeholder, expressed through knowledge, skills and capabilities. In addition, the organizational component, which controls the permissions/authorities needed to solve the tasks, should not be disregarded, because only then a role is fully described. In reality task-oriented, competency-based and organization-oriented role concepts are often combined in all aspects of a concept. The first contains the task package, which a stakeholder has to deal with because of its role. To operationalize the competencies a basic set of skills is determined that a stakeholder must possess in order to perform certain activities. This approach is particularly important for the coordination of workflows in Workflow Management Systems. The third concept is used to illustrate the organizational structures, to represent hierarchies of substitution rules, and to agree to delegate tasks or establishing the position of a user within the organization.

Defined roles can be allocated in the rights management stakeholder of the Smart Digital Factory Platform. Usually this is performed by the administrator of the whole system.

Within such role models there can be different stakeholders taking the position of “Controller” or “Operator”, depending on the planning scenario and workflow.

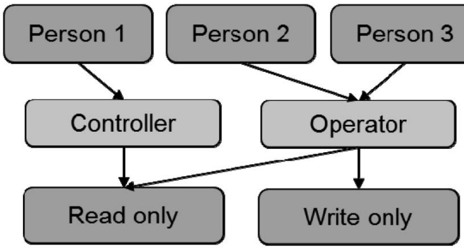


Figure 5. Example of role models

3.2 Factory Data Model and standards for data exchange

A Factory Data Model builds the basis for a Platform Architecture. The Data Model has to be considered as the shared "language" providing a common understanding and unified definition of the information that will be managed by the involved tools and as a bridge for external components. The effort to develop such a common Data Model has to be approached, according to the main perspectives of the project purposes. In general a Factory Data model contains the main planning objects, which have to be taken into account within the whole planning environment and planning process.

The main factory planning objects are the product, the process, the plant and the resources. The main specificity of the Product-Process-Plant-Resource factory Data Model is its Life Cycle orientation. The Data Model enables the creation of independent structures of the main planning objects products, processes and plants. The Life Cycle orientation is enabled by the opportunity of planning alternatives and different planning status, the so-called "Revisions".

The planning object "Product" includes data for product manufacturing and assembly. The factory and process planning receives this data from the product development. The products, assemblies or components are linked to the appropriate processes, operations and activities.

The planning object "Process" describes the manufacturing and assembly of the relevant products. These processes are described by so-called operations and activities. Each process contains operations which specify the stages of the manufacturing and assembly in detail.

The operations/activities are allocated to work areas/stations in the planning object "Plant". In addition the predecessor and the successor of processes, operations and activities and their chronology are defined. The data of the factory is mapped on the planning object "Plant". The plant structure consists of so-called "Work Areas" which describe the structure of the factory from manufacturing networks, sites, lines, stations down to work areas.

The planning object "Process" represents the connection between the product data (planning object "Product") and the factory data (planning object "Plant"). Revisions can also be created in order to perform planning alternatives and changes in the planning processes. In the Product-Process-Plant-Resource Data Model resources are not considered as planning objects. The planning object "Resource" stores and manages data of the manufacturing systems required for the manufacturing process. Resources can be, for example: machines, equipment, workers, material containers, means of transport, fixtures, devices, tools, etc. Resources can be structured in plants, zones, lines and stations. Resources are managed and stored in a library and are assigned to processes.

The "Production Order" object can be seen as a connection type between the other Planning Objects.

A "Production Order" is an order to produce a specific quantity of material within a predefined time frame. It contains all of the relevant information required for the execution of the process, including how much should be manufactured, and when, as well as information about the work site and all high level steps involved.

Within the Production Order a product with an existing production bill of materials can be described. Herein, the components and quantities required to make the product are defined. The component allocations for the production order can be stated as planned or released. This enables tracking of materials quantity and cost and of the product completion in the manufacturing process. All these main planning objects and their interrelationships are represented in Figure 6.

Generally, a Reference Factory Data Model and factory data management has to support the planning process, the planning phase and the planning tasks as well as to minimize technical and economic risks associated with digital planning tools. The resulting advantages are:

- Avoidance of incorrect and misguided planning,
- Reducing time in the realization of investments and in the re-planning, revitalization and optimization of structures and processes,
- Activation of synergies through cooperation,
- Reduction of the development and implementation costs.

The data model has to support the parallelisation of the planning processes and to standardize the relationships and interfaces between different factory data models used by the Digital Tools. Another aspect on the factory data model is that it has to be suitable and synchronized to the real factory as far as possible.

The basic requirements arising on the described goals and on the reasoning, as well as on the state-of-the-art of factory data models are that the model has to be: generic, scalable, modular and open.

The generic factory data model has to ensure a holistic vision and structure, to enable a holistic optimisa-

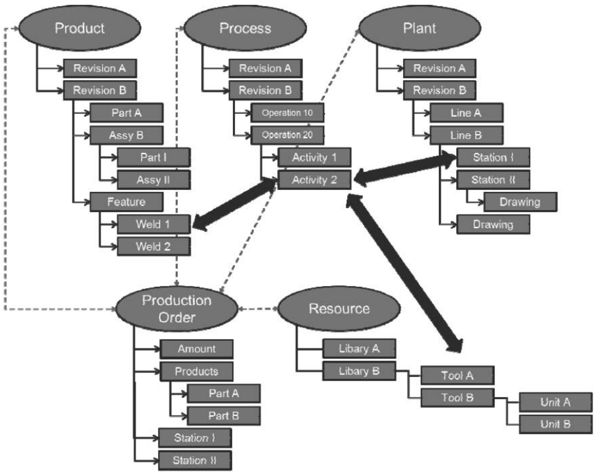


Figure 6. Schematic Structure of a PPP Factory Data Model

tion of the factory and its processes and to guarantee the structuring of all relevant data for the factory and process planning workflow. With the holistic view all connections and relationships between the planning objects are represented. Impacts on planning processes, related planning steps and tasks, as well as possible planning errors are also highlighted. The scaling in different time dimensions allows long and short term strategies as well as planned and unplanned changes to be taken into consideration.

For example for optimising and evaluating the system performance current simulation models of processes, machines, work stations etc. and even the logistic networks of multi-site factories are required. The more precise these models are based on reality, the closer the factory model represents the reality of the real factory. For the factory data model the different scales of the factory have to be represented accurately. It is required that factory data models are expandable, it must be possible to use them partly, and they have to be flexible and customisable for several planning tasks and planning goals. An open factory data model provides the opportunity to expand its functionality and scope through the addition and the integration of several planning tools. These planning tools can be certain tools for special planning tasks. Open is meant as the possibility of expansion of further components, modules and tools. It is essential to ensure the opportunity that certain software tools can be added into existing factory data models and therefore to facilitate and to support special tasks and to exploit synergies.

In order to enable a basis for a flexible connection between applications standardized formats for data exchange and data management has to be introduced and used. There are four central challenges in data management: capture, storage, retrieval and exchange of data. For the exchange of data, standards are necessary.

A business data exchange standard is EDI, short for Electronic Data Interchange. It is a computer-to-computer interchange of strictly formatted messages that represent documents. Another data exchange format is the STEP format (STandard for the Exchange of Product model data) which is a standard for exchanging product data. Thereby not only spatial but also functional aspects of a product along his life cycle can be represented. For this reason the standard is mostly used in Computer-aided design (CAD), Computer-aided manufacturing (CAM), Product data management (PDM), Digital Mock-Up (DMU) and computer-aided engineering (CAE) activities. Further exchange formats, like PLCopenXML and DWG/DXF support the data exchange between digital tools while planning and optimizing a factory or a product. VDA-FS (Verband der Automobilindustrie - Fl?chenschnittstelle) and IGES (Initial Graphics Exchange Specification) are additional standards to enable a low loss data exchange in a digital manufacturing engineering environment. Another Approach to represent the whole data- and information exchange is the data format AutomationML (Automation Markup Language), which is based on the integration of several xml-based exchange formats into a comprehensive format. Thereby multiple phases from Product design to Ramp up of machines and systems are covered through the employment of different xml-based standardized data formats. These are CAEX (Computer Aided Engineering Exchange), COLLADA (Collaborative Design Activity) and PLCopenXML.

However, the most promising and flexible approach to reexamine the technology of data exchange is the Extensible Markup Language (XML). Some of the mentioned data exchange formats also are based upon XML.

XML as a subset of SGML is a common standard for document markup. Because of its ability to deliver portable data, XML is considered as a key web application technology. XML defines a basic syntax used to mark up data with simple, human-readable tags, and provides a standard format for computer documents. This format is flexible to be customized for transforming data between applications. The XML specification defines the exact syntax this markup must follow: how elements are delimited by tags, what a tag looks like, what names are acceptable for elements, where attributes are placed, to name a few. XML does not have a fixed set of tags and elements that are supposed to work for everybody in all areas of interest for all time. It allows developers and writers to define elements as they need them. The major XML elements are the XML document, which is an XML file containing XML code, the XML schema, an XML file that describes the structure of a document and its tags and the XML style sheets, an XML file containing formatting instructions for an XML file. Once an XML file is created it can be presented in multiple ways by applying different XML style sheets. Additionally it is hardware and software independent. XML files are standard text files and they can be read by any application. The unique strengths of using XML as a data exchange format includes the simple syntax, the nesting support, the easy debugging and the platform independence.

There are two options to define elements, attributes and grammatical rules which should be used in a XML document, the Document Type Definition (DTD) and the XML Schemas (XSD). A DTD is an example of a schemata or grammar for a XML document. Such schemata languages typically constrain the set of elements that should be used in a document. It also defines which attributes may be applied to them, the order in which they should appear, and the allowable parent and child relationships. XML Schemas are exceptionally powerful and have several advantages over the Document Type Definition. XSD provides much greater specificity than DTD. Furthermore, XSD is namespace aware, and enables the creation of enhanced XML-based languages. Furthermore XML Schemata are written in XML. Due to the nature of the schema language, after an XML document is validated, the entire XML document, both content and structure, can be expressed in terms of the schema itself.

3.3 Smart Digital Factory Platform architecture

To achieve an optimal collaboration of planners, which work in a worldwide spread enterprise, different digital tools have to be employed and connected in a suitable manner. Thereby, the whole planning and operation activities have to be covered by Digital Tools. Their characteristics and categorization are described in Section 3.3.4. The connection of these Digital Tools and the other components forming the Smart Digital Factory Platform are described in the following sections. Figure 7 shows the basic architecture of the Smart Digital Factory Platform.

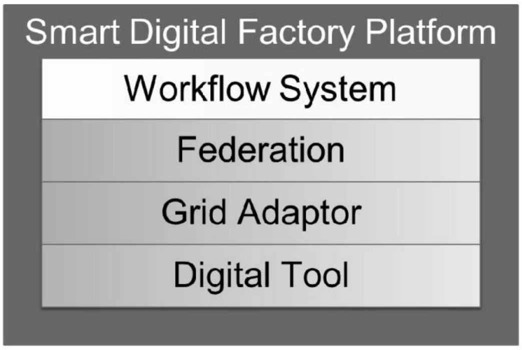


Figure 7. Smart Digital Factory Platform Architecture

3.3.1 Features and Expected Benefits

The Smart Digital Factory Architecture has to provide different features to enables an efficient collaboration of all stakeholders along the whole life cycle of products, processes and factories. These are as follows:

Open and Extensible

The Smart Digital Factory Architecture has to be conceived as an open and extensible platform. This means, that new contributions like methods, tools or technologies can be integrated employed and used by the stakeholders.

Modular

The structure of the platform has to be modular. This means that methods, tools, technologies and even hardware solutions can be changed with less effort, through their structured employment in application-oriented units. Additionally, if standardized interfaces are employed between these application-oriented units the modularity feature is supported more efficiently.

Grid-based

This feature will allow the distribution of data, models, tools and computer resources and the parallelization of work or simulations. Thus an efficient use of the available and provided hardware and software is ensured.

Life cycle oriented

The Smart Digital Factory Architecture has to support the planning activities in all phases. Therefore the platform has to comprise approaches for simultaneously representing and employing the whole life cycle of products, processes, factories and supporting ICT applications.

With this mentioned features the evolvability and scalability of the Smart Digital Factory Architecture is enabled and its flexibility as well as robustness is ensured. Evolvability, which is mostly based on the features open, extensible and modular, in this context means that new methods, emerging technologies and innovative tools can be flexible implemented and integrated. Thus the platform is able to provide state-of-the-art methods, tools and technologies, at any times. Scalability, which is mostly based on the features modular, grid-based and life cycle oriented, means that the range of employed tools and hardware components can vary for every planning activity. For simple planning activities, e.g. layout planning, one or two digital tools and a single workstation can be used and for complex planning activities, e.g. production network simulations, more digital tools and a HPC cluster can be employed (Figure 8).

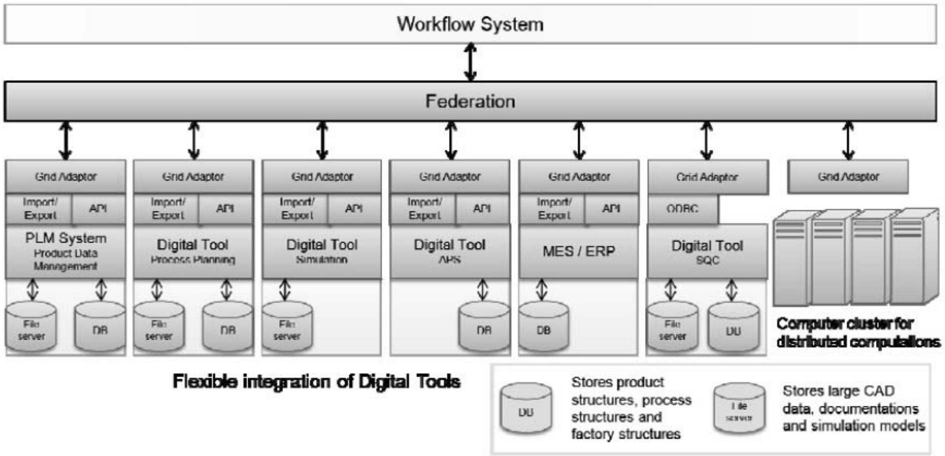


Figure 8. Smart Digital Factory Platform Architecture with Digital Tools

These features and characteristics of the Smart Digital Factory Architecture result in different benefits. These are the collaborative sharing of resources and competencies, the integrated and continuous management of the entire product, process, factory and operation life cycle data with the avoidance of redundant data and assurance of their consistency and the collaborative, participatory, interdisciplinary planning of all stakeholders.

3.3.2 Federation

In order achieve the requirements and features the concept of a federation layer is introduced in the sense of a middleware in the Smart Digital Factory Platform. The main reason for the introduction of the federation concept into this platform is to achieve the required flexibility and scalability as well as robustness. The basic idea of a federation is to query, collect and combine information from different sources (here Digital Tools) and provide it through one single interface. The communication and information exchange between both the different tools and the Workflow System is performed via the Federation. Close to this the form of communication is related. This means that a query of an information or different function (e.g. a material flow simulation) is usually not directly addressed to a specific physical Digital Tool. Furthermore, the type (e.g. Production order), the area (e.g. site) or the function (e.g. simulation) is specified and send to the federation. This enables that different Digital Tools matching to the specifics of the query can be considered. For the query some kind of protocol or language is required. It can be based on languages such as Business To Manufacturing Markup Language (B2MML) [B2MML] or Geography Markup Language (GML) [GML] which have to be extended with commands. Two types of command classes required:

- an information query type, which specifies the type of the query (e.g. insert, query, modify, delete) and
- a command execution type, which specifies the command toe execute (e.g. open, close, simulate, …).

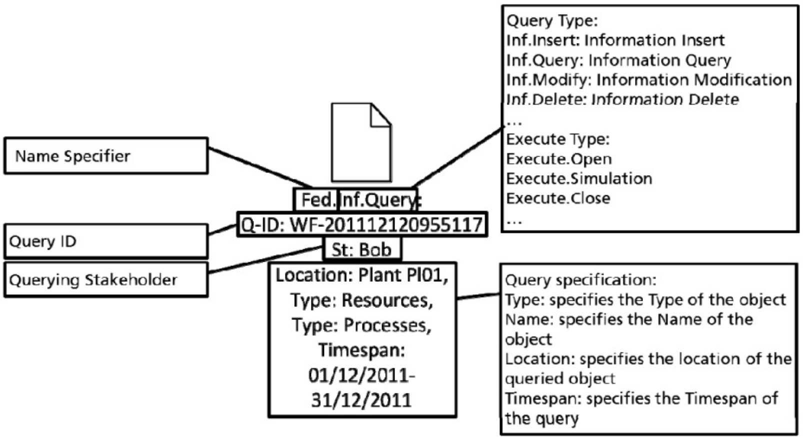


Figure 9. Example of an information query to the federation

Furthermore, the query requires an address in order specify the receiver of the query and a unique query ID in order to assign the responses to the querying stakeholders correctly. The querying stakeholder profile is embedded in the message as well in order to identify him correctly in the federation and connected Digital Tools. The query specification details the query concerning types, names, locations and timespans of the requested information. Figure 9 depicts an example of a possible information query message to the federation from a Digital Tool.

As a result the different Digital Tools among each other and the Workflow System are decoupled. This enables that a new Digital Tool can easily be integrated into the platform or outdated Digital Tools can be replaced without changing the workflows. Depending on the granularity of the query to the federation a certain Digital Tool can be addressed as well, but then the advantages of the decoupling of the Digital Tools do not exist anymore. Furthermore, the decoupling feature adds a more of robustness to the whole platform, in the case a Digital Tool disconnects. Moreover the Federation concept enables the cloud capability of the whole platform by the use of the single interface for operation paradigm. In the following the components of the federation (Figure 10), are detailed which are

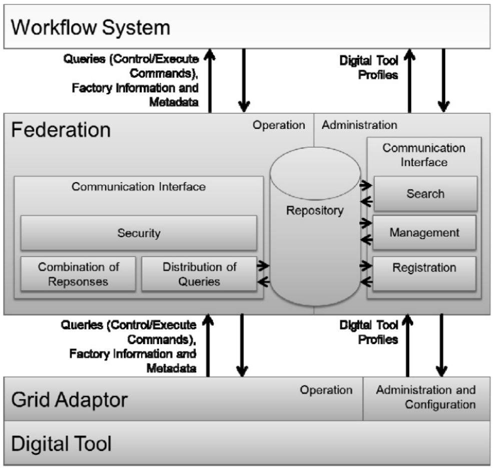


Figure 10. Federation Functions

classified in the two categories operation and administration and configuration.

Registration

The Registration has the function to register the Digital Tools via the Grid Adaptor at the Smart Digital Factory Platform in order that the Federation and the Workflow Management System know the Digital Tools and their characteristics. The characteristics of the Digital Tools are stored in a profile, which is detailed in the following example:

- Name (e.g. ERP-System)
- Location/Address (e.g. German Plant Stuttgart)
- Types of information provided (e.g. Factory Structure, Processes, Resources and Production order)
- Timespan of provided information (e.g. 01.01.2000-01.01.2012)
- Types for functions provided (e.g. information query, information modification, information insert, simulation, …)
- Memberships and roles in the different networks

The registration function stores the Digital Tools profiles in the repository.

Search

The Search function enables to search the profiles of the connected Digital Tools in the repository. This is required for the design of new workflows in the Workflow System.

Management

The management functions include the required functionalities for the modification and deregistration of the Digital Tools in the repository.

Repository

Main function of the repository is to store the profiles of the connected Digital Tools in order to provide it to the function for the distribution of the queries and for the design of the workflow.

Distribution of queries

The distribution of queries is one of the core functions of the Federation. It processes incoming queries from the Workflow System or single Digital Tools. These queries specify the requested information. Then they will be mapped to profiles of the Digital Tools available in the repository. After that operation the queries will be forwarded to the matching Digital Tools. An example of the service flow of this function is in section 3.3.6 described.

Combination of responses

The combination of the responses is the second core function of the Federation in the operation category. It combines all the response from the different queried Digital Tools and to one single response, which is provides to the Workflow System or a single Digital Tool. Depending on the complexity of the platform the combination of responses function includes sub-functions for a consistency check or redundancy check and reduction of the received information.

Communication interface

The communication interface provides all the technical functions required for the information exchange between the different components of the Smart Digital Platform. This includes the communication standards and protocols (e.g. TCP/IP), the functions for a secure information exchange, the sending and receiving of the control commands, and the sending and receiving of the Factory Information as well as the processing of metadata of the connected Digital Tools. Here, metadata are data describing the current status of Digital Tool as a resource and its related functions or notifications (e.g. busy 90% of material flow simulation for Korean PCB Making inner layer site completed).

Security

The Security functions of the federation are mainly to set up secure connections between the components of the Smart Digital Factory Platform. The stakeholder authentication and access to the functions and information is controlled by the Digital Tools directly. The aspect of user authentication is considered in the function for distribution of the queries, which checks the membership and role of the query and the Digital Tool and addresses the right matching only.

3.3.3 Workflow system

The defined references workflows, as described in chapter 3.1, have to be implemented in a Workflow System. In order to achieve maximum of effectiveness and efficiency during the situation-based planning processes many planning activities have to be standardized. The possible solution to cope with this challenge is the situation-based factory, equipment and process planning implemented by using Workflow Systems. The Workflow System can be seen as a specific external Digital Tool that is connected to the Federation. These types of systems represent a kind of middleware systems, which are application-independent and support the modeling, the enactment and the monitoring of workflows. Possible other functions are the support of simulation and analysis of workflows. In particular, Workflow Systems are capable of construing (semi-) formal workflow specifications, inducement of executions of different process steps through corresponding units - personnel or application systems - and of provision of

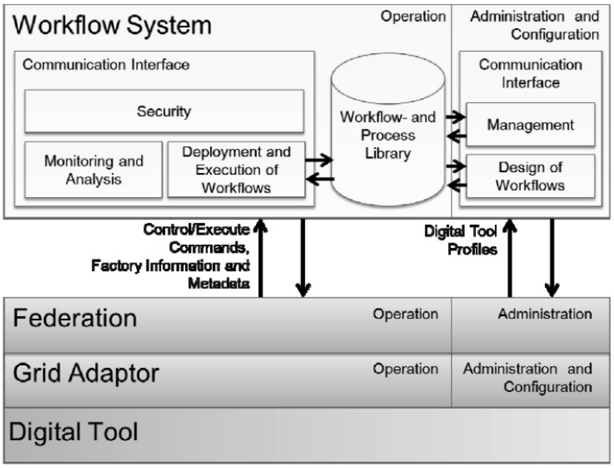


Figure 11. Workflow System Functions

any required information (e.g. instructions or documents). Figure 11 shows the functions of the envisioned Workflow System which are detailed in the following paragraphs.

Design of Workflows

Regarding to the situation-based character of planning projects a holistic modeling of the planning workflow, which has to be individually prepared for each planning project, is required. Different Models within the Workflow can be structured and represented. First of all the organizational structure of the whole environment (enterprise, network, etc.) can be modeled and described. According to this, the corresponding operational structure can be defined. That means, it can be defined, how the operational interrelationships between all stakeholders are structured. Afterwards, the Data Integration as well as the Integration of the Digital Tools can be modeled and designed. When all these models are defined and described, the different workflows can be simulated and analyzed afterwards. All the described components of a workflow can be designed by using templates out of the Workflow- and Process Library, where specific planning objects and planning steps are predefined. During this activity, the current state of the factory and the established planning goals have to be considered. While designing the workflows, the connection to the Federation can be used for searching and identifying existing Digital Tools that have to be involved in the single planning steps.

Workflow- and Process Library

To realize the overview of each workflow, a structured workflow library is required.

This workflow library includes predefined single planning steps, which are involved in the whole planning scenario and are common in the corresponding industry. An expansion of the library is possible at any time. For each of these steps different workflows can be determined and subordinated. This workflow library has the function of selectively retrieving individual planning steps and eventually coupling them to each other. The integration of standardized and predefined workflows from a workflow library into the created planning process leads to a significant reduction of planning time.

Deployment and Execution of Workflows

The modelled and defined workflows as well as their different single activities can be instantiated for the current status of the whole environment. They are deployed and executed, so that the predefined activities can be performed by stakeholders with the corresponding Digital Tools. With the help of the Workflow System, the single stakeholders can be notified or triggered, in order to ensure the right process sequence of the overall workflow.

Monitoring of running Activities and analysis of performed Activities

During executing and running the overall or the different single workflows, these workflows have to be monitored and each activity within the workflows can be analysed. Each activity within the workflow can be monitored over the complete workflow / process duration. The overall Workflow System can analyse for example the utilisation of the different stakeholders (planner and Digital Tools, etc.) in order to identify deviations from the predefined Workflow Model. That means while running and after finishing a planning project, specific statistics are generated, and the modeled aggregated workflows can be stored in the Workflow and Process Library, so that best practices can be used furthermore by implementing the learning concepts in factory planning. This enables improvement processes and re-use of knowledge for the overall workflow management process.

Communication Interface

The communication interface provides all the technical functions required for the information exchange between the different components of the Workflow System. This includes the communication standards and protocols, the functions for a secure information exchange, the sending and receiving of the executing commands, and the sending and receiving of the administrative information from the design and the management module.

Security

The Security functions of the Workflow System are mainly to set up secure connections between the different single workflows and between the Workflow System and the Federation System. This can include also some kind of filtering mechanisms, in order to ensure a secure data exchange between involved stakeholders.

Management

The management functions include the required functionalities for the deployment, the modification, and the extinction of the workflows in the Workflow- and Process Library. The management functions administrates the workflow data, so that the single workflows, which are separately enacted by a different workflow enactment service, could be parameterized, coupled and synchronised by the inter-operability of workflow engines.

In the context of a Workflow System, the modeling of workflows is usually performed through a graph-based process definition interface. Generally, the specification of the workflows is described by the Business Process Execution Language ? BPEL, which is an XML-based description language. It uses web services for interactions with external applications.

3.3.4 Digital Tools

Today, the product design, process planning, factory planning and operation phases are supported by different mostly isolated Digital Tools. These can be structured into Digital Factory and Digital Factory Operation Tools. Thereby, Digital Factory Tools enable an effective planning and early optimization of the products, processes and factories. Digital Factory Operation Tools however support the monitoring, analysis, optimization and visualization of the running production (Figure 12).To illustrate the functionalities and the employment areas of the different Digital Tools a short example will be given.

Typically, a planning process starts with the product design phase. Thereby, Digital Factory Tools, which support the design and the construction of products fall in the category of Computer-Aided Design (CAD). In this category Computer-Aided Engineering Tools, which additionally concentrates on the integration of design and construction tools with data processing systems, can also be employed.

In a further step the process planning is supported by Computer-Aided Process Planning (CAPP) tools. There the necessary processes to manufacture a product are planned. The associated work plan thereby is planned with Computer-Aided Planning Tools. Automated Manufacturing processes, like machine, robot and less transportation system controls are planned with Computer-Aided Manufacturing (CAM) tools.

For more complex product simulations have to be carried out, to ensure their quality. Therefore, the Finite Element Method, to analyze stress and deformation issues and the Computational Fluid Dynamics (CFD), to analyze fluid mechanically issues can be employed.

With all this information a Virtual Commissioning (VICO) can be carried out. Thereby, a close to reality ramp up of the planned production will be conducted, to identify failures early and to prevent them.

All these mentioned steps can be supported by Quality-Aided Quality Assurance (CAQ) tools, to ensure a proper product and production quality.

Digital Factory Operation Tools enable the use of manufacturing and shop floor data for re-planning and optimization processes. Thereby Machine Data Acquisition (MDA), Factory Data Capture (FDC) and Manufacturing Execution Systems (MES) are employed.

All this steps are supported through common Tools. The Enterprise Resource System enables the efficient planning of resources and operational processes. To support the interface between the procurement and the production, Production Planning and Control (PPC) systems are employed. Additionally Computer-Aided Office tools are employed to support office tasks.

To reach higher synergy effects and to provide a collaborative planning, operation as well as optimization environment these digital tools have to be connected. Thus, the following Section 3.3.5 describes a proper integration technology of these tools in detail.

3.3.5 Grid Adaptors

The Grid Adaptors are the main components in the Smart Digital Factory Platform to access and exchange

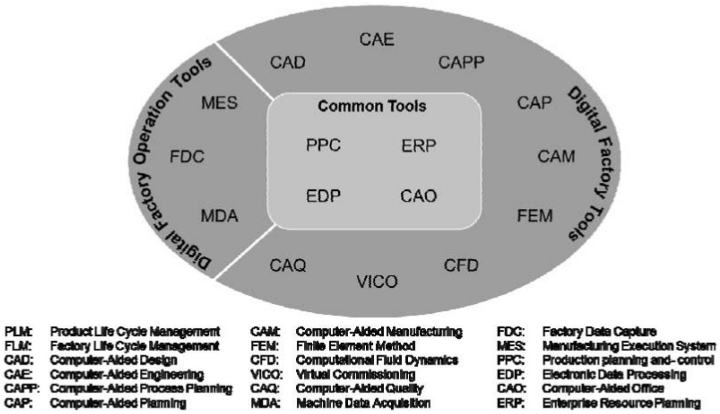


Figure 12. Digital Factory and Factory Operation Tools

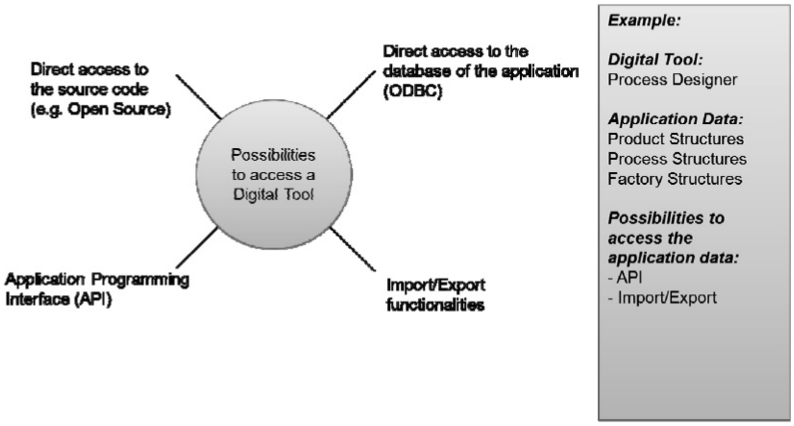


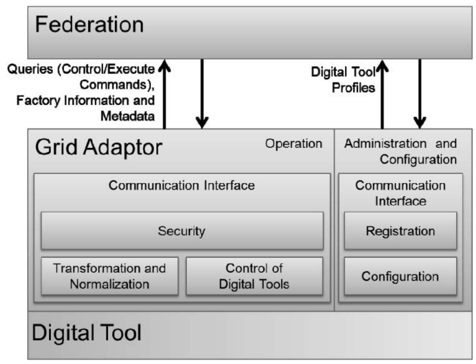
Figure 13. Categories of Grid Adaptors

the information stored and processed in the different Digital Tools. A Grid Adaptor transforms and normalizes the information to the standard defined in the Factory Data Model. This ensures the interoperability of the different Digital Tools in the Grid.

The Grid Adaptors can be classified into the four following categories, according to the access to the Digital Tool, as shown in Figure 13:

- Direct access to the source code (e.g. Open Source); The Grid Adaptor is embedded into the source code and information model as a part of a Digital Tool. It has full access to the functions and information.
- Application Programming Interface (API); The Grid Adaptor has access to the functions and information of a Digital Tool via an API.
- Direct access to the database of the application (ODBC); The Grid Adaptor has access to the information of a Digital Tool trough a database connection.
- Import/Export functionalities; The Grid Adaptor uses input and output of the build-in Import/Export functions of a Digital Tool e.g. file based export of process data.

Figure 14 shows the functions of a Grid Adaptor which are detailed in the following sections:



following sections:

Figure 14 Grid Adaptor Functions

Registration

The Registration function registers the Digital Tool at the federation. The registration includes as main information exchanged a profile which is stored in the repository of the federation. An example of a profile can be found under the subsection "registration" of chapter "Federation".

Configuration

The Configuration function includes all sub-functions required for the configuration of the Grid Adaptor such as the modification of the profile of the Digital Tool.

Transformation and normalization

The main function of the Grid Adaptor is to transform and normalize the factory information (products, processes, resources, factory structures and production orders) from the specific data formats used within the Digital Tools to information exchanges standards used in the Smart Digital Factory Platform. This is an internal function and cannot be accessed through the communication interface directly.

Control of Digital Tools

The control functions contain all functions for controlling the Digital Tools behind the Grid Adaptor. They can be different according to the capabilities of the Digital Tool. The Control functions can be categorized into two main groups. Firstly, control functions for information access and provision which include function for the insert, modification and query of information dependent on type, location, condition and time. Secondly, control functions for remote execute functions such as the simulation of a material flow or production order scheduling.

Communication interface

The communication interface provides all the technical functions required for the information exchange between the different components of the Smart Digital Platform. In order to ensure the interoperability it has to use the same standards and protocol as the communication interface of the Federation and the Workflow System. Therefore, the main functionalities are to ensure a secure information exchange, to send and receive the queries including the control commands and to send of the Factory Information as well as the provision of metadata.

Security

- The Security functions of the Grid adaptor address two main aspects:

User authentication and access to functions and information of a Digital Tool

In order to enable access between the different Digital Tools different roles have to be specified on a Platform level. Each role a certain level of information and function access is assigned in the Digital Tool (e.g. The role PCB Mounting Company has the access rights for Production Order Information). The Grid Adaptor passes the authentication information to the Digital Tool, due to the fact that many Digital Tools have already security features including role models. It guarantees as well that the owner of the information and function can control which information he wants to share in the grid network. Furthermore, in order to constrain information only to members of one certain supply chain, the roles are defined separately for each supply chain. The requested information is then transformed and normalized by the Grid Adaptor.

- Secure connections between the components of the Smart Digital Factory Platform

The other relevant security aspect of the Grid Adaptor is to set up a secure connection between the components of the Smart Digital Factory Platform.

For the implementation of Grid Adaptors state-of-the-art technologies like Web Services Resources are suitable. They are enabling stateful web services that are required for the Grid Adaptors for the provision of information and the corresponding metadata. Web Service Resources (WS-Resources) are standardized by the Organization for the Advancement of Structured Information Standards (OASIS) in the Web Services Resource Framework (WSRF). This type of web services is used as well in the Open Grid Services Architecture (OGSA), which provides suitable technical foundations for the implementation of the envisioned Smart Digital Factory Platform.

4. Conclusions and further work

In order to overcome the challenges of the rapidly changing market demands towards complex and customized products new solutions are required to support the especially Korean small and medium enterprises to survive in the market. The concept of the Smart Digital Factory Platform envisions an efficient collaboration of all stakeholders along the whole life cycle of products, processes and factories in the PCB Industry. In order to match the requirements regarding the improvement of information exchange and efficiency of planning activities between the different stakeholder (e.g. different departments, sites, enterprises and the corresponding Digital Tools) it consists of the three logic structures the Workflows and Roles, the Factory Data Model and the Smart Digital Factory Platform Architecture. The Workflows and Roles as well as the Factory Data Model as with its reference models provide the logic foundation. The Smart Digital Factory Platform Architecture focuses the functional components and features. For coping the requirements on a technical level the Smart Digital Factory Platform Architecture is open, extensible, modular, Grid-based and life cycle oriented and as a result of the previous features it is evolvable during the time as well as scalable from only one factory with several site to a network of suppliers.

Main topics for the future work are the development of the Workflows and Roles as well as the development of the Factory Data Model. For the development and implementation of the Smart Digital Factory Platform the next steps are:

- to develop a set of basic Grid Adaptors for the Digital Tools, which are the foundation of the Platform. This includes the detailed specification of the required interfaces.
- to develop the Workflow System, which controls and executes the implemented and instantiated workflows between the stakeholders.
- to develop the Federation, which simplifies the information access to different Digital Tools through one single interface. It further enhances the envisioned platform to be implemented as a cloud due to the decoupling of the Digital Tools.