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An Automation Approach Based on Workflows and Software Agents for Industrial Product-Service Systems

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Abstract

Industrial Product-Service Systems (IPS²) fulfil specific customer needs. This often implies the flexible reaction to changing requirements, impacting the adaption effort for the IPS² provider. Additionally the modelling of individual business processes for the IPS² delivery imposes a challenge to the provider. A great variety of process types, ranging from production to maintenance process, has to be covered in order to ensure a smooth and economically feasible IPS² operation. Therefore, an approach for the modelling and automation of IPS² delivery processes is of specific interest.
In this paper an IPS² automation approach will be presented that allows the modelling and deployment of the specific business processes and enables the integration of service shares into the automation solution of the product share. The presented approach allows for an easy adaption of the product share configuration.
To achieve this goal, a workflow management system represents the backbone of all customer provider relationships that distributes the tasks and responsibilities to the IPS² network partners according to the IPS² business model. For machine-oriented service shares the workflow management system interacts with an implemented Java-based software agent system by means of web services.
Lastly, an application example of a prototypical IPS² in the micro production domain will be given. The control system architecture and its implementation will be described and the application use case of manufacturing in the area of micro milling machine tools as a service share will be presented. An outlook of further work and future potential will complete the paper.

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Keywords: *Industrial Product-Service System; micro production; multi agent system; service-oriented architecture; workflow management system;*

1. Introduction

Industrial Product-Service Systems (IPS²) are characterized by the integrated development and delivery of product and service shares in the industrial area [1, 2, 3]. The ability of existing machine tools and plants can not necessarily exploit from customers. As a result reservations about the procurement of high-quality machine tools or plants may occur. To dispel reservations and to avoid the procurement of machine tools from low-wage countries as a consequence of financial incentives the approach of IPS² provides several advantages. The IPS² provider develops a solution of product and service shares that offers high customer individuality [1, 2, 3, 4, 5]. To achieve the mentioned customer individuality the customer integration has to be focused during all IPS² lifecycle phases [3, 6]. Thus, the enhancement of the classical relationship between providers and customers to a cooperation of coequal partners is indispensable. Contrary to the existing service delivery, where services, e. g. maintenance or training, are an add on in the operation phase, the engineering of IPS² requires the integrative and coequal combination of product and service shares over the entire lifecycle [7]. Therefore the

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potential of industrial services arises through the optimized adjustment of product properties and service-providing processes [8]. Furthermore changing customer requirements may arise during the IPS^2 operation phase and can be satisfied by the adaption of product and service shares, which requires a dynamic IPS^2 lifecycle [9]. The variety of possible combinations of product and service shares assumes the setting and organization of an IPS^2 network [2, 10]. Inside such network the partners develop and deliver IPS^2 product shares, IPS^2 services shares or IPS^2 modules cooperatively but self dependently. The configuration of shares and modules as well as the coordination of the IPS^2 network partners shall be administered by the IPS^2 provider [10]. The IPS^2 provider's main challenge arises through the customer individuality. For every customer an individual IPS^2 business process, which differs by time flow and content, has to be modelled and executed to meet the customer needs.

In the framework of this paper a method will be presented and prototypically executed to model the business process of a relationship between an IPS^2 provider and a customer efficiently. Therefore reusable process fractals will be applied. Subsequently the method allows the simulation and execution of the developed customer individual IPS^2 business process. First of all, the method will be described by means of the necessary activities, the deployed tools, the participating roles, and the stakeholder value. Afterwards the application will be demonstrated on the basis of a scenario based example of an IPS^2.

2. Method

2.1. Activities

To describe a method, the necessary activities and their results have to be structured in a procedure model, see Fig. 1. In the beginning of a relationship between a provider and a customer the submission of customer master data is necessary. A master data set will be created for new customers and updated for existing customers. As an IPS^2 business process always represents a solution for an existing challenge at the customer's site, the submission of initial information which describes this challenge is evident. Regarding a result-oriented IPS^2 business model the submission of manufacturing drawings is mandatory to enable the development of the IPS^2 business process.

Information considering the access conditions to customer's site are relevant for the delivery of an availability-oriented IPS^2 business model. Subsequently the business process will be generated by setting the necessary lifecycle phases. The basic sequence for the IPS^2 delivery consists of the phases implementation, operation, and closure.

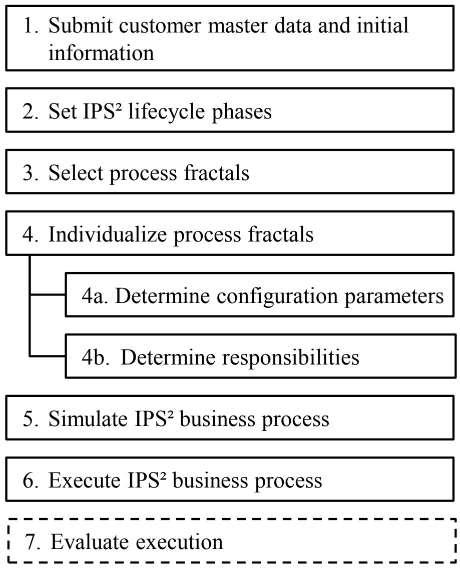

Fig. 1. Procedure model of the method's activities.

To consider changing customer requirements and to raise the flexibility, the demand of a further development in the IPS^2 operation phase may occur. Therefore another implementation after the first operation phase is needed. After determining these lifecycle phases, suitable process fractals can be assigned to the particular life cycle phases.

The determination of configuration parameters and the assignment of responsibilities for tasks inside the process fractals enable their individualisation. Hence an adaption of the business process to the individual customer requirements occurs. The selection and configuration of process fractals according to the particular IPS^2 lifecycle phases lead to an overall IPS^2 business process. For answering the question whether the modelled business process fulfils the customer requirements or if the IPS^2 provider is able to perform that process economically the simulation of the business process is suitable. Results of simulation experiments identify potential weaknesses and their improvement leads to an optimized IPS^2 business process. Subsequently the approved and executed process represents the collaboration platform of all IPS^2 network partners to deliver an IPS^2. The subsequent evaluation of executed business processes for acquisition of information is possible, however will not be considered in the framework of this paper.

2.2. Tools

To apply the method, the application of several tools is necessary, see Fig. 2. For the identification of customer master data and initial information, the direct customer contact through a meeting or a telephone conference is indispensable. As a result of the heterogeneity of possible basic conditions at the customer's site it is impossible to standardize such process. During the customer contact the identification of all necessary initial information for the planning of the IPS² business process is crucial. Simultaneously the involved employees or roles in the lifecycle phases at the customer's site have to be identified.

The existing process fractals and configuration parameters are stored and managed inside a database. The graphical user interface of that database allows the selection of process fractals and the determination of configuration parameters for the particular lifecycle phases of customer individual IPS² business processes. Furthermore a database is deployed to ensure the automated transfer of the configured business process into a workflow management system.

Inside the applied workflow management system IYOPRO, which is based on Business Process Modelling Notation (BPMN) and developed by intellivate GmbH, the responsibilities for tasks and simulation parameters are required. On the basis of the completed business process simulation, experiments for the optimization will be conducted. Subsequently the workflow management system executes the business processes by assigning the manual tasks to the responsible roles in the IPS² network.

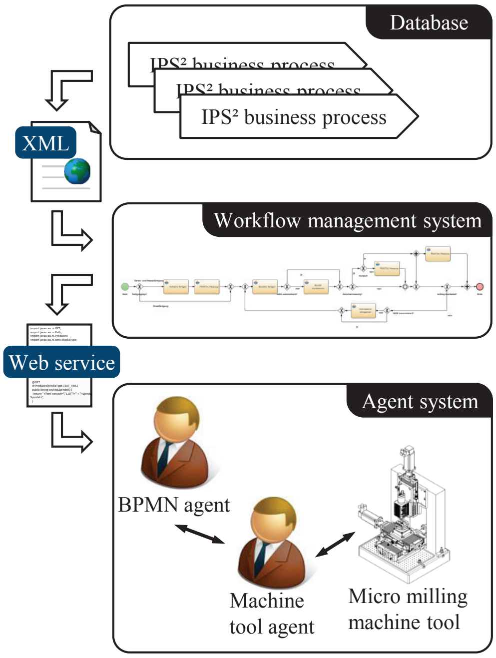

Fig. 2. Tools applied within the method.

Automated tasks will be processed through an agent system. The workflow management system calls the particular agent system, implemented on the provider's product shares, via web service and selects services, e. g. milling or component self-test. After finishing a service inside the agent system the workflow will be continued through the workflow management system.

2.3. Roles

For the application of the method several roles at the IPS² provider's site are necessary. The role 'sales' determines the problem definition at the customer's site and identifies appropriate product and service shares and selects them inside the database. This role needs the ability to develop customer individual approaches to solve their problems in a limited period. If the solving of the customer's problems is not possible by assigning the existing process fractals, the role 'process modelling' is appealed to model a suitable process fractal. Therefore a closed interaction with the role 'engineer' is necessary. This role possesses know-how to build process fractals and configuration parameters under consideration of technical conditions.

After modelling the entire IPS² business process to solve a customer individual problem the role 'simulation' simulates the process. For this task, the knowledge of simulations of prior business processes is essential to identify appropriate simulation parameters. Necessary changes to optimize the simulated process have to be agreed upon with the role sales.

The simulation results of the optimized process are the basis for the approval of the role 'management'. Possibly further changes are necessary to obtain the approval. The approved IPS² business process will then be executed. During runtime tasks are assigned to employees inside the IPS² network to deliver the IPS².

2.4. Stakeholder Value

The application of the method offers benefits for the IPS² provider as well as for the customer. Considering the immateriality of services, customers are uncertain whether a provider has suitable product and service shares for the customer individual solution of a problem. The developed method enables the visualization of the spectrum an IPS² provider is able to deliver. Thus, the support appears already during the first customer contact, as the modelling of business processes for problem solving is efficient. The prompt simulation of the business process enables a fast preparation of an offer. The accelerated handling of customers' needs leads to a trustful relationship between employees of the provider and customer, so that the probability of a successful business connection increases.

A further challenge, arising through the inherent characteristics of services, is the procurement dilemma for the IPS² provider. The integration of an external factor leads to the consideration of its behaviour during the delivery and affects the moment of request. To operate economically, providers attempt to procure the greatest possible amount of production factors after the receipt of order. Thus the risk of revenue loss arises, as the demanded service cannot be delivered on time [11]. The method facilitates the representation of the process responsibility for all relationships between an IPS² provider and its customers over the entire lifecycle. Simulating these processes enables the development of sufficient prediction about the necessary production factor to satisfy the customer needs in the regarded period. Thus the method provides support for the IPS² provider's personnel and procurement planning.

Furthermore the process engine controls the collaboration of all network partners on the basis of the particular IPS² business process model. Thereby the method supports the IPS² network as a collaboration platform to deliver IPS².

3. Application

3.1. Introduction

Despite the advances in technology development for micro production there still exist considerable entrance barriers for companies planning to manufacture parts with micro scale precision requirements. This is particularly due to the high investment costs of the machine tool equipment and the lack of technological experience of the customer regarding these new technologies [12]. Such circumstances lead to high organisational and technological risks for the customer when integrating micro production technology into his production.

Within the fictitious scenario that is presented here, the customer company Omichron intends to produce clockwork base plates in serial production and is aware of the abovementioned entrance barriers. The IPS² provider company MicroS+ develops solutions in the field of mechanical and plant engineering, particularly in micro milling machine tools.

3.2. Business process modelling

In the framework of a workshop meeting, the sales department of MicroS+ identifies the customer master data as well as the initial information of the customer-provider relationship. Omichron intends to integrate a micro milling machine tool into its own production facilities. Due to the lack of technological process know-how, the responsibility for production will initially be on the side of MicroS+. Parallely, the staff of Omichron will be trained for the new machine tool during operation and take over the production responsibility after 12 months. After that period of time, MicroS+ is going to assure only the technical availability of the machine tool. Based on these conditions and requirements, the sales department identifies that a flexibility option is necessary after 12 months and that in the first phase of the customer-provider-relationship, a result oriented IPS² business model has to be provided. In the framework of this phase, the machine tool is set up at Omichron's facilities and integrated into the production line.

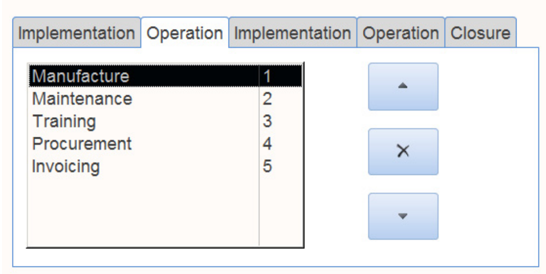

Fig. 3. Graphical user interface (GUI) for assigning process fractals to IPS² lifecycle phases.

Although being operated by staff of MicroS+, workers of Omichron are trained under production conditions as part of the preparation for the transfer of production responsibility after the first 12 months. During this period, Omichron pays MicroS+ according to the number of fault-free produced parts. After realizing the flexibility option, the responsibility transfer results in an availability oriented IPS² business model. Within this IPS² business model, the provider MicroS+ guarantees a specified level of technical availability, while the production responsibility is held by Omichron, whose trained staff will operate the machine tool. Concerning a customer-provider relationship under these conditions, a duration of five years will be agreed upon by provider and customer. The realization of the flexibility option leads to an additional implementation phase, as components of the micro milling machine tool have to be replaced in order to fulfill the requirements imposed by the new business model. Subsequently, an operation phase under the new business model follows the implementation phase, see Fig. 3.

As an example, the process fractals of the first operation phase will be elaborated on further. Due to the result oriented business model, the IPS² provider holds responsibility for the production processes at the micro milling machine tool. This is expressed by the manufacture fractal. Furthermore, maintenance processes necessary to ensure the machine tool's uptime are covered by the IPS² provider MicroS+, as downtime will negatively influence the production quantity and lead to a decrease in sales for the provider. Therefore, the maintenance fractal is necessary. Furthermore the training fractal will be added for the training of the customer company's staff. The procurement fractal ensures the regular sourcing of tools and raw material. The monthly proceeds are determined by the number of produced parts.

After selecting the fractals, the configuration parameters have to be determined. The manufacture fractal will serve as an example for this step, see Fig. 4. The considered production type is a serial production, therefore the production of initial test parts is modelled within the manufacture fractal. Furthermore, the loading of work pieces is not automated and therefore performed manually.

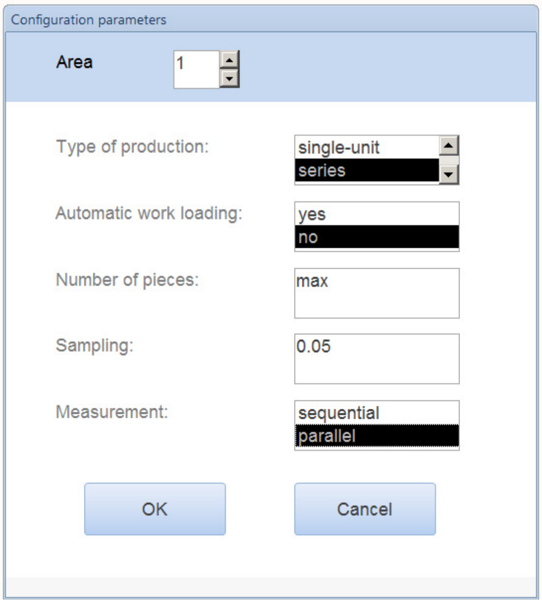

Fig. 4. GUI for the determination of configuration parameters.

The number of parts is to be maximized during the considered, first phase of the customer-provider relationship and quality assurance will be performed by a metrological assessment for every twentieth produced part. The measurement process is performed parallel to the production and therefore doesn't interrupt the manufacturing process.

3.3. Business process execution

After the simulation and assessment, the process model can be executed. Manual processes such as carrying out training sessions are transmitted to staff members through task lists. Automated processes such as the manufacturing are executed by a software agent system, which is implemented in the machine tool and all of its subsystems by the provider MicroS+. The software agent system consists of so-called role agents and interface agents. Agents of the first category represent key roles in the IPS² delivery and act upon their behalf, whereas the latter serve the purpose of integrating heterogeneous systems such as databases, machine tool controls or sensors into the automation of IPS² delivery processes. For a detailed description, see [13]. The agent system and the presented workflow management system communicate by means of web services. For this purpose, a so-called BPMN agent encapsulates all functions of the machine tool that are needed in the framework of the business model and provides these functions by means of web services. This makes it possible for external applications such as the workflow management system to access these functions. The internal communication between the software agents is performed through the asynchronous exchange of ACL (agent communication language) messages. The communication concept between the workflow management system as well as the software agents is illustrated in Fig. 5. After the BPMN agent is contacted via the web service, he sends a request to the directory facilitator (DF) agent searching for agents capable of fulfilling a milling task. The DF agent, serving as a yellow page directory for the whole software agent system and thus being aware of all available agents and their functions, returns the requested information. In this case, the machine tool role agent can provide the requested function. Subsequently, the BPMN agent checks, if the offered service is currently available via a call for proposals (cfp) protocol.

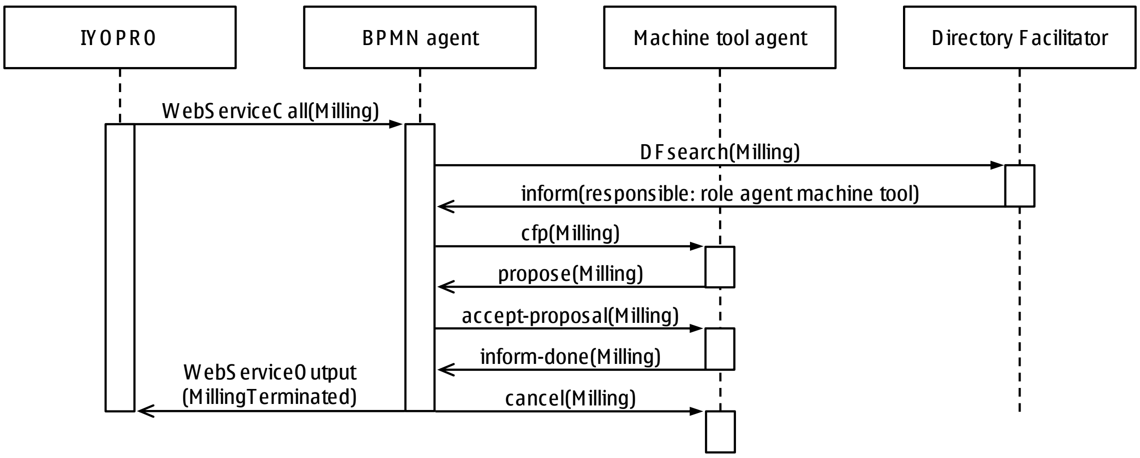

Fig. 5. Unified Modeling Language (UML) diagram of the communication inside the agent system.

The machine tool role agent then contacts all necessary, subordinate interface agents such as the PLC and sensor bus agent, to check if the milling task can be executed. This communication is not illustrated in the shown interaction diagram. In case of a positive answer of all involved interface agents, the machine tool role agents sends a confirmation to the BPMN agent by answering the cfp protocol with a 'propose' message. The BPMN agent can then accept the proposal and the machine tool role agent hereupon starts with the execution of the milling process. After the execution, the machine tool role agent confirms the completion via an 'inform-done' message. The BPMN agent then sends a confirmation to the workflow management system via the web service. Afterwards the business process is continued by the workflow management system.

4. Conclusion and outlook

In the framework of this paper an approach for the efficient, customer individual process modelling for IPS² was illustrated. Additionally the use of an agent system allows the control of product shares in the operation phase. Therefore the approach covers tasks from the initial customer contact in the development to technical process steps in the IPS² operation phase. The approach was prototypically applied by means of a scenario of a relationship between IPS² provider and customer along an IPS² lifecycle.

Future work will focus the development of process fractals and configuration parameters for different industrial sectors. Simultaneously the application of the approach takes place with industrial project partners to receive feedback regarding additional requirements from potential operators.

Furthermore the shift of existing IPS² business processes through changed customer demands will be considered. Therefore a history function of executed business processes and their changes has to be implemented. This enables the identification of patterns regarding the behavior of customers and other network partners during the entire lifecycle. Achieving that knowledge enables the suitable transformation of customer demands and boundary conditions into an IPS² business process with less need of changes.

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