Reference Architecture for Dynamical Organization of IPS² Service Supply Chains in the Delivery Phase

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Abstract

Flexibility is one of the main demands onto the organization of delivering Industrial Product-Service Systems (IPS²). IPS² development specifies all product shares, service shares and their interdependencies in an IPS² product model. The management of the service deliveries ans resources is the task of the IPS² organization. For the containment of influences, a reference architecture for dynamical organization to create and operate IPS² service supply chains is developed.

This paper describes a reference architecture for the IPS² organization by an modular organzition unit concept and how processes within the operation of IPS² can be managed by software agents.

Keywords

Industrial Product-Service System, IPS², IPS² organization, IPS² network, service supply chain, multi-agent system

1 INTRODUCTION

Industrial Product-Service Systems are characterized by an integrated and mutually determining process of planning, developing, provisioning, and using product and service shares [1]. Providing IPS² is based on a long term relationship between a customer and the IPS² provider. This implies a need to organize the delivery of service processes focusing customer conditions and the realized IPS². Future unknown influences or changing customer requirements demands a dynamic organizational system with strong customer integration [2]. Thereby not only the organizational structure of the IPS² provider but also the service supply chain is affected. Every partner in this service supply chain needs the qualifications to solve problems out of a heterogeneous field of requirements. The delivery processes determine resource attributes and necessary decision knowledge. The IPS² organization is responsible to plan and schedule delivery resources for right time, right quality and right place. Challenge is to find the right balance between over capacity to avoid supply shortages and high fixed costs. Thus the planning and scheduling have to be changed until the service process is finally started. An IPS² organization reference architecture helps to organize the delivery of IPS² service processes in service supply chains. For efficiency reasons communication and coordination between the supply chain partners are handled via software agents. Also controlling of manual and semi-automated as well as an execution of automated process steps is being realized by software agents.

2 IPS² ORGANIZATION REFERENCE ARCHITECTURE

2.1 IPS² Product Model

The IPS² product model is built up by the developed and configured product and service shares, all necessary technical and physical resources for delivering the service processes and its economic valuation in the state of the IPS² development.

The IPS² product model contains the process model that specifies the service processes of the delivery phase [3]. To achieve a desired quality and result the process model is described with attributes for the needed resources. A task of the IPS² organization is to find the resources to realize the service processes of the IPS² product model. The IPS² organization structure is created by finding the necessary resources for the process elements and by establishing coordination units that can schedule the resources.

The creation process for the IPS² organization structure will be initiated for the first time when developing an IPS². During the delivery and use phase of the IPS² life cycle the IPS² organization structure can change by gaining knowledge about the behavior of resources, behavior of IPS² system components, quality of service delivery result or replacement of resources or processes. The IPS² organization reference architecture describes a model for structuring intra-organizational and supplier resources within an IPS² service supply chain.

2.2 Structural Reference Framework

The customer integration is a requirement for the delivery planning and scheduling of IPS². Existing organizational structures and planning methods have the disadvantage of being optimized either for production processes or service processes. New ways for intra-organizational structures and supply chains become necessary. Controlling raising product and process complexities with these structures have to be a new key competence for IPS² providers. Interconnections between the production and the service domain result out of the new IPS² product model. The need and initialization of service deliveries can be linked with the behavior or condition of the IPS² component shares. For example preventive maintenance has a long time variance for the delivery time instead of the breakdown that has got no time variance because of the condition of the machine tool.

Manifold papers about the organizational integration of industrial services state that a universal solution does not exist [4]. Every company has to decide which organizational structure should fit best by weighing pros and contras. Therefore a modular organization structure needs to be developed [5]. The modular concept for enterprise networks developed by Picot et al. [6] provides the structural and characterizing framework for the concept of this paper.

A new understanding of partnership roles and responsibility for actions during the IPS² lifecycle is developed to guarantee that the customer has always one permanent contact person [7, 8]. The IPS² provider represents as the One Face to the Customer (OFC) and manages all communication in the network. Target of the IPS² provider is to optimize the service delivery processes in time, quality and costs. He can distribute service process shares to network partners to create a service supply chain. Capacities of this service supply chain have to be planned and scheduled to guarantee an efficient and qualitative high service delivery.

In the context of our research a modular organization unit (MOU) concept has been introduced that represents the resources for the service delivery processes [9]. With these modular organization units a structure for the IPS² network can be created and adapted on changing circumstances during the delivery and use phase of an IPS². Figure 1 illustrates the exemplary implementation of modular organization units on existing organizational structures and the combination of the units to a network.

Different network partner types are identified to work together in an IPS² network to deliver IPS² service processes. The different types of IPS² network partners are customer, IPS² provider, IPS² module supplier, service supplier and component supplier [7, 8]. Each partner has an individual part of the IPS² to deliver and can coordinate this in different ways. The MOUs combine resources of network partners that have the abilities to deliver service processes with desired requirements. If the IPS² provider decides to outsource a service process resource he has to assure that his intellectual property will be protected.

The MOUs are used to get a process oriented structure. With sharing service delivery parts to network partners centralized and decentralized combinations evolve. Centralized organizational structures can help to coordinate external MOUs and to share service relevant knowledge. Decentralized organizational structures will work autonomous, but they can be coordinated from a centralized MOU in the form of customer provider relationship. Synchronal to the implementation of a MOU a software agent is instantiated for communication and coordination.

An example for a maintenance process will show possible situations that determine the creating of an IPS² network.

3 NETWORK POOL

3.1 Process Modeling

For the buildup of a company network for service delivery and especially to realize the needed potentials for a special process the fully described service process is needed. Most of the process descriptions exist only in a very abstract way that will lead to uncertain conditions for process planning and scheduling.

To reduce the uncertainty in the service delivery the process must be described as detailed as possible. This description can be developed for the IPS² product model by the IPS² provider or can be estimated concerning the

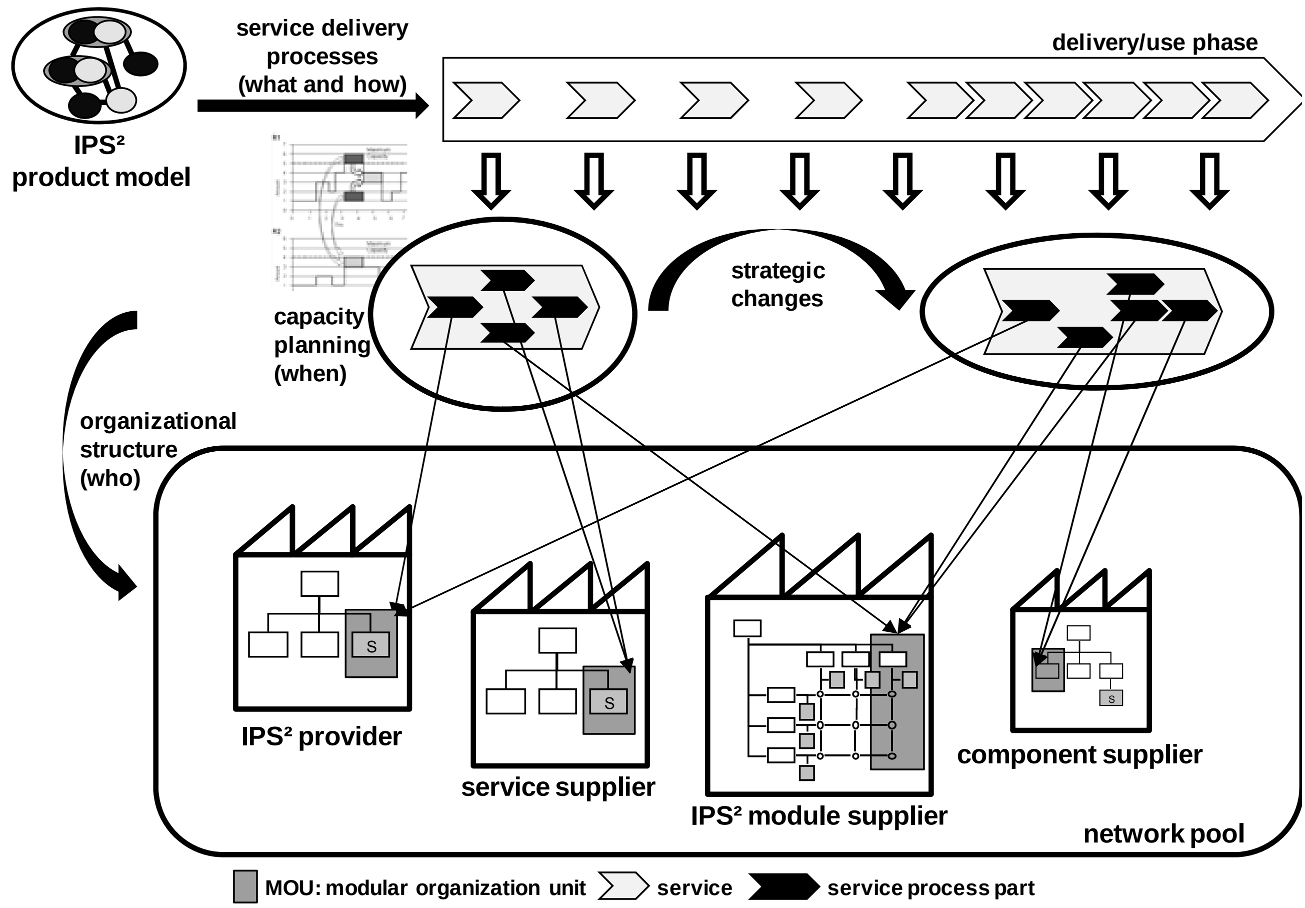


Figure 1: Network architecture for IPS² service supply chains

product design.

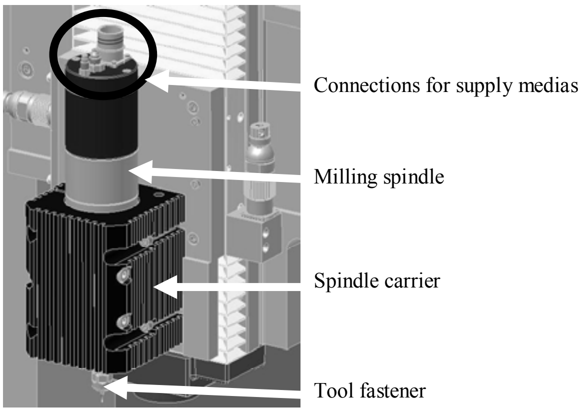


Figure 2: 3D-Model of the machine tool component milling spindle

The IPS² product model also includes construction drawings of the product share of the IPS² (Figure 2). By these drawings the interdependencies of the used parts and e.g. needed tools can be named. Further the process step of e.g. disassembling of a machine tool component is analyzable.

Therefore the methods-time measurement (MTM) is useable [10]. The MTM is a method to characterize and analyze mainly manual processes in the industrial field, especially in mass production. This is important for the planning phase to identify, how long a person, e.g. a technician, needs to finish an action.

The exemplary, manual process to show the reference architecture for dynamical organization of IPS² is an exchange of a milling spindle. The scenario of a milling machine tool is selected for the research project TR29, so that the process “spindle exchange” is based on the built-on realization of this scenario.

To ensure e.g. the availability of an IPS² in an availability oriented IPS² business model, special planning and monitoring systems of the shares in the operation phases can be used. Therefore this paper presents a method for the dynamical organization to achieve the guaranteed availability of a critical machine tool component.

The spindle is the core component of a milling machine tool. This component is therefore function relevant for the production with this machine tool and has to last high stresses, e.g. by the cutting force.

The detailed MTM result in 14 different process steps, wherein three steps are defined as optional. These optional steps can be activated by inspection of the technician, which result in e.g. the exchange of screws (Figure 3). Optional process steps are not often used in the task “spindle exchange”, but have to be considered to reach a high detailing of all process influences and to reduce the uncertainty.

The duration for the process delivery is 22 minutes beginning with process step 1 “Preparation of workplace” and ending with process step 14 “Pack tool case up and mark old spindle” and the main resource is the service executing “technician”. That means that the process starts with the arrival of the technician at the machine tool and ends with his departure.

The process “spindle exchange” is described with the following resources and their belonging attributes. The attributes can be used to characterize the resources:

- Technician,
- Tool case,
- Wrench, size 12,
- Wrench, size 8,
- Hex-wrench, size 8,
- Torque wrench, size 5,
- Screw driver, slotted, size 6,
- New spindle,
- Case of new spindle,
- Marker for the used spindle,
- Box for the tool fastener,
- Hardware for control and function test of the spindle,
- Software for function test of the spindle,
- Technical documentation of the spindle,
- Optional: Head mounted display (HMD) for support of the technician,

Code	MTM-1 spindle exchange page 0					
Description	Spindle exchange					
Start	Preparation of workplace					
Content	Sub processes 1-11 (Options sub process 4.1 and sub process 5.1)					
End	Function test					
Limitation	Times valid for spindle exchange by IPS² provider					
No.	Notation	Code	TMU	A x H	Overall TMU	Conversion [min.]
1	Preparation of workplace	MTM page 1	12420.7			7.45
2	Take tool fastener out	MTM page 2	326.4			0.19
3	Realize machine condition for the spindle exchange	MTM page 3	155.7			0.09
4	Disaggregate the spindle for supply	MTM page 4	2564.3			1.54
5	Check hoses and exchange them if necessary	MTM page 4.1	2689.2	2	5378.4	3.23
6	Check screws for the cover of the spindle and exchange them if necessary	MTM page 4.2	167.8			0.10
7	Loosening of the spindle carrier	MTM page 5	183.0			0.11
8	Check screws for the carrier of the spindle and exchange them if necessary	MTM page 5.1	167.8			0.10
9	Insertation of the new spindle in the spindle carrier	MTM page 6	527.0			0.32
10	Aggregate the new spindle with the supply	MTM page 7	1038.0			0.62
11	Realize machine condition for the new spindle starting	MTM page 8	155.7			0.09
12	Take tool fastener in	MTM page 9	2037.7			1.22
13	Function test	MTM page 10	13886.7			8.33
14	Pack tool case up and mark old spindle	MTM page 11	426.2			0.26
	Sum		36746.2		42124.6	22

Figure 3: List of sub steps for the process “spindle exchange”

- Optional: Hose, length= 2 m, diameter= 6 mm, nontransparent,
- Optional: Hose, length= 2 m, diameter= 6 mm, transparent,
- Optional: Screws, 2 units, M5x40 and
- Optional: Screws, 4 units, M8x70.

With this resource list it is possible to combine resources into clusters of company profiles (Figure 4). These profiles can be used for the job announcement and the IPS² provider has the possibility to identify his competences for this process delivery (see 3.2). With the denotation by the IPS² provider a first decision has been made which resources have to be outsourced to network partners.

Company profile:
Employment agency
Related resource:
Technician

Company profile:
Technician support
Related resource:
HMD

Company profile:
Spindle manufacturer
Related resource:
- New spindle
- Technical documentation
- Marker for old spindle

Company profile:
Hardware supplier
Related resource:
Hardware for control and function test of the spindle

Company profile:
Plastic part manufacturer
Related resource:
- Case for new spindle
- Tool case
- Optional hoses
- Box for tool fastener

Company profile:
Tool manufacturer
Related resource:
- Wrench, size 12
- Wrench, size 8
- Hex-wrench, size 8
- Torque wrench, size 5
- Screw driver, slotted, size 6

Company profile:
Software programmer
Related resource:
Software for function test

Company profile:
Screw manufacturer
Related resource:
Optional screws

Figure 4: Potential company profiles

To characterize the process more in detail and to show the influences and interdependencies of the process elements, the integrated enterprise modeling language can be used [11]. Method for object oriented business process optimization (MO²GO) uses the integrated enterprise modeling language to model the “spindle exchange” process in a software tool (Figure 5).

In this model the attributes for the resources can be allocated and be revised after accepting the job. E.g. initial information’s about the resource “technician”:

- Needed qualification and skills,
- Needed delivery time,
- Needed delivery cost.

Resulting attributes after job acceptance:

- Service process delivery duration, timetable,
- Membership: IPS² provider.

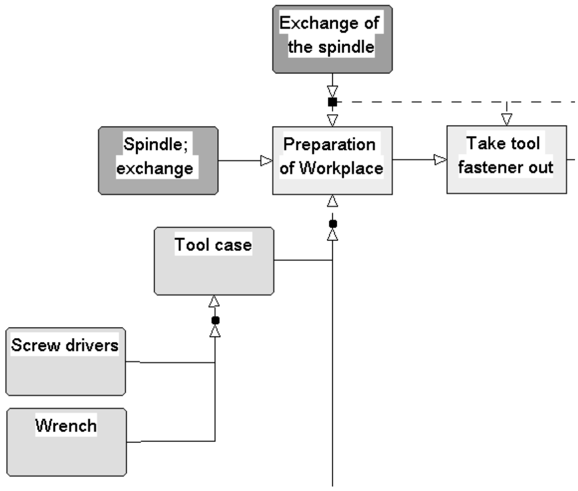


Figure 5: Process model in MO²GO for the process “spindle exchange”

This model can be used by the IPS² provider to generate detailed information for the different network partners by the retention of process overview. To guarantee the availability of e.g. a machine tool, this overview is very important and has to be realized also by the selected network partners.

3.2 Network Cases

The resources for the maintenance example can be categorized in standard tools, process individual tools, spare parts and optional helping tools. The spindle will be supplied by the spindle manufacturer. He provides the spindle with a transportation case, technical documentation and a stamp to mark the spindle. A supplier of plastic parts can offer the box for the tool fastener and replacement hoses. Screws can be supplied by a dealer for such mass products. Standard tools for the technician and more specialized tools like the torque wrench are available from tool manufacturer. The HMD is an additional tool to get support from an expert who guides the user through a problem [13]. Suppliers for HMD offer the unit for rental in the IPS² network. Network partners can rent the HMD and can get help by using it if they need it.

Four strategies based on different combination to find suppliers for the resource groups exist to find resources. The strategies vary from delivering all processes with internal resources of the IPS² provider to externalize all parts. Figure 6 shows the network combinations for the four cases. By assigning process elements to a supplier the IPS² provider has to establish a coordination unit that controls the delivery time, quality and cost goals. The HMD can be used for all four strategies. Every time when the technician is not able to solve the maintenance himself he has the possibility to use the HMD to get contact to a back-office expert.

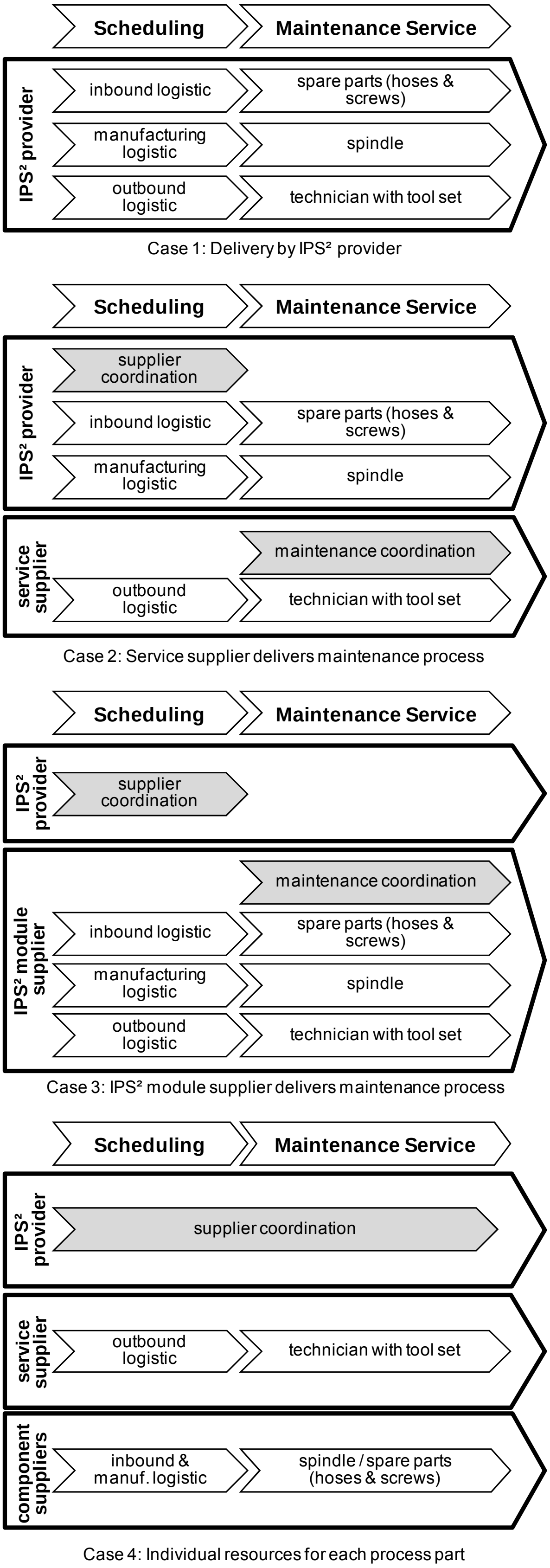


Figure 6: Strategies for IPS² networks for the example of spindle maintenance

The delivery process in the cases is divided in two parts. The first process part describes the scheduling which is necessary to guarantee that the process can be realized. The second process part describes the maintenance service process itself. For the scheduling processes the network partners have to make different logistical coordination. Logistics can be inbound, manufacturing or outbound logistics [13].

Case 1: Delivery by IPS² provider

The needed resources for the maintenance process, like tools, spare parts, are delivered by IPS² provider. The IPS² provider is also in charge of coordination and scheduling of the service delivery process. This could be the case if the IPS² provider is the manufacturer of the spindle and has the resource capacity to make the service business. The IPS² provider decides to build up a service supply chain with component suppliers for tools and spare parts. Spare and wear parts, like screws, will be bought from a dealer and stored at the IPS² provider side. A technician has a tool set with the categorized tools and spare and wear parts. The technician, a new spindle, the plastic parts will be scheduled by an organization unit from the IPS² provider to deliver the maintenance process.

Case 2: Service supplier delivers maintenance process

The IPS² provider decides to use a service supplier for the maintenance process. The service supplier has to provide the resource “technician” that is able to make the service based on the process model. The spindle, spare parts and plastic parts are provided by the IPS² provider. All parts, this includes the technician, is scheduled by the IPS² provider. A coordination unit by the IPS² provider is necessary that can communicate with the resources to change for example time schedules. The coordination unit has to manage the availability of the service resources together with finding the best time of delivery for the customer. This case could exist if the IPS² provider is the manufacturer of the spindle, but has not enough capacity of its service resources to deliver the process itself.

Case 3: IPS² module supplier delivers maintenance process

Maintenance of the spindle is provided by an IPS² module supplier. The IPS² module supplier is inside the network of the IPS² provider to develop a micro production machine tool with an integrated milling spindle. The spindle has a high complexity and needs individual services to guarantee the availability. Therefore the IPS² provider has decided to outsource the process of spindle maintenance to the IPS² module supplier. The exchange spindle, spare parts and hoses have to be organized by the IPS² module supplier. Thus two coordination units become necessary. One becomes necessary for coordination by the IPS² provider and the IPS² module supplier and another coordination unit between the IPS² module supplier and his suppliers.

Case 4: Individual resources for each process part

The IPS² provider outsources all maintenance parts to external suppliers, but he keeps hold of the coordination responsibility. This case has the advantage that no capacity has to be considered if a job has to be coordinated. An IPS² provider can change the time of delivery by making new requirements for the service process or by negotiating with each partner individual. A possible service supply chain can have a coordination unit of the IPS² provider and every supplier is directly connected with this coordination unit.

4 SOFTWARE AGENTS

Meanwhile the use of software agents within personal information management [14], support of business processes [15] and electronic commerce [16], [17] is common practice. In contrast, commercial software agent applications in the field of industrial production are still rather seldom. An example is the ongoing research project SOPRO (Self Organizing PROduction). One focus of the project aims at enabling parts of the production system including workpieces to autonomously optimize production processes by cooperation and coordination.

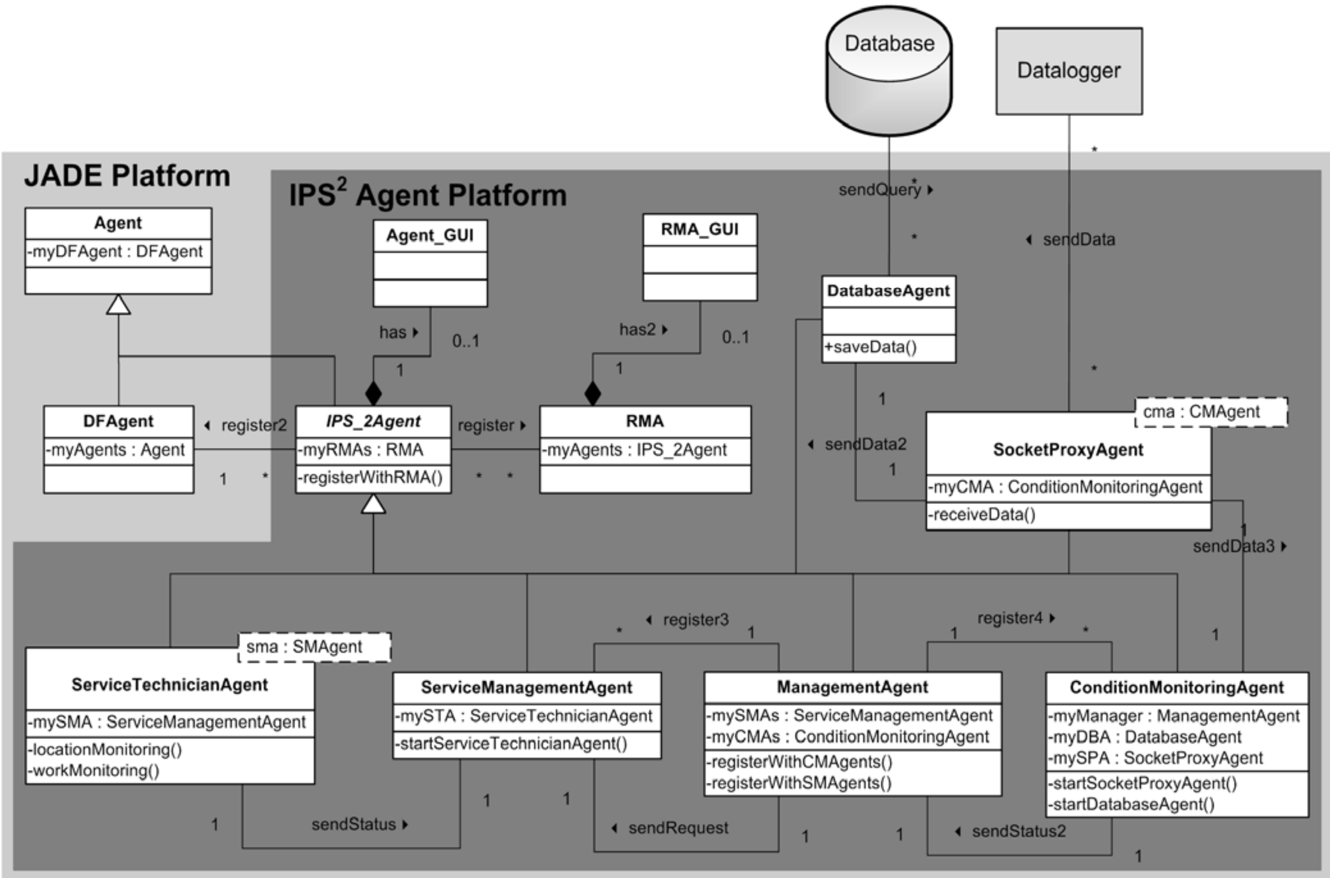
For these purpose machine tools, assembly lines and workpieces are equipped with miniaturized embedded microprocessors with integrated sensors and wireless communication interfaces. Based on software agent technology, these so called process eGrains are able to percept and act following their implemented goals [18], [19]. Aspects of integrated product and service shares are disregarded.

According to the idea of IPS² software agent systems can be used to build up the initial IPS² network [8] as well as to support IPS² in the delivery and use phase, taking into account integrated treatment of product and service shares including the human factor. Every object that is involved in IPS² delivery and use has defined tasks specified in the IPS² product model.

All these objects should be represented by software agents due their interactions needed to ensure proper use of the IPS² [20]. Thereby involved shares and their tasks vary depending on the customer needs and the chosen IPS² business model. In principal, these models can be divided into function, availability and result oriented IPS² business model. The agent class structure model of the availability oriented IPS² business model is exemplarily shown in Figure 7. As mentioned before the specifications of the software agents to be implemented depend on the involved shares and their roles within the IPS² product model. The distinction of different cases as given in chapter 3.2 is used to define roles of and interactions between the software agents and therewith the general system architecture while concrete descriptions of service processes like the MTM of the spindle exchange help to determine interfaces for software agent perception and action, e.g. using sensors respectively actors.

Within the research project SFB/Transregio 29 a multi agent system based on JADE (Java Agent DEvelopment Framework) [21] for the support and control of IPS² operation was developed.

Figure 8 shows the graphical user interface (GUI) for the creation and administration of the software agent. It provides initialization and termination of IPS² agents using predefined agent classes (cf. Figure 7). The GUI also visualizes the communication of agents and offers debugging features for the development software agent.



Legend:

▪ Agent:	Base agent class provided by JADE platform
▪ DFAgent:	Director Facilitator Agent provides yellow pages service
▪ IPS_2Agent:	Abstract agent class in an availability oriented IPS²
▪ Agent_GUI:	IPS² agent specific GUI
▪ RMA:	Remote Management Agent provides administration GUI
▪ RMA_GUI:	Administration GUI
▪ SocketProxyAgent:	Provides TCP/IP interface
▪ DatabaseAgent:	Provides database functionality for knowledge database
▪ ManagementAgent:	Controls IPS² operation and is central communication node
▪ ConditionMonitoringAgent:	Monitors condition of product shares and adapts process data
▪ ServiceManagementAgent:	Manages, initializes and terminates ServiceTechnicianAgents
▪ ServiceTechnicianAgent:	Monitors state of service processes and supports service measurements

Figure 7: Agent class structure model at the example of availability oriented IPS²

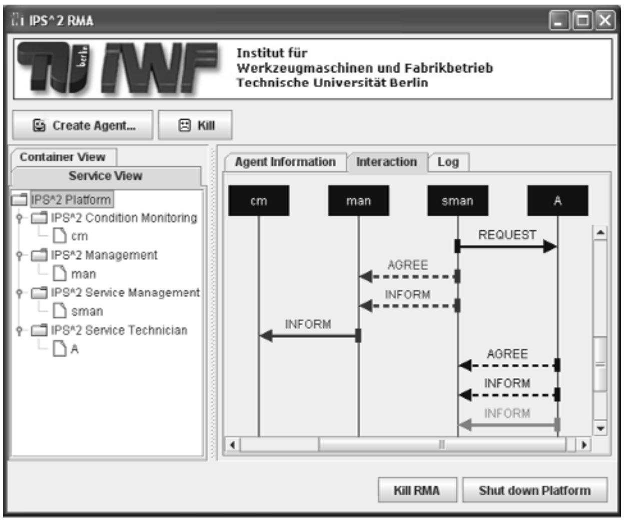


Figure 8: Administration GUI for IPS² software agents with communication visualization

5 SUMMARY

Industrial Product-Service Systems are delivered by a network, whereby the network partners are chosen with respect to their competences and tasks needed for IPS² delivery. These tasks are specified in the product model. This product model includes detailed descriptions of product and service shares as well as a list of all required resources. Due to future unknown influences or changing customer requirements IPS² demand a dynamic organizational system with strong customer integration. Therefore, a reference architecture is proposed in this paper that is able to deal with changing demands by dynamic adaption of the organizational structure of the IPS² network. For this reason, the concept of modular organization units was introduced.

The use of the methods-time measurement (MTM) for the analyzation of processes within IPS² delivery was presented at a micro production scenario. This process analyses is an important prerequisite for the built-up of the IPS² network. While MTM enables to identify time constraints the integrated enterprise modeling defines the attributes for the resources that have to be provided by network partners.

The paper closes with the presentation of a multi agent system for the support of initial network generation and IPS² operation. Since software agents can be applied on machine components as well as on human actors software agent technology is an adequate tool for automated coordination and communication within an IPS² network. In a next step human actions within service processes have to be analyzed more in detail to optimize the cooperation between human actors and technical systems.

In future research optimization methods and interdependencies to find optimal module sets or combinations of modules by using of software agents have to be investigated.

6 ACKNOWLEDGMENTS

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