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Dynamic IPS²-Networks and -Operations Based on Software Agents

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Abstract
This article describes how an IPS² network should be build up by considering the dynamic behavior of the IPS² along its life-cycle. How the network partner could participate and how they allocate their capacities will be also discussed as questions regarding the commissioning by considering the business model.

The realization of this concept is based on a multi-agent system. Therefore all service delivery involved IPS² objects like product, network partner and service technicians are represented by software agents.

All this will be pointed out by an availability oriented maintenance scenario in the field of micro production.

Keywords:
Industrial Product-Service Systems; IPS²; Organization; Multi-Agent System; IPS² Network

1 MOTIVATION

Industrial Product-Service Systems (IPS²) can be characterized by the fact that they consist of a combination of tangible product and intangible service shares, whose service shares provide a value to the customer via the complete life-cycle [1] [2]. In the different function-, availability- or result-oriented use models [3] the order for the service performance is either given by the customer (function-oriented) or by the provider (availability-/result-oriented). Overall Industrial Product-Service Systems deliver value in industrial application for the customer [4]. But this objective is just attractive for the IPS² provider if he gains an acceptable profit by offering this solution.

To reach this win-win situation the operation of the IPS² respectively the service delivery has to be organized efficiently. This includes the internal structure of the IPS² provider as well as the buildup of the IPS² network and its control. The cooperation of companies is one of the main aspects of organizations in the service sector. The reasons are high efficiency of value creation and flexible combination of complementary resources by keeping economical independency [5]. The approach to be shown will point out the typology of the service supply chain under the context of the different targets of delivery flows.

Due to that each IPS² has got its own network as well as the dynamic of the IPS² and the connected dynamic of each IPS² network, the establishing and control of the IPS² delivery becomes very complex for the IPS² provider. This challenge can be managed just by an information and communication technology (ICT) support. This system has to merge automatically the IPS² network depending on the characteristics of the IPS², its tasks and on the prospective network partner. Further on it has to control the planned delivery processes. Therefore the basis of such a system has to be the automated communication within the network as soon as a concept to handle this in an efficient way by autonomous decisions of system parts considering the current circumstance of each decision.

A multi-agent software system will provide the needed advantages. After the software agents are set they will bargain autonomous about the different objectives in the determined borders. The coordination of the distributed software agents has to be managed by a central agent located at the IPS² provider to reach efficient collaboration within the whole network and to assume the responsibility for the IPS² to the customer. Therefore potentials but also problem fields within an automated customized IPS² delivery will be characterized.

2 BASICS OF THE IPS² NETWORK

2.1 Network Partner Roles

The delivery of IPS² needs a new understanding of partnership roles and accountability for actions during the IPS² life-cycle [6]. The roles of the IPS² network partners can be characterized by different delivery flows, communication partners and communication directions and the relationship to the IPS² or to the customer.

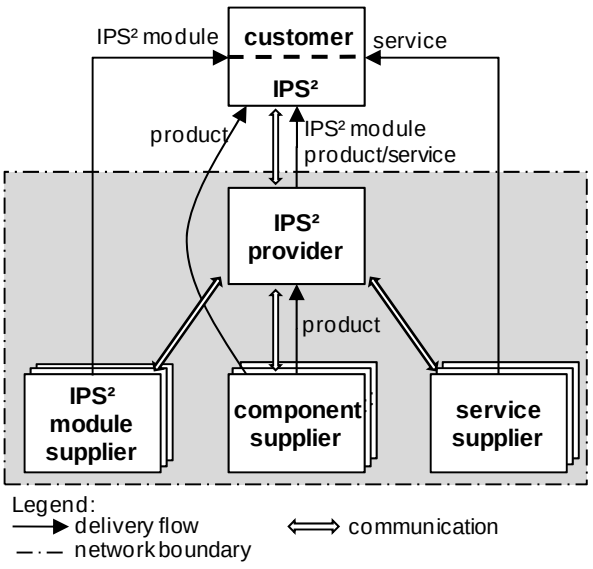

Figure 1: Typology IPS² Network Organization

Figure 1 shows the relation and the main elements of the IPS² supply chain. It consists of the customer of the IPS², the IPS² provider, the IPS² module suppliers, the

component suppliers and the service suppliers. In the following the different elements will be detailed.

Customer:

The customer receives the IPS² from the IPS² provider. Depending on the customer needs the IPS² provider has to keep the operability during the use phase. Dependent on the optimal solution for the IPS² the customer pays for the delivered function, the availability or the result. The resources of the customer can be embedded in the delivery processes. The responsibility of the customer for processes of the IPS² changes between the sold business models.

IPS² Provider:

The IPS² provider has the business relationship with the customer. He represents the one face to the customer and manages all communication in the network. The IPS² provider takes risks depending on the chosen business model. Therefore he coordinates the delivery flow for the IPS² network. Parts of the IPS² can be subcontracted to IPS² module, component or service suppliers by keeping the leadership and responsibility.

IPS² Module Supplier:

An IPS² module is a product-service subsystem of the IPS². It consists of product and service shares with an integrated development. He delivers the IPS² module by himself or by offering parts of it to sub-suppliers over the life-cycle. The IPS² module supplier can change all necessary processes by guaranteeing the same result to the IPS² provider.

Component Supplier:

A component is a tangible part of the IPS² without integrated service. It is storable and can be delivered either to the IPS² provider or the customer.

Service Supplier:

The service is the intangible part of the IPS². It is not storable and therefore it has to be delivered directly to the customer and will become manifest in the IPS².

All needed input to carry out a delivery process like material, energy, information [7] and, additional in service delivery, human resources will be described as resources. The needed resources, including those to manage the byproducts [8] have to be planned in advance and have to be allocated in the right time, place and quality. In service delivery this parameters change between each IPS² and even between the delivery processes. While place and time obviously change in connection to the customer the quality, e.g. of a spare part, may vary depending on the chosen business model.

Further on, the resource planning and scheduling has to be able to react on the dynamics of the IPS² and of course on breakdowns. Therefore the IPS² provides a set of optimization parameters like the time variance, the process variance or the partial substitution of product and service shares [9]. This optimization has to fulfill the demands of the customer by using all resources over the described IPS² network - including the customer resources. This is just possible with a new operational and organizational structure and the described automated communication within the network.

2.2 Operational and Organizational Structure

Processes or business processes are very common objects to illustrate the operational structure and process structuring can be found in a growing number of publications. But an exact definition especially for the use of processes in businesses is not given so far [10]. Most of the publications do not divide between process and business process and use them synonymously. For operational businesses it is defined that the class of business processes is a subclass of processes. ZELLNER tries to analyze the complete variant of different definitions to extract the commonness for a better process understanding [11]. Every process has an input and an output. The process between the input and output is a combination of activities or tasks that are structured by time or event [11].

The process organization of businesses and also of cooperation and of customer communication is getting more important. Therefore a transformation from a functional business organization to a process business organization can be recognized. The functional business organization has been led to a business unit thinking and thus to coordination problems between different units [12]. Where the process business organization tries to concentrate on the value stream and therefore support the concentration on the customer. Another benefit of process business organizations are transparent processes for the production or service delivery. Process structures describe the separate process steps und the connection between them. The measurement of different activities in cost, time and quality is subject of the service delivery processes.

The operation of Industrial Product-Service Systems is to manage the delivery of tangible and intangible parts that are designed integrated as product modules, service modules or product-service modules. Due to the new paradigm shift of an integrated and dynamic interdependent development of products and services, an IPS² process and object description is generated with solutions and solution clusters. The organizational tasks of the IPS² provider are the production planning, the operational delivery planning and to assume the responsibility of the IPS². Thus an operational controlling of the tasks and generated results is required.

To work efficiently and to be competitive all work that is not core competence of the own enterprise will attempt to be assigned to other companies or be bought from the market. To fulfill all qualitative and quantitative customer requirements the IPS² provider has to find a reasonable economic size for subdividing the IPS² jobs between possible network partners. Therefore the resource allocation is being done in two different phases during the IPS² operation. Table 1 show the tasks of the resource allocation for the IPS² provider and the consequences for the IPS² network during the initial phase by getting the IPS² product model and the life-cycle phase by getting knowledge about all aspects around and with the IPS².

The starting point and hence the initial factor of the job assignment to generate the organizational structure is the developed IPS². At this stage of the IPS² development process the IPS² product model contains detailed descriptions of every part and process with qualitative and quantitative requirements. These requirements are used to build a target state for the organizational IPS² structure. Beginning with the initial phase different possibilities to distribute the responsibility for the necessary processes exist. First the own competencies of the IPS² product model are identified and transferred to the resource planning by the IPS² provider. Beside the identification by competencies also strategic targets have to be considered to allocate the delivery responsibility of IPS² parts. The resource planning depends on the time to the date of delivery and its duration. Possible conflicts with other jobs can be solved by strategic resource upgrading. The IPS² parts that are delivered by external partners are leading to new organizational requirements.

The willingness from the IPS² network partners to externalize their IPS² delivery relevant data to the IPS²

provider has to be one more requirement. Also the customer has to link his processes with the IPS² to allow the offering of availability-oriented and result-oriented IPS². If the IPS² provider wants to react in a desired time it is necessary to know the production or manufacturing plans or downtimes from the customer. To share data in the IPS² network IPS² execution system interfaces have to be established by the network partners.

Phase	IPS² provider	Result for IPS² network
Initial Phase: IPS² product model	• Resource planning • Strategic capacity planning	Network creation: • Supplier job assignment • Clear responsibilities in IPS² product model • Interface coordination • Commitment of goals and aims
Life-cycle phase: generated knowledge from delivery and use of IPS²	• Substitution • Time variance • Resource attributes changing	Network Optimization: • Substitution of suppliers • Adaptation of IPS² network partner pool

Table 1: Tasks of IPS² Provider during IPS² life-cycle

The second phase, the actual use of the IPS², describes the use of knowledge out of the life-cycle phase to optimize the job and resource planning [13]. Options to change the job and resource planning are to substitute product and/or service shares, time variances and the upgrading of resource attributes from the IPS² provider or the IPS² network. Changes of the IPS² job demands will affect the partner selection and the job assignment dynamically in existing IPS² networks.

2.3 Job Association

The definition of IPS² as the delivery of value in use for the customer in industrial application implies a wide variety of different functions in the IPS² product model. This variety of different functions can only be handled by a cooperation of companies to reach the optimal solution [14]. In this chapter the association of external partners by the IPS² provider will be described.

First additional requirements for the IPS² job assignment are emerging from the concept “one face to the customer” and importance of IPS² parts. The “one face to the customer” concept implies the central communication between the customer and the IPS² provider. Even questions from the customer to a part of the IPS² that is being handled by a network partner have to be communicated over the IPS² provider. This does not necessarily contain an explicit action of the IPS² provider, e.g. to send the customer question forward to the network partner. But the IPS² provider should be able to build a history of IPS² delivery information. The job assignment will be done by the IPS² provider and the afterward job control will be done by the individual selected partner.

The job association depends on the art of the process and whether the process can be planned easily. For example a critical IPS² process that could lead to a malfunction of the IPS² will be assigned over a longer period of time than non-critical processes. Contracts have to guarantee the delivery even in the case of unpredictable initiation of critical processes. Better planable processes that are not critical for the IPS² operation are assigned for shorter time periods. This would lead to more competition between possible network partners and to an advance of qualitative job results.

The purchase of the IPS² parts from external partners is mostly influenced by service characteristics. The manufacturing and use will be at the same time for the “product” (uno-actu-principle). Thus the three dimensions of a service – potential dimension, process dimension, result dimension – have to be exactly defined for every job description [15]. The tangible parts of the IPS² are described by object lists, technical and production drawings and can be produced definite. A controlling of the process parameters can be done with the manufactured part instead of a service that is more difficult to control before the delivery. Therefore the IPS² parts need standardized description to enable a successful purchase from suppliers. It is helpful for a better communication and a common understanding of the goals and restrictions of the jobs. Next step could be the trading of intangible parts.

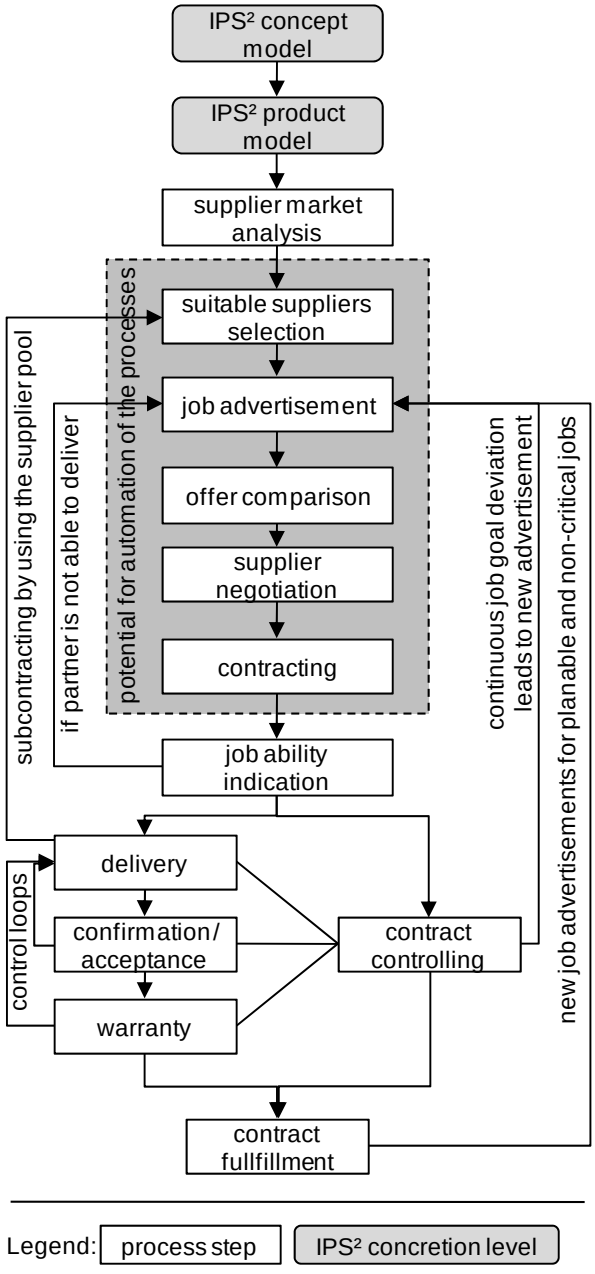

Figure 2: IPS² Job Association

Figure 2 shows the business process for the initial job association of IPS² product model parts. The process steps are based on the DIN PAS 1018 model for “the essential structure for the description of services in the procurement stage” [15]. Current service procurements

are starting with the needs recognition and the needs description. The described services will then be calculated to determine costs and prizes. After that step possible suppliers will be detected, then the job will be offered and last the best fitting supplier will be selected. Next the model describes the delivery of services and parallel controlling. The business process ends with the contract fulfillment.

For IPS² job procurement the DIN business process model has to be adapted. The processes of needs recognition, needs description and cost calculation are already described in the IPS² concept model and the IPS² product model. Job procurement in the context of IPS² that is starting with the delivery and use phase will begin with the market analysis for suppliers. This process is determined of very heterogenic data and the information collection has to be done by the IPS² provider. The data will be collected in a list or matrix to compare the possible suppliers. After that the processes “suitable suppliers selection”, “job advertisement”, “offer comparison”, “supplier negotiation” and “contracting” are following. These processes have a highly potential for automation. Standardized communication and descriptions are needed and can be used to get an automated information flow between the corresponding partners. The overall time for job assignment is the target and an advantage of the process automation.

Another restriction for job procurement is the modularization of the IPS² product model. The different modules have to have a certain kind of independency to minor the coordination efforts to avoid taking more effort in coordination than in the actual job delivery. After the contracting process a monitoring of the delivery ability of the contracted partner is necessary. Until the beginning of the delivery processes the ability will be checked and if other jobs or sudden accidents lead to problems in delivery, a new advertisement of the job will be done.

The IPS² partners in the network have to hold all necessary data up to date. A big problem would be the case if no partner could be found to run the advertised job. Solution could be a specialized team of experts out of every network partner that could be entered to help to deliver. But the consequences and the requirements for the IPS² provider, the supplying companies, the network and the customer have to be analyzed in the future.

3 TECHNICAL ENABLER

The following chapter shows a scenario for the initialization of an IPS² network and the dynamic adaptation with respect to dynamic changes of the IPS² demands.

Before the IPS² network can be initialized, a pool of potential partners is needed. An efficient way to interact with these is the use of software agents. Different types of software agents can be used in the different phases of the IPS². In the phase of initial network building the IPS² provider uses a software agent platform to announce his need for network partners. Software agents of potential partners analyze the task description and in case of capability submit an offer.

After building the initial network another software agent platform is used for communication between the network partners.

On the hardware side is a need of specialized technical support. The investigation of wear mechanisms and the development of condition monitoring algorithms for the detection of wear and tear of mechanical machine components is part of current research projects [16] [17] [18]. First industrial applications are available on the market [19]. Compared to the IPS² approach available systems are sold as additional physical products that have to be integrated into the spindle after the spindle was designed.

To ensure an efficient use of the IPS² a high degree of automation is needed. For an IPS² provider it may be useful to distribute different tasks within the IPS² to several network partners with regard to their core competences. One of the most important duties in networking is the organization and control of service activities. The use of software agents is the focused solution to manage these duties by automated communication and interaction between IPS² objects.

3.1 Software Agents in IPS²

There is still no uniform definition of an intelligent software agent. In this research project the characterization by Jennings is preferred [20]:

“An agent is an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in order to meet its design objectives."

According to this definition a software agent can be described in an easy way by its ability to observe its environment, to interact with its environment to reach a defined goal, and in the case of a multi-agent system (MAS) to communicate with other agents. A software agent acts as a virtual representative of a physical object. It is a piece of software that is provided with the profile of the objects needs and is able to act autonomously.

Typical application areas for software agents can be found in personal information management [21], the support of business processes [22] and of electronic commerce [23]. An example for an industrial application of software agents can be found in [24]. There, the concept of an agent based production monitoring system in the field of automotive industry is proposed.

In the IPS² context software agents can be used to control the IPS² operation during its life-cycle. Every object that is involved in IPS² operation has defined tasks. A MAS is suitable to support and control these tasks by its high degree of automated communication and autonomous action.

4 DEMONSTRATOR SCENARIO

4.1 Initial Conditions

The following scenario describes the software agents’ interaction in the event of a detected imminent breakdown due to wear and tear. In this illustrative example an industrial customer wants to act as supplier for a manufacturer of a product that includes micro components. It is agreed by contract that the customer has to deliver a defined number of parts per time interval. The contract also includes a warranty for the quality of the fabricated parts.

Therefore, the analysis of the customer requirements in the early phase of IPS² design lead to an availability oriented use model. In this scenario the resulting IPS² represents a three axes CNC micro milling machine for the manufacturing of micro parts, including all services that are needed to ensure the availability of function relevant components.

The further description of the scenario focuses on the milling spindle as the most stressed core component of the machine tool and how to warrant its availability. Due to the analyzed customer requirements the resulting product model of the IPS² has following attributes:

- Milling spindle with integrated condition monitoring system (CMS) and communication interface as enabler for condition-based maintenance.
- Condition-based maintenance of the spindle and periodical maintenance of non-critical machine components. This includes inspection, replacement of wear parts, and repair.
- Spare part service.

4.2 Initial IPS² Network

An optimized operation of this IPS² can only be reached, if the IPS² provider takes the responsibility for all needed IPS² processes. Nevertheless, different IPS² processes have to be distributed to different stakeholders within an IPS² network, due to restricted competences and man-power of the IPS² provider. The resulting network consists of partners with special core competences to fulfill the attributes of the given product model. Let us suppose that the following network partners are chosen:

- **IPS² provider:** He is the only contract and contact partner of the customer. He is responsible for all activities, needed to use the IPS² as agreed in the contract. He is the leader of the consortium that builds the IPS² network.
- **IPS² module supplier:** He is the manufacturer of the spindle with an integrated condition monitoring system. The monitoring of wear parts' condition (data acquisition, signal analysis, data storage, and notification) is the integral service part of the module.
- **IPS² service supplier:** This network partner offers the periodic maintenance service for the milling machine and the condition based for the spindle. This includes the organization of spare parts, which he may obtain from a third party as second tier supplier.

The contracting of second tier suppliers lies in the sole responsibility of each network partner.

4.3 Software Agents in the IPS² Network

A condition monitoring software agent (CMSA) collects and analyzes condition relevant data during the spindle's life-cycle. Based on an implemented set of inference rules the agent detects critical trends of the condition of function relevant components, e.g. bearings or parts of the gripping mechanism. When a critical trend is detected, the CMSA calculates the remaining time until an alarm limit will be exceeded. This information will be send by the agent to the IPS² network management software agent (NMSA) which is located on a server at the site of the IPS² provider. If available, more detailed information can be attached to the message, e. g. kind of expected failure. Figure 3 shows the principal structure of interaction for the CMSA.

The NMSA logs the information and forwards the message to the IPS² module supplier respectively to his software agent. Based on the received information the IPS² module supplier allocates a plan of service procedures needed to restore the spindle's origin state. This includes a list of required spare parts, tools and a detailed process description. The maintenance planning software agent (MPSA) sends this service procedures to the NMSA. This information is used by the IPS² provider to organize the logistics for the maintenance activities.

In a first step the NMSA sends a request to the maintenance service software agent (MSSA) of the IPS² service supplier. This message contains the detailed job description and the schedule. After checking the internal enterprise resource planning system (ERP) the MSSA declines the job offer, due to a capacity constraint on the part of the IPS² service supplier. To avoid a contract penalty in case of the imminent breakdown of the spindle the IPS² provider has to expand the given IPS² network temporarily. For this reason he may use again the software agent platform for IPS² job association (cf. Figure 2). Depending on whether he finds an alternative service supplier that fulfills all required specifications regarding the three economical aspects of time, cost and quality the scenario differs:

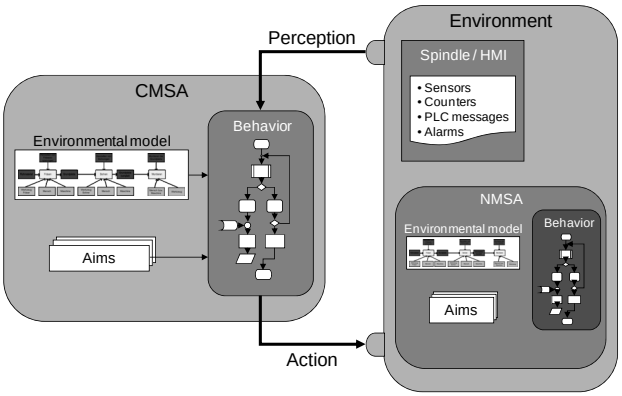

Figure 3: Principal Structure of CMSA Interaction

Case 1 (alternative IPS² service supplier):

After contracting an alternative service provider a service technician software agent (STSA) is initialized to control all service related activities from work preparation (e.g. organization of spare parts and tools), journey up to maintenance. All these processes are defined within the IPS² product model and have characteristics to enable monitoring and control. The task of the STSA is to monitor the activities and to adapt correcting-variables of the processes if the actual process workflow differs from the planned one. To ensure process reliability the STSA has to perceive data from the environment, e.g. current position from the global positioning system (GPS), duration of a maintenance process step. The software agent's behavior can effect two different actions:

- Adaptation of a correcting element in terms of feedback control engineering or
- sending a request to NMSA.

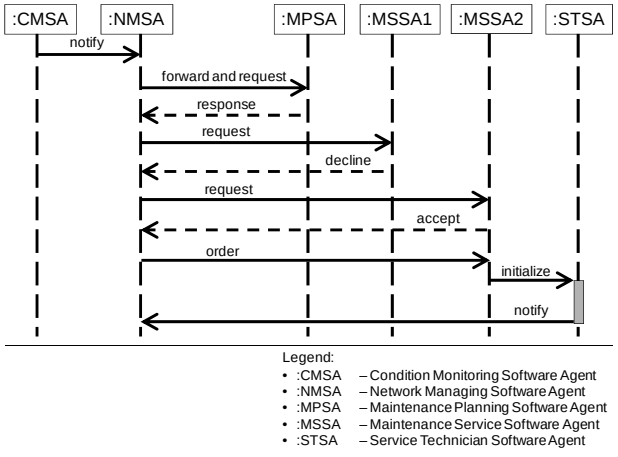

Figure 4: Principal Sequence Diagram of the Scenario

This control is active until the service process is completed. Additional to the control functionality all process steps are documented by logging their characteristic variables. The principal interaction process of the above described scenario is shown in Figure 4.

Case 2 (no IPS² service supplier available):

If the IPS² provider is not able to find an alternative service supplier for this job within the remaining life-time of the spindle, the NMSA can upgrade the CMSA by

sending an expanded behavior. In this case, the new behavior is the command to go into a fail-safe mode to avoid consequential damage of other machine components. This results in a breach of the agreed availability warranty and identifies the limits of automation using a MAS.

5 CONCLUSION

The paper shows the need of a new network organization that supports the operation and delivery of an IPS² with its special characteristics, e.g. the high dynamic of changes of the IPS² during the life-cycle. To manage this challenge the illustrated network is characterized by its ability to change flexible the network partners. Therefore an automated communication between the potential network partners is essential to fulfill the real-time demands. A multi agent system has the ability to cope with the network demands. Thereby one multi-agent system is needed for initial network configuration and another one for the control of the delivery processes during the IPS² life-cycle. To demonstrate this approach an example scenario for the agent communication concept was described. It shows the different communication levels in case of an imminent machine breakdown.

6 ACKNOWLEDGMENTS

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