Towards Adaptable Industrial Product-Service Systems (IPS²) with an Adaptive Change Management

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Abstract

Compared to single physical products or services, IPS² are characterized by a very high degree of dynamic changes not only during their planning, but throughout their entire life cycle. These changes have to be managed, tracked and documented by a change management process and supported by a change management system. As IPS² changes and change processes are very difficult to plan during the IPS² development phase, existing static and deterministic change management solutions are not appropriate to be used for IPS². This paper describes a new concept of an adaptive change management for IPS². The concept described allows for appropriate redesigning, adaption and execution of change processes of IPS² throughout its entire life cycle to carry out an IPS² change most efficiently with regard to time and costs.

Keywords

Industrial Product Service Systems (IPS²), Engineering Change Management (ECM), Adaptive Processes, Adaptability

1 INTRODUCTION

Industrial Product Service Systems (IPS²) is defined as “an integrated industrial product and service offering that delivers value in use” [1]. In this respect, it is the lasting satisfaction of the customer benefit that constitutes the central aspect of the IPS² approach. Dynamic adaptability and changeability of IPS² throughout the entire IPS² life cycle are hard to plan deterministically during the development phase. Yet they are a basic requirement for its successful implementation and application. To fulfil these conditions, change management processes have to possess a high degree of adaptability and flexibility, i.e. they have to adapt appropriately and respond promptly to new situations during their runtime.

This paper describes the concept of an adaptive Engineering Change Management (ECM) for IPS² which allows for appropriate redesigning, adapting and executing of change processes of IPS² throughout its entire life cycle in order to carry out an IPS² change most efficiently with regard to time and costs.

The concept presented in this paper has been developed in the research project Transregio 29 “Industrial Product-Service Systems – Dynamic Interdependency of Product and Service in the Production Area“, which is funded by the German Research Foundation (DFG).

2 CURRENT SITUATION

Competitive IPS² providers must be able to adapt their share of products and services within an integrated IPS² to quickly respond to unforeseeable changes in their environment throughout its lifecycle. Various factors, the so called *change drivers*, can cause such changes. They can be technological (e.g. emergence of new technologies), environmental (e.g. increasing shortage of resources), political (e.g. legislation amendments), social (e.g. new customer demands), or economic (e.g. decrease in customer demand due to the current economic crisis). Hence the prompt reaction to these unpredictable changes along the overall IPS² lifecycle has a significant impact on the economic success of the companies involved in the IPS² network. This challenge can only be met by an adaptive engineering change management.

In the last decades, several methods and standards such as part 4 of DIN 199 (Technical Product Documentation), ISO 10007:2003 (guidelines for configuration management) and Release Management and Recommendation VDA 4965 (Engineering Change Management) have been developed for the management of technical changes. The focus of these methods and standards is the management of technical changes of physical products (not of services), which is why they are strongly geared towards the life cycle processes of these products.

However, the life cycle processes of IPS² are much more complex than those of technical products. For instance, IPS² producers, as a rule, are also responsible for the delivery of IPS² and have to optimize it and to dynamically and promptly adapt it to customer needs during the use phase. Therefore, current change management methods and standards can only consider specific characteristics of IPS² to a small extent and support an efficient implementation of IPS² change management processes in a limited way. The following points serve as examples for the most important weaknesses of current change management methods and standards with regard to IPS² change management:

- Existing change management methods focus exclusively on the development and manufacturing phases and neglect the delivery and use phases.
- Existing change management methods cannot sufficiently consider the complexity of IPS², which arises from the networking and mutual influence of technical products and services as well as change dynamics during the delivery and use phases.
- Previous change management methods do not provide a fast reaction to changes that occur within the delivery and use phases of IPS².
- Existing change management methods only support or provide static and deterministic change processes and do not provide an appropriate adaptation during the process runtime.

- Existing change management methods do not allow an integrated view of the product and service share of an IPS².
- Existing change management methods limit corporate innovation skills and the responsiveness to unpredictable changes.

3 REQUIREMENTS

Current obstacles to IPS² adaptability are deterministic and fix-planned static change management processes, which serve as a basis for the implementation of all activities within an Engineering Change Management (ECM).

Such processes limit corporate innovation skills and the responsiveness to unforeseeable changes. Within a given scope, adaptive change processes can make an important contribution to IPS² adaptability. They automatically respond and immediately adjust to new conditions. Thus ECM process buildup and implementation priorities of the process activities must be determined automatically in real time and be adequate to and in accordance with the conditions that apply at that time.

Adaptive change processes enhance IPS² adaptability through:

- an integrated consideration and analysis of the technical products and services as a hybrid performance package (IPS²) during ECM process implementation.
- a continuous and prompt optimization of the various interacting IPS² modules (i.e. technical product and service) to grant the best possible customer benefit.
- enhancement of the real time responsiveness of the IPS² provider (fast and adequate to the situation) to the unpredictable and permanently changing customer requirements during IPS² delivery and use phase.
- real time definition of executable ECM process activities and their execution priorities depending on ECM contents, context, objectives, and the current conditions (i.e. adaptive process design and management).
- prompt configuration and immediate startup (e.g. continuous real-time plan-and-execute rather than static plan-the-execution) [2].
- management of changes during IPS² development and delivery phases.
- taking into account all aspects of the complexity of IPS² during the change management, which arise through strong networking and IPS² modules interdependency and which are thus not directly visible to IPS² developers.
- taking into consideration the great uncertainties which arise in IPS² development and delivery phase during ECM process execution.
- ascertaining the effects and determining the spread of IPS² module change on the whole IPS² and its environment throughout its lifecycle.
- auto-ascertaining ECM process variations in the implementation of IPS² changes and adaptations.
- integration and close interaction of all IPS² network partners during IPS² change (product manufacturers, service providers, IPS² providers, IPS² customers, etc.).

4 RELATED WORK

In recent years, numerous pieces of work have been carried out with the focus on change management. In the following, the outcomes of the crucial projects that are related to this work project are listed and briefly discussed:

The work of Burmeister et al. [3] is among the important works that deal with the issue of developing agile process modeling methods. For this, they have combined the agent technology and the goal-oriented modeling method to model und implement agile business processes. The developed approach has been applied and validated in line with a case study in the domain of Engineering Change Management of technical products. The demands arising due to the high complexity and the permanent changeability of IPS² have not been taken into account in this work.

In several research projects, Eckert et al. [4, 5, 6] have addressed the question of how designers can be made aware of the impact of a proposed change before they carry it out. The main result of these projects is the implementation of a tool to evaluate change proposals during ongoing design processes where the state of the development of parts is taken into account. This presents an extension of the Cambridge Change Prediction Method, which assesses the risk of changes propagating between two parts. The research works have only concentrated on the change of technical products arising during the design phase and they have not considered those that arise during the delivery and use phase of technical products relating to the added services.

Conrad et al. [7] also propose an approach to support the processes of analyzing and assessing the effects of changes in the product development process. This approach is based on the CPM/PDD theory (Characteristics-Properties Modelling/Property-Driven Development) and the FMEA method (Failure Modes and Effects Analysis). The proposed approach only deals with the effect of changes in the CAD models during the design phases of technical products.

Amaral et al. [8] suggest an NPD model (New Product Development) named PDNet, the singular characteristic of which is the integration between a business process reference, a maturity model and a change management model in order to support the full product development change cycle. This work also focuses on the development phase of technical products and does not consider the special requirements of the IPS² change management.

In order to investigate the behavior of change management processes in practical work and to develop a practice close change management approach, several case studies [9, 10, 11] have been carried out in various industrial sectors. However, the aspects of the adaptive change management for IPS² have not been in the focus of these approaches.

5 CURRENT PROCESS MANAGEMENT METHODS

Since the nineties, several process management approaches and methods (e.g. ARIS, SA, OMEGA, SADT) have been developed to design, manage, execute and control ECM processes and related data. They are commonly known as BPR (Business Process Reengineering), BPM (Business Process Management) or CPI (Continuous Process Improvement).

These methods have been implemented into various IT tools (e.g. ARIS Design Platform, PAVONE ProcessModeler, Bonapart) to support companies with the carrying out of company specific ECM processes. In view of ECM process adaptability and thus also company adaptability, however, current process management methods show the following weaknesses among others:

- The processes can only be mapped as fixed and static sequences or as a concatenation of activities.
- Existing Continuous Process Improvement (CPI) methods aim at improving adaptation of process models to changing boundary conditions in order to optimize business processes [12]. However, these methods only allow the presentation of fixed sequences of activities. Thus, the adaptation to changed boundary conditions must be made a priori. This is a very time-consuming process, as the process manager does not receive systematic support in their solution determination.
- Objectives and goals of a business process are not defined and modeled explicitly and are thus not always visible. Hence, adaptations and changes to processes evoke the necessity to ascertain that, in the end, the original aim of the process is indeed reached.
- Process flexibility can only be achieved by defining additional process variants. That way processes become ever more extensive, unclear and complex.
- In most cases the executed processes do not correspond to those planned a priori, as the implementation of change processes is rather elaborate and expensive ("shadow processes" may arise).

Adaptive ECM processes are important prerequisites for IPS² adaptability. To design ECM processes, adaptively new process management methods are required. These methods are supposed to warrant systematic process design and control. On the other hand, they need to leave enough space for creativity and permanent changeability. ECM processes must thus be designed and executed in a way that ensures the continuous IPS² adaptability to new and unpredictable situations.

The new process management methods need to be goal-oriented, not activity-oriented. Thus, ECM processes are to be defined and modeled in real time, i.e. during process runtime whilst taking into account newly occurring conditions and requirements. They should no longer be defined a priori as fixed processes. This will also render the entire process clearer and more intelligible, which is a prerequisite for a fast adaptation, change and transformation of ECM processes.

6 GOAL-ORIENTED PROCESS MANAGEMENT METHOD

This section introduces a new goal-oriented process management method for modeling adaptive processes. The method is based on the Business Process Management approach by [3], which was defined by Daimler AG and Whitestein Technologies.

The aim of this new goal-oriented management method is to replace those processes that are planned in a fixed and sequential way and a priori, with dynamic and adaptive processes. When executed, the latter allow for near-independent, real time responses in specified situations.

To reach these goals, the processes are defined and modeled by the new method according to the following principles (Figure 1):

- First and foremost, the processes are intended to capture and characterize the defined business goal, independent of the solution. Goals can be construed into further sub goals.
- Each goal is assigned a generic implementation plan, which is merely made of independent tasks or activities without any predefined execution sequence or priorities.
- The specifications of and the order in which tasks or activities are carried out are determined during process execution, in real time, and depending on the main process issues and the current situation (rules) of the process.

Within the process, the tasks or activities are defined as intelligent agents. They represent the appropriate road to the (sub) goal, appropriately, independently, and subject to the rules. They also provide the process manager with recommendations for decision-making in view of the occurrence of further process steps.

These agents are modeled as modular, intelligent services according to the BDI principle (Belief-Desire-Intentions) [13]. The services are fitted with assumptions about their environment (Belief), knowledge of the target issue (Desire), and the purposes of how that issue can be reached (Intentions). To possess the required knowledge (Belief, Desire and Intentions) during process runtime, the intelligent services need access to process ontology. The process ontology then serve as a common basis for process data management and as a source of knowledge generation for real time process control (Figure 2).

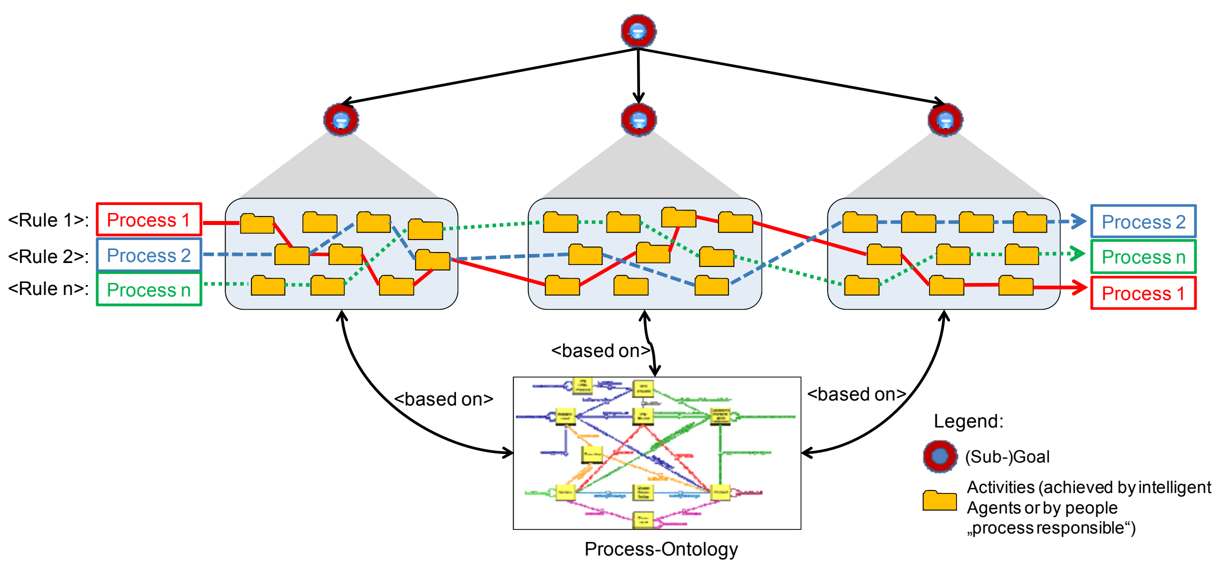

Figure 1: Goal-oriented process management method

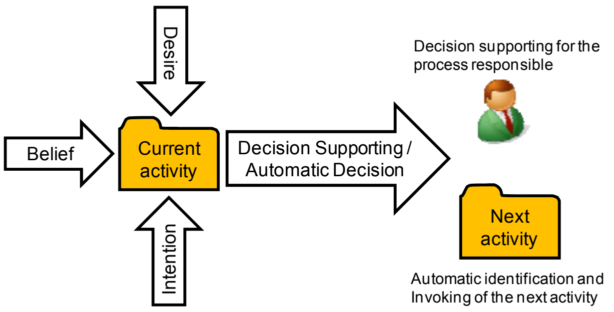

Figure 2: Intelligent agents (process activity) according to the BDI principle

The main differences between current process management methods and the new goal-oriented method are summarized in Table 1.

Characteristics	Current Methods	New Method
process modelling	fixed sequence of activities	goals, activities, rules
process optimization	in the design phase	in the execution phase (real time)
process control	central	decentralized / autonomous
IT technology	Rigid Workflow Management System	Adaptive Service Oriented Architecture
Separation Process Definition/ Execution	yes	no
Sequence of Process Events	fixed (in the design phase: fixed process chain)	adaptive (in the execution phase: real time sequence definition)

Table 1: Comparison of current process management methods and the goal-oriented method.

Based on the new defined process management method, process execution and control resemble a GPS system: Once the goals and sub goals as well as any further boundary conditions have been entered, the route is calculated dynamically in real time taking into account all possible disturbances. Divisional routes are chosen autonomously, or they are presented to the driver's assistance.

7 ADAPTIVE CHANGE MANAGEMENT APPROACH FOR IPS²

This section introduces an approach to an adaptive change management that supports and enhances IPS² changeability and adaptability. At the core of this approach stands an adaptive ECM process (Engineering Change Management Process) that maps the activities of an IPS² change order based on the goal-oriented principle (as described in section 6). In addition, this paper defines a top level IPS² ontology as a knowledge source of real time ECM process execution and control.

7.1 Adaptive ECM Process for IPS²

The adaptive ECM process for IPS² has been developed by means of the defined goal-oriented management method. The basis for ECM process definition is VDA recommendation VDA4965 Part 1 "Engineering Change Management" (ECM). This recommendation supplies a standard and a generic description of change processes of technical products along the entire supply chain in the automotive industry [14]. In this work, the ECM-process (Engineering Change Management process) of VDA4965 has been extended by further IPS²-specific aspects in order to enable an integrated change management of a whole IPS².

The main goal of the adaptive ECM process „IPS²_ECM_Managed“ is management, i.e. the execution and control of an IPS² change order. The accomplishment of this main goal presupposes the accomplishment of several sub goals (Figure 3). First of all, the requirements or wishes for an IPS² change are registered and their relevance and priority are checked: „IPS²_ECM_Inquired“. Based on the results of the preceding goal, a Change Request is made which specifies all the details of the change: „IPS²_ECM_Created“. The next ECM process goal is a comprehensive and profound technical, logistical and economic analysis of IPS² change: „IPS²_ECM_Analysed“. Subsequently, IPS² change is evaluated and commented by various experts (e.g. development, production, logistics and service): „IPS²_ECM_Commented“. Finally, based on the evaluation and comments, a decision regarding the execution of IPS² change is made: „IPS²_ECM_Decided“.

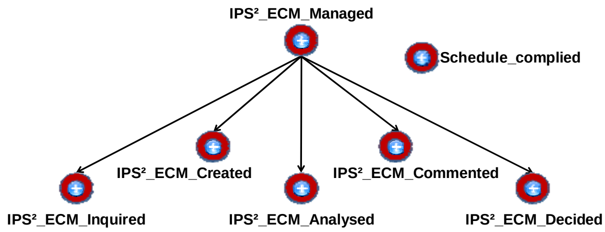

Figure 3: Overview of the adaptive Engineering Change Management (ECM) for IPS²

At the beginning of an ECM process, organizational restrictions, e.g. the maximal processing time, can be defined: „schedule complied". To accomplish this organizational goal, ECM process control automatically determines the optimal process path.

The above-mentioned goals are accomplished by invoking intelligent, modular services, which are mapped as modular, isolated tasks or activities in this ECM process. Tables 2 and 3 show examples in excerpts of the activities to achieve the goals "IPS²_ECM_Inquired" and "IPS²_ECM_Analysed" respectively.

Several process parameters have been defined for real time execution and control of the ECM process. These can be set at the beginning of or during process execution on the (sub) goal and activity level. Operators (e.g. AND, OR, XOR, If, Then) define a priori and in real time rules. By use of these rules the required (sub) goals and activities as well as their execution sequence and process runtime can be determined to ascertain optimal ECM process flow. Table 4 shows excerpts from the process parameters defined in this work including their possible parameter values.

Activities	Description
change registration	register requirements and wishes for IPS² change
change classification and prioritization	• classify changes to be performed (e.g. product change, service change, technical change) • prioritize changes to be performed (e.g. high, medium, low)
condition for ECM creation checking	check requirements for the initiation of an ECM process (e.g. customer relevance, manufacturer relevance, security relevance, competition relevance)
concerned parties determination	determine areas or parties concerned by the changes (e.g. development, service, manufacturer, customer, logistics service provider).
change- responsible determination	determine areas or parties responsible for the execution of the changes (e.g. development, service, manufacturer, customer, logistics service provider)
next goal determination	based on the results of the individual activities the next ECM process goal is determined

Table 2: Excerpts from the activities to achieve the goal "IPS²_ECM_Inquired"

Activity	Description
new IPS² requirements identification	identify change-related new IPS² requirements
new IPS² function identification	identify change-related new IPS² functions
concerned IPS² function identification	identify change-related concerned IPS² functions
concerned IPS² modules identification	identify change-related concerned IPS² modules (products and services)
next goal determination	Based on the results of the individual activities, the next ECM process goal is determined.

Table 3: Excerpts from the activities to achieve the goal "IPS²_ECM_Analysed"

7.2 Top Level IPS² Ontology

To manage the entire IPS² life cycle, a top level ontology has been developed within the research project Transregio 29 "Industrial Product-Service Systems – Dynamic Interdependency of Product and Service in the Production Area". It is based on the STEP reference model "AP 214" and consists of several classes and relations mapping and describing the various IPS² modules (e.g. technical product, service, function, requirement), the entire IPS² structure as well as IPS² life cycle management processes (e.g. change management, release management). In addition, the top level IPS² ontology has been augmented by axioms that automatically generate knowledge, conclusions, and relations based on IPS² data. This ontology has been used throughout this work as a source of knowledge to provide all necessary information regarding process parameters and rules of real time ECM process execution and control.

Parameter	Parameter Value
ECM_Activator	• IPS²_Provider • Product_Manufacturer • IPS²_Customer • Service_Provider
ECM_Reason	• IPS²_Enhancement • IPS²_Optimization • Product_Optimization • Service_Optimization • Customer_Wish • Quality_Problems • legislation amendment
Change_Complexity	• High • Medium • Low
Design_Relevance	• Product_Design • Service_Design • IPS²_Design • No
Cost_Relevance	• Product_Change_Cost • Service_Change_Cost • IPS²_Change_Cost • No
Safety_Relevance	• Product_Safety • Service_Safety • IPS²_Safety • No
Quality_Relevance	• Product_Quality • Service_Quality • IPS²_Quality • No
IPS²_Use_Model	• Result_Oriented • Function_Oriented • Availability_Oriented
Necessity	• High • Medium • Low
Technical_Risk	• High • Medium • Low
Financial _Risk	• High • Medium • Low
Schedule_Risk	• High • Medium • Low

Table 4: Excerpt from the ECM process parameters

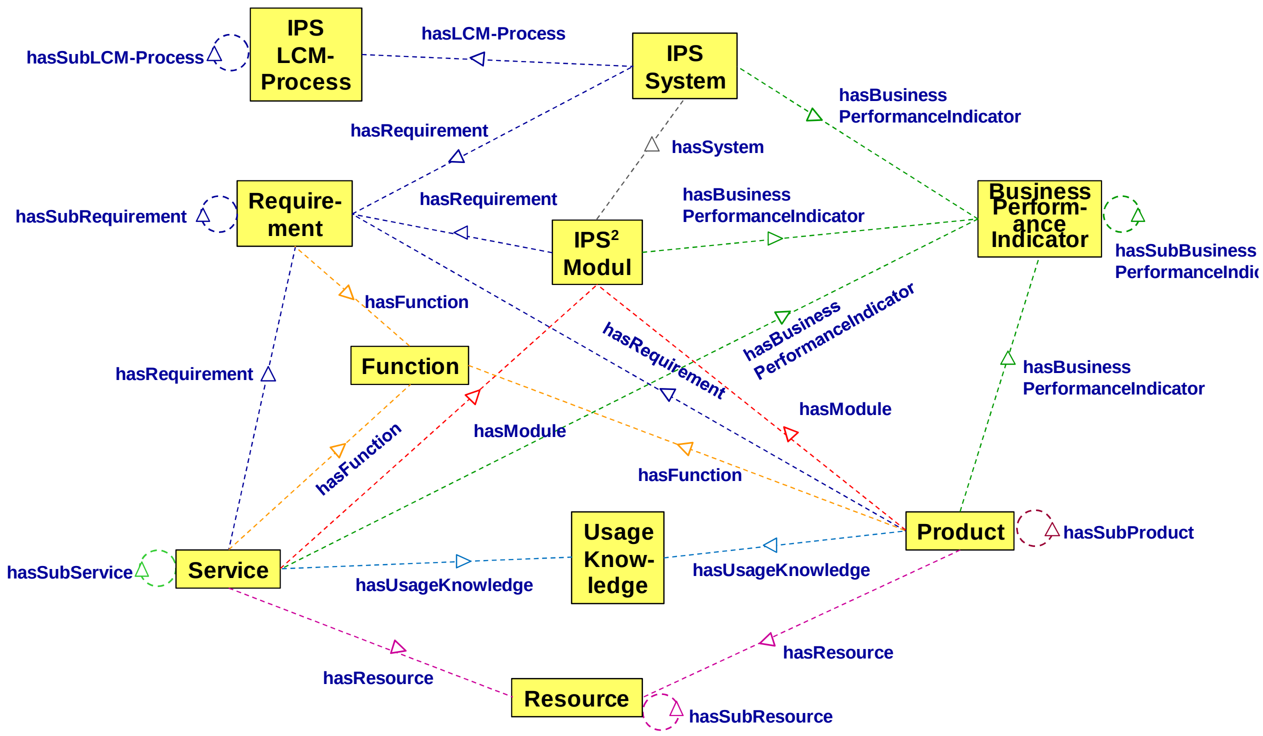

Figure 4: Overview of the top level IPS² ontology

Figure 4 shows the top level class structure of the developed IPS² ontology, which is an extract of the complete ontology model. A comprehensive description of all IPS² ontology elements and the respective opportunities for generating knowledge, conclusions and relations has already been presented in a previous paper [15].

8 IMPLEMENTATION OF THE CHANGE MANAGEMENT APPROACH FOR IPS²

The standard process description language WS-BREL4People (Web Services – Business Process Execution Language for People) has been used for the modeling and prototypical implementation of the developed change management approach for IPS². WS-BPEL4People is an XML-based language that describes business processes the individual activities of which are implemented by modular, isolated web services [16].

As of late, WS-BPEL4People has been implemented into many IT tools, so called BPEL editors. By use of these BPEL editors, a process and its activities can be described and mapped graphically. However, this can also be done using different workflow modeling techniques. Unlike other techniques, it can generate an executable XML process code from the graphically modeled business process directly and in real time.

Figure 5 shows the prototypical realization of the goal “IPS²_ECM_Inquired” and the related activities, which have been implemented as modular web services.

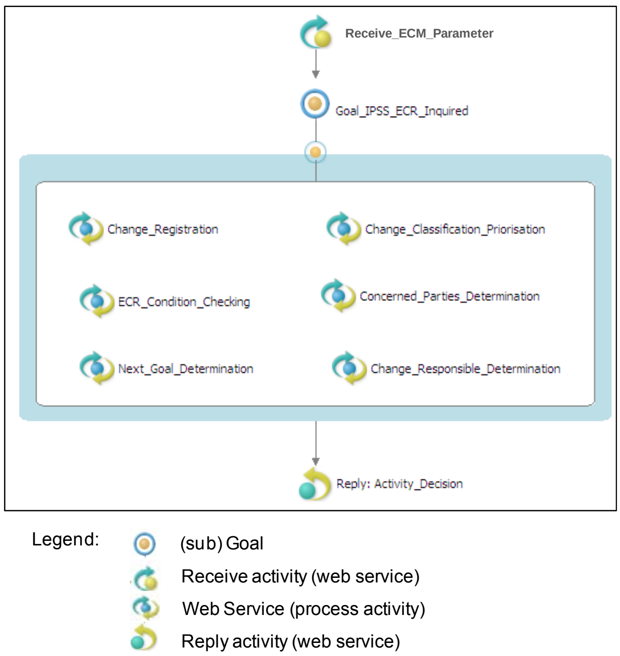

Figure 5: Modelling of the goal “IPS²_ECM_Inquired” by using of the WS-BPEL4People

9 CASE STUDY

A case study has been carried out to validate the approach developed in this work. The IPS² treated in this case study is an Electrical Discharge Machine (EDM) [17]. These machines are mostly used in the manufacturing of micro-structured work pieces by using electroerosion techniques. The customer (IPS²_Customer) who owns the EDM machine gives the supplier of the EDM machine (IPS²_Provider) the task to upgrade the existing machine to also manufacture rotational-symmetric µm work pieces such as, for instance, clock spindles [18, 19]. While executing these changes the following boundary conditions must be adhered to:

- Additional customer employees training is necessary to produce µm parts.
- Both customer and IPS² provider employees must be deployed to produce µm work pieces.
- The change estimate does not exceed €100,000.
- The upgraded machine possesses a minimal technical availability of 90%.
- The IPS² change is implemented within a maximum of 6 months.
- Annual maintenance by the IPS² provider does not exceed €10,000 and does not use more than 4 working days.
- The entire ECR process is carried out within a maximum of 4 weeks.

In view of the description of the change and the boundary conditions, the ECM process parameters (see Table 5) have been defined. These parameters have partly been concluded from the IPS² ontology and partly been input (acquired from the change context or from experience) by the process user.

Parameter	Parameter Value
ECM_Activator	IPS²_Customer
ECM_Reason	IPS²_Enhancement
Change_Complexity	High (basic IPS² structure is changed)
Design_Relevance	• Product_Design • Service_Design
Cost_Relevance	IPS²_Change_Cost ≤ 100;000 €
Safety_Relevance	No
Quality_Relevance	IPS²_Quality
IPS²_Use_Model	Availability_Oriented ≥ 90%
Necessity	High
Technical_Risk	High
Financial _Risk	High
Schedule_Risk	High

Table 5: Excerpt from the ECM process parameter for EDM machine enhancement

In this case study the execution of the ECM process has lead to the following main decisions [18, 19] (Figure 6):

- Enhancing the EDM machine by an additional portable rotary spindle.
- This rotary spindle is mounted on the machine table of the EDM system by means of an adaptive clamping system.
- This rotary spindle is incorporated into the production process by an integrated IT control system.
- The entire maintenance concept of the EDM machine is adjusted.
- The entire training concept of the EDM machine is adjusted.

10 CONCLUSION AND OUTLOOK

IPS² is developed to permanently meet the demands of the customer through the synergy of technical products and industrial services. Its prerequisites are integrated planning, development, delivery, and use of both service quotas, as well as their dynamic adaptability throughout the entire IPS² life cycle.

To support this approach, this paper has treated the development of a new goal-oriented process management method. Contrary to the classical process management methods it allows for an adaptive process design. By applying this new method an adaptive change management approach for IPS² has been developed. This approach enables adaptive responses in the ECM process, i.e. during their execution ECM processes can, to a certain degree, respond and adapt to specific situations autonomously and in real time.

In the course of this work, the developed adaptive change management approach for IPS² has been prototypically implemented by means of the standard process description language WS-BPEL4People. A case study of an IPS² (EDM machine) change management has validated the approach.

In the future, further case studies will be conducted in various other business sectors. Their aims are to enhance ECM process parameters, rules and the axioms of the IPS² ontology to increase the self-adaptivity of ECM processes and the transferability of the solutions to other branches.

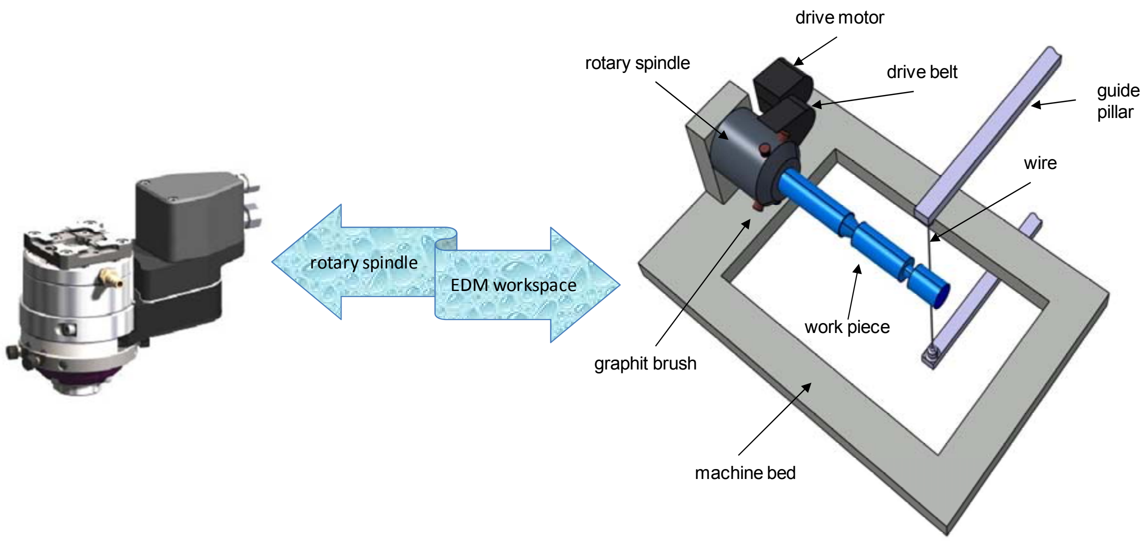

Figure 6: Illustration of the enhancement of the EDM machine.

11 ACKNOWLEDGMENTS

We express our sincere thanks to the Deutsche Forschungsgemeinschaft (DFG) for financing this research within the Collaborative Research Project SFB/TR29 on Industrial Product-Service Systems – Dynamic Interdependency of Products and Services in the Production Area.

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