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Knowledge management: managing organizational intelligence and knowledge in autopoietic process management systems – ten years into industrial application

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Abstract

A new approach to knowledge management in engineering domains was presented in the CIRP General Assembly 2001 with the title "An Autopoietic Approach for Building Knowledge Management Systems in Manufacturing Enterprises" [1]. Based on this a new process management system was developed and deployed. Today the system supports day to day engineering work of more than 300 engineering related staff on three continents. It drives organizational behavior by mimicking intelligence and the acquisition of knowledge, using both to derive suitable processes. This paper reports on lessons learned and may shed some light on future developments of knowledge-based manufacturing systems.

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1. Background

Key to the work presented here was a new understanding to and a new concept for intelligence and knowledge on an organizational level proposed by Thannhuber, Tseng and Bullinger [1] in 2001 and Thannhuber [2] in 2005. Up until this point knowledge management in industrial applications focused on acquiring data and information as well as managing them together with contextualizing meta information in IT Systems and delivering the right information at the right time to individual employees for their decision making or to support their value adding tasks. While these activities undoubtedly deliver their benefits however a new complementary approach was proposed that should better utilize efforts spent in the real world and potentials made available by phenomena that are described by 'intelligence', 'knowledge' or 'cognition'. Instead of purely empowering the individual in an industrial organization the focus should be shifted to the organization itself and how its behavior, responsiveness and efficiency can be improved by organizational knowledge and frameworks that breed intelligent behavior.

1.1. Phenomenological discussion of knowledge and intelligence on an organizational level

Although knowledge and intelligence are widely discussed for the human domain they are phenomena that evolution brought to emergence for natural systems in general to succeed in the competition to best adapt to their ecological niche and to best exploit the resources within it. Knowledge and intelligence help natural systems to derive successful behavior. Looking closer this 'successful behavior' in particular needs to balance three mutual exclusive abilities at highest levels: precision in execution wasting a minimum amount of internal resources while at the same time being able to cope with increasing dynamics in environments that constantly change and being able to cope with an increasing

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complexity. A situation well known to the engineering domain, too! Constituted out of human beings, cooperating to exploit marked niches, industrial organizations are nothing else but natural systems themselves [2].

Knowledge and Intelligence belong to the fundamental mechanisms to derive successful behavior. In the industrial context an organization's behavior is derived from coordinated activities its human staff develops by 'enacting' organizational processes. It is the sequence of activities, their coordination and interplay that leads to a company's successful behavior.

Intelligence in this context is a framework that enables an organization to derive well-coordinated and effective processes to behave responsive and successful. A framework that is built upon a suitable structure (physical infrastructure, components, … as given by IT systems, the hierarchy of command, process planning departments, etc.) and its organization (defining the interplay of the components as given e.g. by procedures on how to coordinate activities to a process). This processing framework allows an organization to take in stimuli, derive a suitable response process, support its enactment and capture the proceedings and success of the enacted process.

Knowledge is the content gathered or established in the processing framework based on which the framework's organization derives the assembly of activities to a suitable process. It is the content that drives intelligent processing and defines how the processing framework is further developed.

Knowledge management on an organizational level now gets a rather differentiated notion. There is no knowledge without intelligence! Managing knowledge on an organizational level first of all requires the management of intelligence. Managing knowledge in addition is all about deriving the right coordination of activities of staff members rather than increasing the individual knowledge of a single staff member.

1.2. Prerequisites for managing intelligence and knowledge on an organizational level

Earlier thoughts throughout the research on this topic suggested that there are a few necessary prerequisites to a working industrial implementation [1].

First of all system intelligence is to be institutionalized by a suitable processing framework. In today's industrial engineering context, systems institutionalizing the setup and enactment of industrial or engineering processes are 'Process Management Systems' (PMS). These systems typically come along side with modern Enterprise Resource Planning (ERP) or Production Planning Systems (PPS) or are complementary standalone solutions next to ERP and PPS. It is indicated that a suitable IT-based 'PMS' is an essential part of the processing framework.

In order for a 'PMS' to play an integral role in the described framework that implements the organization's intelligence it needs to provide a conceptual solution for Taylorization. Meaning that it needs to allow processes to be regarded as compositions of work units or work steps, which are the building blocks of any process. The system needs to be able to model them as generic 'Process Building Blocks' (PBBs) [1][2] that implement capabilities of staff members and that can be assembled to form different industrial processes. They are part of the system's structure. In order to support a reasonable assembly of building blocks (leading to a reasonable coordination of work steps) the PBBs need to be equipped with contextual information (descriptive data, wrapping information) which forms a part of the system's organization. The processing framework then needs to implement what was called 'declarative processing' [1] in other words it needs to be able to link up building blocks on demand and create a workable process instance by using the contextual information of PPBs against a given situative context.

We learned that suitable processing frameworks of intelligent systems require that available constituents of the system, the system's structure (PBBs, etc.), are permanently rebuilt. This does happen by incorporation of new capabilities, the encapsulation of complex procedures consisting out of several PBBs as one new single PBB (internalization), the depreciation of existing PBBs, and other 'deriving transformations' [1][2].

So does the system's organization, defining the interplay of all structural elements, mainly given by contextual information such as sequence information, rules that branch or control the invocation of PBBs, descriptive information and the like. In intelligent systems the organization, too, is permanently altered, adapted and rebuilt. [1][2].

The PBBs as the fundamental structural elements as well as their contextual information define the contents of the processing framework. They encode the knowledge of the organization that holds the processing framework. Knowledge management on an organizational level is the effort to promote this permanent acquisition of structural elements, new PBBs und contextualizing Information, the permanent evaluation of their effectiveness in operation as well as their adaptation and refinement thereafter.

This imposes high demands on the framework that should support the organizations processing. It must implement the possibilities to select and thus assemble PBBs in a suitable way as response to a situative context. This, being a process by itself, should be implemented self-similar [1]. From a system theoretic perspective a framework that permanently reproduces its structure and its organization is not just any framework, rather is it a highly special system. A System for which the cognitive biologist Maturana in 1972 coined the term autopoietic system, as a system that has the ability to generate its specific constitution – its components (structure) and their interplay (organization) – on its own [3]. In contrast to usual system definitions in the engineering world, where the system is an arbitrary set of elements, an arbitrary domain or space separated from the rest of the world by its boundary which is setup freely by the observer who intends to describe certain principles or theories for the system, for autopoietic systems the boundary is not up to the observers definition. The system rather is defined by all those constituents that are required to implement its autopoietic operation. They are real systems, just like the processing framework that implements the organization's intelligence.

2. Managing organizational intelligence and knowledge in the real world

During the years 1999 and 2001, when the conceptual approach was worked out, we developed an IT-based solution for the processing framework, called GCEN, to demonstrate and visualize our thoughts. At that stage we spent most efforts to realize an autopoietic processing framework that should be self-sufficient, modelling industrial engineering problem domains by modelling capabilities in PBBs and modelling all necessary functions to do the process assembly with PBBs, too. Autopoiesis this way was limited to a virtual world. The environment implemented a declarative processing approach. It was built up on a state-of-the-art agent-based system, introducing 'Believe-Desire-Intention' (BDI) reasoning, with each agent modelling a PBB. Processes where assembled by instantiating PBB agents that lived throughout assembly and enactment of a process as an agent community. The situative context as well as work-step results were acquired and presented for reasoning by the means of generic key-value-pairs (KVPs) built on a simple ontology. Being suitable for the 'lab environment' and demonstration purposes, difficulties did arise however when it came to real world engineering domain situations. In Complex real world situations e.g. the KVP structures and contents would not be sufficient for a successful BDI reasoning and declarative process assembly.

2.1. Building a new autopoietic processing framework

For its first industrial application we needed a new physical implementation of the autopoietic processing environment. Knowing of the importance of a proper process management we first built a new process management system based on the company's existing ERP System. It should provide the core functionality to the autopoietic processing framework similar to e.g. genetic encoding and genetic production of biostructures in living systems – just extremely simplified. Yet, we knew that this would not be the autopoietic framework itself but rather only a subsystem or functional part of it, as without the principles of self-containment, self-reference and the power of Artificial Intelligence (AI) the proclaimed permanent refinement and rebuilding of structure and organization would not be possible in an ERP-based process management system. A new approach to implement the true system scope would therefore be necessary.

The implemented process management system, which was simply called 'PM Tool', would provide all fundamental functionality to model, assemble and execute engineering processes. It caters for the modelling of staffs capabilities in PBBs, implements a KVP based documentation environment reflecting the real world at a given situation and capturing work progress as well as achieved results along the execution of work packages (PBBs), it guides the enactment of an assembled process (the execution of PBBs in the right sequence), it cares for resource assignment to executing PBBs, maintains 'To-Do'-lists for all staff members, and so on. In addition it does provide useful standard functionalities known from other process management systems such as records of true enactment sequences, process times or resource times and it allows for process or resource standard times to be pre-set to calculate typical engineering performance parameters such as utilization, resource performance, and the like. These allow the success of an enacted process to be evaluated and thus provide valuable input for structural and organizational refinements in the autopoietic system.

Unlike the original approaches implemented at GCEN, where process alterations during execution time always triggered a new declarative assembly that built a complete new process, in the PM-Tool new process control mechanisms were implemented that can alter the execution flow by selecting alternative pre-assembled process branches based on an evaluation of the situative context and/or execution results [4].

In GCEN most of the organization was modelled as contextual information, rules to be used to reason on the situative context, descriptive targets etc. all of which needed to be expressed on a high level of abstraction in order to enable declarative processing. In the PM-Tool we later took a much simpler approach mainly focusing on sequencing information, follower and predecessor or information on needs of sequenced or parallel execution of PBBs. Most of this contextual information to PBBs is modelled in simple tree-structures. In addition we introduced interfaces to subsystems that would provide own data structures to support the system's organization in a broader sense.

The biggest tweak of the new approach taken however was to identify a different scope of the autopoietic system itself. With GCEN every effort was taken to limit the system's scope tightly. We tried to confine autopoiesis to a virtual world in which structure and organization was permanently rebuilt in a purely digital manner. Employees, management staff or in general any human interacting with the system was regarded as an external resource, providing to or consuming from the system. They would not directly influence the declarative assembly of processes.

This has been changed for the implementation of the PM-Tool. Now staff members can be directly involved in the assembly of processes. They are now embedded in the systems organization – the new system is built with them rather than around them. The autopoietic process management system as a whole is now 'PM-Tool' PLUS 'human staff' with the PM-Tool playing the role of a defined part only. Next to the digital organization now human organization blends in and involves in process control, preparation of contextual information for process assembly and providing PBBs. Being natural real systems themselves this does not contradict the theoretic concepts but it rather establishes a tighter link between system levels [2].

2.2. First application field: Lab operation

The first real world industrial application of this new approach to manage intelligence and knowledge on an organizational level was the laboratory operation of Einhell Shanghai. The lab does testing and qualification of consumer power tools and power gardening equipment - both electrical and petrol driven items. The challenge here is that the process to be enacted is unique for every sample to be tested in the lab. Every product has a different technical structure implying different technical aspects to be tested to ensure a proper quality performance in field later on. For safety aspects the products need to be tested against numerous national and international standards. And even samples of the same product won't be tested along identical test processes as tests are allocated to different samples.

The processes to be enacted are all the test procedures sequenced to a work process for a single sample. The process building blocks (PBBs) are the single tests to be carried out. The challenge in this context is selecting the right tests, sequencing these tests correctly without influencing results of later tests, allocating the right tests to the right samples, collecting test results in a structured way, evaluating test results against defined verdict criteria and last but not least a suitable reporting. All of this is typically carried out manually in the hands of experienced management staff and assigned test engineers.

We have been introducing the process management module (PM-Tool) in 2006 transforming the lab operation in a test factory. The easy part was modelling the PBBs as they represented well known tests, the capabilities of the lab and its staff. The PBBs contents typically had to cater for Standard Operating Procedures (SOPs), descriptions of test parameters to be adjusted and test result parameters to be collected all of which was achieved by the generic KVP environment provided by the PM-Tool. The difficult part was the organization of the autopoietic system driving the assembly of workable test processes and ensuring their completeness. For this purpose the PBBs where wrapped in contextualizing information describing their typical application in relation to other PBBs or in the context of demands typically posed by the situative context. They were organized in little branches that typically ensured a suitable sequencing while the branches belonged to schemes or templates that are selected based on the projects context such as the product type of a sample defining its needs to proof compliance. In addition a Failure Mode and Effect Analysis (FMEA) system was established that evaluates in field data against given product structures and proposes dedicated test. It is driven by statistical models delivering unique suggestions at any point of time and for any given product structure. Both approaches are used for the assembly of tailored test processes for every lab sample.

Since the introduction in 2006 more than 16500 projects with 25500 samples have been carried out. We have been executing roughly 300000 test PBBs to finish qualifications acquiring almost 2 million physical results. Today the lab operates in a process landscape maintaining KPI-sets such as process performance, utilization, primary and secondary processing times, etc. well known in industrial engineering but untypical for lab operations. Aside from optimizing the industrial performance the consistency and overall quality as well as the diversity of the qualification work could greatly be improved.

2.3. Second application field: Design, engineering and development

The second industrial application of the 'PM-Tool' was the domain of design, engineering and development where technical projects would be developed to marketable products. By nature design and development are characterized by the uniqueness of their contents, the unpredictability of whether technical solutions prove themselves feasible and with-it the uncertainty about engineering challenges that need to be sorted out on the way to a successful product. Again this is typically a project-organization's world. Yet it was clear that certain proceedings are more successful than others and that certain work packages and sequences are mandatory for successful projects.

In 2007 we have been introducing a systematic process management with the PM-Tool and transferred the design, engineering and development operation into a project factory. In this case modelling the initial sets of PBBs was a bigger challenge than introducing the right organization. Representing the work packages along technical projects it was difficult to find the right level of abstraction and granularity. Lifting the PBB modelling onto a higher level of abstraction is necessary as the particular content of a work package, its microscopic execution, is very much driven by the technical context, its problem and solution domain – which would be hard or even impossible to model. On the other hand there is a target or goal to every work step in a development project that fits the work package into its larger context. To derive a proper PBB modelling we focused on these abstract targets and their descriptions, the parameters that would define under which conditions work packages are to be carried out and the parameters that would describe what was achieved (results). After some time of experimenting we found a proper approach to model with the right degree of abstraction and in the right granularity – from then on newly built PBBs replacing others further improved these aspects.

The organization of the autopoietic system was implemented based on a similar approach as already in operation in the test factory: The PBBs were wrapped in contextualizing information that would organize them in branches which ensured a suitable sequencing while the branches belonged to schemes or templates that are selected based on the projects' situative context. This time however the size of schemes or templates was of a different order. A typical technical project enacts a process with 900 to 1100 work packages. To gain efficiency in the process assembly the templating functions were improved allowing the preparation of alternative process branches upfront. In addition, process control mechanisms have been introduced in the PM-Tool to allow (semi-)automated selections of branch alternatives by evaluating execution results documented in the KVP-framework.

Since 2007 we have been enacting more than 10500 projects developing just as many products or product modifications. Along with the technical department others such as the purchasing, product management and marketing have joined the system. The system today operates extending across locations in Europe, Asia and Australia. Today more than 330 users directly engage with the system having executed more than 1.3 million PBBs.

R&D, engineering and design are a typical project oriented domain, with engineers driven by virtues like creativity, flexibility and solution orientation the introduction of a process world is typically a very difficult if not impossible task. Engineers in this domain are used to project management and they feel they lose responsibility and trust if they have to operate under process regimes that they do not directly control. Introducing the PM-Tool we faced exactly this challenge. After a while in operation however the engineers found they are relieved from coordinative workload leaving them with more time to spend on real engineering issues, more room for creativity and a better value added gained out of their daily work.

3. Results and learning from ten years of industry application

The biggest learning for us was that knowledge management on an organizational level requires to spend most efforts on modelling and managing the organization's capabilities and their interdependencies. Understanding them as the fundamental building blocks for the assembly of industrial processes it is crucial that organizing information is available supporting the right sequencing and selections.

Having moved the organization's human staff to the center of the autopoietic knowledge management system was essential as pure AI approaches for process assembly in an industrial world would have been a too big and too risky step to take. The defined integration of human interaction in the process assembly and definition as well as in monitoring and execution control allowed staff members to sit in the driver seat while having superb drive assistance systems in place to guide their activities and limit their efforts to a minimum. This lead to a good system acceptance.

Coordinated processes in the context of the presented approach are a natural result of the mechanisms implemented with the autopoietic framework. Instead of leaving procedural enactments completely open and just documenting their results as typically done by ERP systems and instead of tightly restraining processes as in workflow systems, processes now are just a result reflecting the situative context within which they are enacted. They are 'per se' agile and do not need to be artificially 'agiled' as in workflow systems. This way the processes naturally work in industrial contexts, not only over a few process steps but are enacted in 900 to 1100 steps as typically experienced in R&D and design engineering projects. Projects enacted in coordinated processes and executed under the regime of the PM-Tool process management environment relieved the engineers from coordinating activities which we estimate to have occupied as much as 30% of their worktime.

But was knowledge and intelligence really applied to the benefit of productivity and leverage the company's profitability? A question that needs some thoughts to be answered as annual comparisons are difficult with engineering projects strongly depending on the types of projects, products and context under which they are carried out. But intelligent organizations, systematically acquiring and applying knowledge, should be able to cope better with complex environments or in other words complex contexts. A paradigm suitable for evaluating the interaction of processes and their respective context has been developed by A. Bruntsch [5]. It contrasts the dynamics inherent to processes and their corresponding context in terms of measured entropies. While in its physical origin, entropy quantifies disorder in a system or the uncertainty of a system's state [6, ch. 5], process entropy H_p has been derived as a measure of variation in process enactment [5, ch. 4]. A static process that is repeated identically over time thus apparently implements zero entropy. Yet, the more frequent a process is reconfigured dynamically, the larger H_p gets. Process context entropy H_c, analogously, has been introduced for quantifying the diversity in contextual situations that a process operates in.

By applying this paradigm using actual process data of activity-level granularity we were able to measure how both entropies developed over time (see Fig. 1). We found that the entropy H_c of the processes' context, as a measure for the complexity of the organization's environment, increased on average at a rate of 1.5% p.a. over the years 2009 to 2012. This can be explained by rising customer expectations as well as increasing demands to demonstrate compliance against national and international regulations and standards. Notably, at the same time the entropy H_p of processes, representing the complexity of project executions, decreased with remarkable 7.5% p.a. under the PM-Tool regime [5, ch. 12]. In typical R&D environments one would expect that the more complex projects get, the more complex their realization becomes, thus implying a positive correlation between both entropies. Here, in contrast, the findings indicate that increasing contextual complexity was handled by an even decreasing internal complexity. Hence, the organization was able to cope with a more difficult environment by applying organizational intelligence and acquiring organizational knowledge that allowed simpler internal processes.

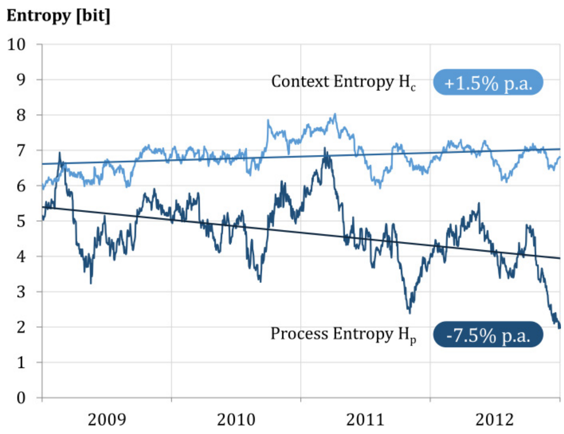

Fig. 1. Despite rising contextual complexity, process complexity could be significantly reduced over time (adapted from [5, ch. 12]).

By limiting the scope of analysis to projects with a rather uniform characteristic, decoupled from external complexities, the resulting actual performance impact can still be uncovered. An exemplary investigation of 163 solely new product development projects, finished between 2010 and 2015, revealed a significant annual reduction in average process and resource times of 13.1% and 16.4% respectively (see Fig. 2). This clearly indicates the effectiveness of the autopoietic approach to process management.

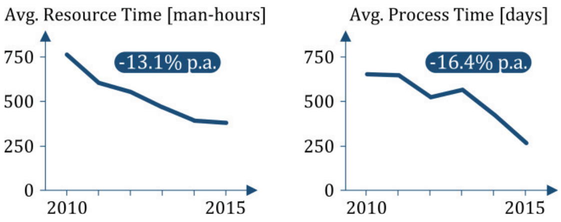

Fig. 2. Effectiveness of the autopoietic process management approach revealed by significant performance improvements.

Aside from numeric performance measures the biggest benefit of the system, however, was of an intangible nature. In times were staff fluctuations become a critical factor the ability of an organization to integrate new employees and get them productive is highly important. We found that the introduction of the PM-Tool with its integrated process management system greatly improved our ability to kick-start newcomers. They feel more comfortable in a network of well-coordinated processes were they can focus on their expertise in well-scoped work packages instead of having the need to coordinate with people or an organisation they hardly know.

4. Conclusion

It is never easy to introduce new scientific concepts to the industrial world in practical operation. Many hours were spent for implementation and even more for persuasion. Today, however, we could not imagine to operate without the processing environment "PM-Tool". It proofed to help us with the growing complexity. It helps us to stay dynamic and efficient. Knowledge Management is now happening within and is applied to our operation and is not something to be done "Add-On".

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