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Engineering Intelligence Ecosystem Concept

Minna Lanz[1], Jussi Aaltonen[1], Pekka A. Ranta[2] , Ossi Nykänen[2], Kari T. Koskinen[1]
[1]Tampere University of Technology, Mechanical Engineering and Industrial Systems, PO Box 589, Tampere, 33720, Finland
[2]Tampere University of Technology, Department of Mathematics, IISLab, PO Box 553, Tampere, 33720, Finland

{minna.lanz, jussi.aaltonen, pekka.a.ranta, ossi.nykanen, kari.t.koskinen}@tut.fi

Abstract Current engineering and production management methodologies and tools have been created for the old markets where the mass-customization was a norm. The IT-tools for these solutions offer separate proprietary services and interfaces, and it's the users' task to figure out and keep track of the critical processes. This paralyses healthy ecosystem growth, emergence of new start-ups, development and neglects the needs of agile and innovative SMEs. Contemporary tools and services, such as cloud-computing, emphasize on technology in favor of actual industry specific business needs. As a consequence ICT-centric solutions tend to help only in communication, but transfer existing (tedious) work practices in the new media. The current solutions are largely developed from the legacy-ICT perspectives, not from the modern industrial, social, and engineering business processes. The solution to these shortcomings is coordinated collaborative work utilizing semantic interfaces, combining the actual substance of the processes and intelligent tools while ensuring that the specific user will receive comprehensive information right time and right manner. This paper will introduce a new concept Engineering Intelligence Ecosystem to overcome these challenges.

1. Introduction

Finnish manufacturing sector is wrestling with the fundamental and rapid changes in their business environment. Business environment is becoming more dynamic and distributed, thus old standardization and mass-customization methods can no longer support the companies. In order to survive the companies must be able to offer fully customized product-service concepts instead of technical solutions. This causes challenges relating to efficiency of collaboration, utilization of information flows, agility and interoperability of technical solutions and operation culture. The products, processes and services need to be designed ***"for humans by humans".*** When tasks become more challenging and complex the legacy assumption of the strict distinction between studies, work, and pastime, gets outdated, and supporting worker motivation and personal needs becomes topical.

This paper presents an approach to tackle challenges within the traditional mechanical engineering and manufacturing industry by proposing Engineering Intelligence Ecosystem (EIE) concept. The EIE concept is new approach addressing aforementioned challenges of complex engineering systems. It

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considers different operation processes of an industrial organization as a network of internal and external systems providing and services. Engineering Intelligence Ecosystem approach takes account the socio-technical framework that would benefit from context-aware digital information. Conceptually EIE shares the Systems Engineering Vision 2020 of INCOSE, which emphasizes seamless flow of information, interoperability and collaboration [2]. In technical perspective the Engineering Intelligence Ecosystem can be defined as a network of (potential) stakeholders contributing to a particular product-service and utilizing a common communication protocol in collaborative digital environment including game-like characteristics. The EIE concept focuses on four fundamental areas: knowledge flows, collaborative processes, competence accumulation and built-in intelligence. It answers the future needs of design, manufacturing and construction engineering fields by developing novel methods, models and tools exploiting semantic computing and extended reality.

Several Ministries under Ministry of Transport and Communication in Finland have a common program Knowledge, Innovation, Digitalization and Ecosystems (KIDE) in progress, which concentrates in developing intelligent strategies mentioned in government platform and promotes ICT-based solutions in different areas [13]. The main objectives in KIDE are growth, innovations, digital services and evolution. This continuous program is defines the main interests of Finnish government and the aim is to be global leader in producing and using digital services. However, while the important topics have been identified the connection between traditional industry and new innovations from the ICT sector has not been established yet. Engineering Intelligence Ecosystem concept aims to implement these objectives into mechanical engineering and manufacturing industry sectors.

The report of ICT 2015 -working group addresses 21 paths towards frictionless Finland related on digital infrastructure, competence, financing and policies [12]. According to report ICT is the most significant growth catalyst and digital services are key to competitiveness. The ICT working group is proposing that new infrastructure for improving companies' real time economy information flows. Also on proposal is that open data ecosystem should be created into Finland. In addition according to report Big Data know how and education should be increased. Engineering Intelligence Ecosystem concept considers all these proposals especially targeting in machine and manufacturing engineering areas.

According Finnish Materials and Engineering Competence Cluster (FIMECC) digitalization is changing our traditional view of services [5]. The service business has become an integral part of industrial firms' business portfolios. The border between a product and a service is vanishing. New services have an essential role in improving competitiveness of industrial companies in global market. Digital services can be produced, stored and consumed time independently. This is changing the world's economy significantly. In addition it is essential to notice that big industrial companies are producing services for internal and for external use. Many machine manufacturers for example have transferred to significant service providers. The added value of services is greatly based on production and export of industrial products.

Aberdeen Group [1] stated that the main pressure (69%) to improve product development is the objective of shorter product development schedules. In addition, according to the study, the main action (71%) to improve design is to improve communication and collaboration across disciplines. It is also stated that to achieve Best-in-Class performance, companies developing mechatronic systems must identify the system level problems early in the design phase by leveraging simulation to validate system behaviour. It is also stated that the companies must accelerate the control design with automated software generation tools and simulations. These both proposed activities can be tackled efficiently by semantic modelling and utilizing context- aware ICT. According to a recent survey by [6], the main trends that company and other organization leaders think offer a major opportunity to consider in their next plan, include green product/services (energy efficiency) (72.7%), social media (65.3%), growing senior population (65.2%), smart phones, tablet, mobile computing (57.9%), and public/private partnerships, collaborative philanthropy (57.6%).

According to [4] major actors in the field knowledge-intensive systems, have been aggressively recruiting the world’s best experts in data analytics, machine learning, and related fields, obviously preparing themselves to be able to better utilize the new opportunities emerging with the new massive data reserves. Finnish the Strategic Centre for Science, Technology and Innovation in the Field of ICT Data2Intelligence (D2I) report defines in this respect the following topics can be recognized as the most promising research directions in near future: Collective intelligence, Proactive intelligence, Human-system joint intelligence, context-awareness and knowledge mobilisation.

2. Background

Digital Frameworks: As suspected, our work builds upon our digital ecosystem related research in the past. In particular, in the Open Philosophies for Associative Digital Ecosystems (OPAALS) during 2006-2010 Network of Excellence program, the Department of Mathematics contributed in the work packages of (modelling) community language evolution, and visualizing the OPAALS Open Knowledge space, utilizing Semantic Web technologies and methods. Considering the other projects of the (past) EU digital ecosystem cluster, we have also actively participated in the Integrated Digital Business Ecosystems Project during 2005-2006. This work has provided us insight both in the socio-economical and in the technical aspects of digital ecosystems [14].

Semantic Domain Models: During Framework Programme 6 (FP6) strong emphasis was put on the development of information models as domain ontologies and it resulted process and system ontologies for modular manufacturing equipment. For example FP6 Flexible Assembly Systems through Workplace-sharing and Time-sharing Human-Machine Cooperation (IP-PISA 2006-2010) resulted large ontology describing products, processes and system capabilities allowing user to populate the simulation environment according to the data saved in ontology, in Figure 1. The ontology utilized Web Ontology Language Description Logics (OWL DL) for describing the classes and relationships [10].

During the last years nationally funded project "Knowledge Intensive Product and Process design in collaborative digital environment (KIPPcolla) during 2009-2011" resulted created methods and tools for defining and designing formal information structures and communication interfaces for intelligent self-organizing entities for manufacturing processes, illustrated in Figure 2. Resource planning in factory floor (or other facility), knowledge flows between design tools and generic element descriptions were seen as evolving entities, which each have requirements for inputs and outputs communicated through well defined interfaces [8,10]

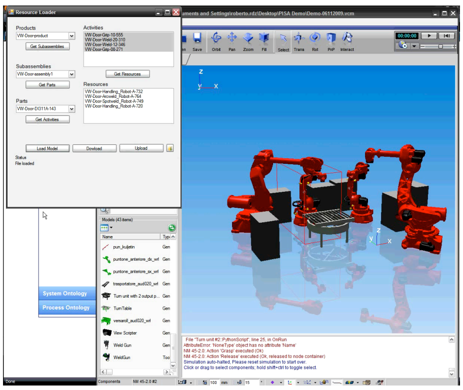

Figure 1: Semantic modelling and core domain ontologies in FP6 IP-PiSA allowed automatic population of robotics simulation [10]

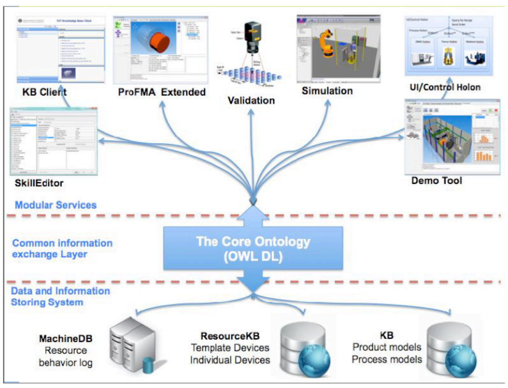

Figure 2: Modular ICT for holonic (agent) manufacturing system. All information was represented in OWL DL format [8,10]

These models have supported the development of agent technologies and automatic reasoning, they all have one common shortcoming - the static knowledge representation. Naturally, the work envisioned in Engineering Intelligence Ecosystem builds upon these achievements, while it will solve the static representation problems by developing dynamic knowledge model. The dynamic knowledge model adapts to the services introduced to the ecosystem, thus ensures that the model supports the distinct life-cycles of product-service concepts.

Virtual Machine Laboratory: Nationally funded projects SEMOGEN I and II during 2006-2012 resulted a semantic design process principles and reference architecture to model semantically rich machine systems. The projects have used open linked data, web -technologies and modern product lifetime information products in the data driven and automatized information pipeline model [7,17]. The sematic model allowed the dynamic simulation to be created and operated as a light-weight model in a web browser, in Figure 3. The main focus in these research projects has been in automatic generation of simulation models of machine system, development of Virtual Machine Laboratory (VML) with Forest machine and with boom design, in Figure 4, and a set production methods for supporting machine system designers [15,16]. These publicly demonstrated methods are providing essential background for Engineering Intelligence Ecosystem in mechatronic systems design domain. Virtual Machine laboratory simulates, visualises and combines different technology areas so, that a worker can understand the connections and functions of machine systems as a holistic way.

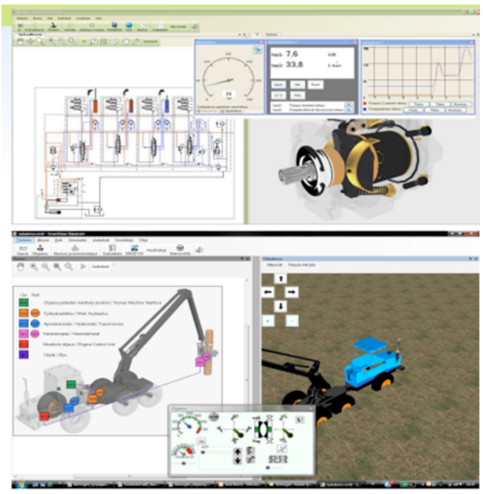
Figure 3: Virtual Machine Laboratory

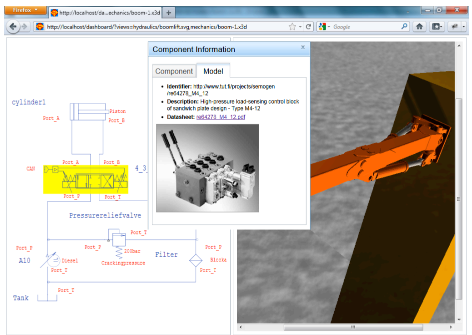

Figure 4: VML Boom design

Visualization of community Interactions: European Social Fund-project Campus Conexus I & II during 2009-2013 resulted methods and tools for inception and visualization of social network in ways that help in resource planning in different formal and informal communities. In a nationally funded project "Social Media Supported Indicators for Monitoring, Evaluating and Visualizing User-driven innovation (Sindi)" during 2010-2012, a data- driven process for creating visual reports on basis of social media data by applying the methods of social media analytics, social networks analysis and, when possible, the standard Web technology stack was developed. This provides essential tools for Engineering Intelligence Ecosystem to visualize the interaction between stakeholders and support the wanted collaboration [14].

In brief, lessons from the past research efforts might be synthesized as follows, as common-sense grounding guidelines for research:

- Successful digital ecosystems need clear domain-sensitive scope, (business) objectives, and policies;
- It is crucial that the dynamic and self-organizing nature of ecosystems is recognized in the system design; and
- The process of studying and developing infrastructure and end-user tools should be separated from the scientific and methodological research.
- To really efficiently utilize semantic information, the processes (such as development, design, manufacturing) have to be redefined in order to achieve systemic structural change
- Semantic modelling, context-aware information management and modern web- technologies have a huge potential for systemic structural change of Finnish mechanical engineering industry.

3. Engineering Intelligence Ecosystem Concept

The Engineering Intelligence Ecosystem emphasizes the service orientation instead of purely technological solutions. The concept ensures that the information content will be shareable between different, modular and upgradable services that can be compiled various ways to suit the customer and consumer needs. Thus, this promotes distribution of information content and services. According to [3] a digital ecosystem is an open, loosely coupled, domain clustered, demand-driven, self-organising agent environment, where each agent of each species is proactive and responsive regarding its own benefit/profit but is also responsible to its system. The Engineering Intelligence Ecosystem is a network of (potential) stakeholders acting around a particular product(s) or product-services and utilizing a common protocol in knowledge management and having shared collaboration based on context-aware digital solutions.

The overall vision is that Engineering Intelligence Ecosystem concept will provide set-up for user-friendly methodology, models and tools, which comprehensive enough to arise first ecosystems based on context-aware digital ICT solutions.

Today ecosystems are normally formed around operation systems, application platforms or specific products or product family. The future ecosystems, in Figure 5, are also formed around information and knowledge considering different technologies, products and services. The essential characteristic is that the information is context-aware, linkable and easy flowing, and the co-creative, co-managed and collaborative processes are in use.

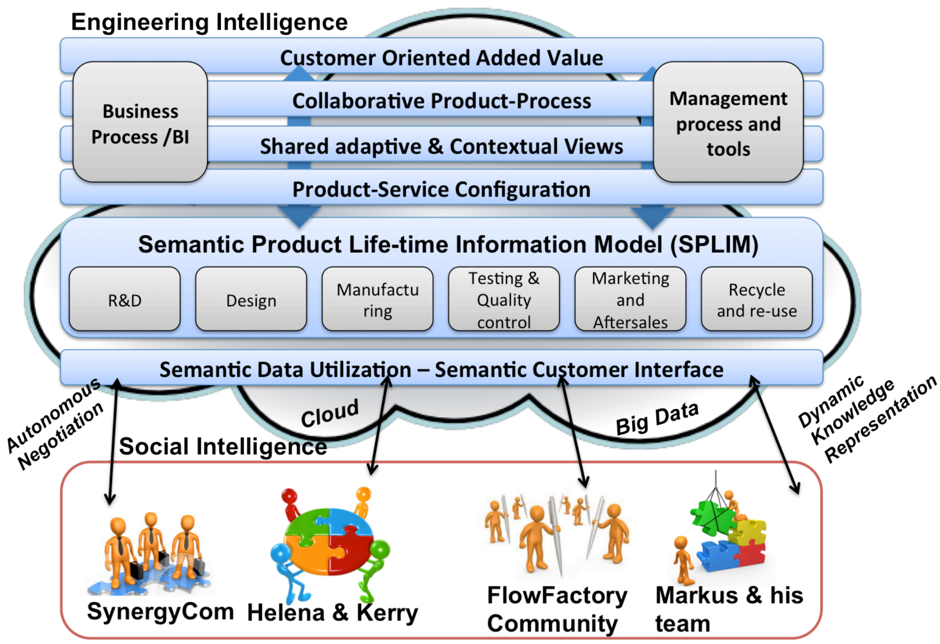

Figure 5: Engineering Intelligence Ecosystem Concept

The Engineering Intelligence Ecosystem concept is based on four fundamental areas; knowledge flows, collaborative processes, competence accumulation and built-in intelligence. These areas are critical foundations for developing next generation industrial ecosystems and industrial business processes. The knowledge flow and how each actor will perceive the essence of the flow is the common denominator in all viewpoints. Considering the direct means within the reach of a strategic research initiative, this mission is achievable in terms of four instrumental high-level objectives are:

1) **Knowledge Flows:** This is achieved by developing and establishing continuous stream of valid information described in such way that different stakeholders can utilize it. The main target is to seize maximal benefit and added value of these services, leading to increased knowledge, comfort, productivity and effectiveness. This will be facilitated through a data creation, capturing and processing pipeline where raw data is enriched through

information and knowledge to be used as basis for intelligence. EIE concept and knowledge model will capture the critical information flow in design process, but leaves room for culture specific organization of individual design tasks and tools. Information flows will be integrated into seamless knowledge flow forming base for the intelligent and collaborative product-service realization and business processes. This allows appropriate collaborators to be able to utilize, enrich, reuse and comment the proposed solutions. The concept for knowledge intensive product and process models ensure the capture of changes occurred to each entity and combine these with temporal requirements valid in that time. Thus EIE concept will answer to the customer needs in real-time based on use case scenarios and context of use.

2) **Collaborative Processes:** Structured methods of collaboration encourage introspection of behaviour and communication thus affect straight to well-being of workers and working conditions. The methods in Engineering Intelligence Ecosystem concept specifically aim to increase the success of teams as they engage in collaborative problem solving across the ecosystem. Main aim of this theme is to increase the ability to scope and structure the process; convene and manage dynamic, multi-interest forums; integrate different perspectives and expertise to produce common ground and momentum on issues; and adapt quickly to the changes as situations demand. This is achieved by utilising the systems engineering principles and holistic approach in all work packages. The various experts come together in order to solve a challenge.

3) **Competence Accumulation:** It is can be clearly noticed in discussions with industry that the competence in a company or in an ecosystem is not accumulating enough - the social capital is not fully understood nor utilized. It can be argued that continuous learning philosophy is only addressed in the higher management level instead where the work is actually done. The storing capacity of organizational memory is quite low due to change of personnel and lack of appropriate cooperative processes and tools. The competence accumulation is achieved by collaborative processes, which are developed for example to product design. These processes have to be able to utilize the best possible tools and systems, but at the same time they have to be collaborative. As an example can be mentioned a modern shareable Virtual Machine Laboratory integrated to semantic design process and with issue tracking and backlog systems. It is argued that the quality of work will improve if developers, designers and workers know what were the previous and following tasks and who did or will realize those.

4) **Built-In Intelligence:** The development of intelligent solutions is in key role in many development programs and research activities. However, many times it clearly seen that the system of machine is not really intelligent but instead controlled by complex control algorithms or equipped with transducers and data storages. When we are approaching real Artificial Intelligence (AI) systems, the context-awareness will be in key role. The ability to utilize semantic information agile and speedy way, real applications for adaptive decision making can be constructed. This built-in intelligence can be integrated to the processes and product-services already in the development phase and not by gluing it in afterwards. For example development of intelligence of machines and life cycle management or organisation's competence accumulation descriptions are good examples of applications for built-in intelligence.

It can be claimed that system complexity is one of the fundamental "pain points" of contemporary (systems of) engineering systems: When a large number (n) of stakeholders collaborate or interfaces are adapted, the resulting interaction network quickly becomes unmanageable (exp(n)). While there is no known efficient solution to the combinatorial problem per se, it can be practically avoided by semantic description of the interactions and by restricted self-organization primitives on top of a common foundational EIE protocol (such as an ontology). Intuitively, this is due to the fact that by enclosing the semantics of the ecosystem, the giant mesh of ill-structured interactions can be organized into several manageable subsystems. Self-adaptation and self-description are required to manage changes in the interactions so that each trivial change does not insist redefining the services and knowledge models.

It is fair to say that the foundations of adaptive knowledge negotiation processes and the related service interfaces are relatively well understood in principle [9,11], attracting also the interest of large information system researchers. Adaptive techniques have not, however, been applied on the level of multi-industry ecosystems before, taking the core engineering, business, and social knowledge models and processes (per se) as the starting point. The problem of industrial semantic computing has not been properly captured in terms of operational requirements and test cases. The prime examples from recent European Digital Ecosystem research include information networks, (p2p) networks on specific business or public domains such as tourism and eGovernment, and infrastructure development, focusing on ICT adoption and ICT development and service provision. (From this perspective, p2p networks, cloud computing etc. are considered "merely" to be parts of the infrastructure.) Socially intelligent tools and work practices for the future work-life. This way the Engineering Intelligence Ecosystem concept do not only facilitate collaboration and accumulation of the competences, but our approach will serve as an agent for change that is strongly associated with the creation of a new kind of working culture.

4. Conclusions and Discussion

The paper introduced the Engineering Intelligence Ecosystem concept, which aims to improve the Finnish manufacturing companies business prospective by strengthening them internally. According to Redman study [18] quality errors in manufacturing relating to low quality data may raise costs 30%. Furthermore, Redman's study indicates that 8-12% revenue losses occur because of data quality issues. Informally, 40-60% of the expenses in service sector may be consumed as a result of poor data. Similar trends can be observed in construction sector. Once products become product-services and service solutions the data inconsistencies, poor information management and re-work will eat out the revenue of these otherwise agile, competent and innovative Finnish companies. None of the calculations take into account the loss of working efficiency, motivation or work-life balance, which also decrease the revenue.

The Engineering Intelligence Ecosystem concept provides tools, methods and technologies to lower design costs and speed up innovation actions taking into account the information, technology and humans. The concept has been created according to the several discussions, interviews and workshops with Finnish companies covering ICT and manufacturing sector. The EIE concept provides common framework for future projects. The detailed work will be carried out in different industrial projects.

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