# 29. Toward the Knowledge-based Enterprise

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*In order to support European industry in its transition process towards the knowledge-based enterprise a set of novel information-based tools for enabling knowledge, skill and data transfer is needed. Their design depends on the organic and functional enterprise infrastructure features and relations between the heterogeneous agents involved across the whole value added chain. This paper presents two approaches aiming at overcoming interoperability barriers arising in communication process among humans and machines. First one is an ontological approach, which focuses on computer-supported human collaboration and human-machine interaction by means of natural languages, enabling semantic independence of shared knowledge and data contents. The second one proposes an approach for machine data exchange and sharing, applying standards as highly extruded common knowledge.*

## 1. INTRODUCTION

European industry is in transition process from a mass production industry towards a knowledge-based customer- and service-oriented one, which aims at a production model on demand, mass customization, rapid reaction to market changes and quick time-to-market of new innovative products.

In this transition, it faces the challenge to produce according to a *lot-size one paradigm* at low cost and high quality. A customizing in final products leads to a strong individualization of product features, which influences the normal course of the product life cycle making risky investments and resource plans in production.

Following this vision, networked, knowledge-driven and agile manufacturing systems stand out as necessary key elements towards this future production scenario, which shall allow European industry long-term competitiveness improvements above all by added values in product-services.

The context of collaborative engineering and manufacturing has witnessed a striking expansion in all fields of the value added chain. In spite of a successful employment of a set of information-base tools, knowledge, skill as well as data transfer it shows many inefficiencies and hurdles (Goossenaerts *et al.*, 2002) and still represents the major problem toward the achievement of a suitable and efficient infrastructure ensuring the establishment of the knowledge-based enterprise.

Therefore, research efforts and technology development on information infrastructures are ongoing, addressing a.o. information architecture, methodologies, ontologies, advanced scenarios, standard machining tools and services. These should contribute in providing a holistic solution for a knowledge-based engineering and manufacturing architecture, which must feature a systemic dynamic learning behavior, where innovation emerges from new complex interaction forms between integrated technologies, human resources, management and organizations in all phases of the valued-added chain, i.e. (i) production preparation, (ii) planning and programming as well as (iii) process execution. Hence, new solution approaches shall allow above all operational knowledge acquisition and knowledge feedback in computer-based collaborative engineering and manufacturing.

Both, already existing and arising industrial know-how should be gathered together either manually from human experiences (usually by experts) and by use of intelligent cognitive sensing systems, or automatically derived from human interventions (e. g. short process corrections at shop-floor level) or other machine equipments. Through knowledge retrieval mechanisms, also machines acquire intelligence reaching the necessary challenging level of efficiency and robustness. Such visionary workflow architecture is shown in Figure 1.

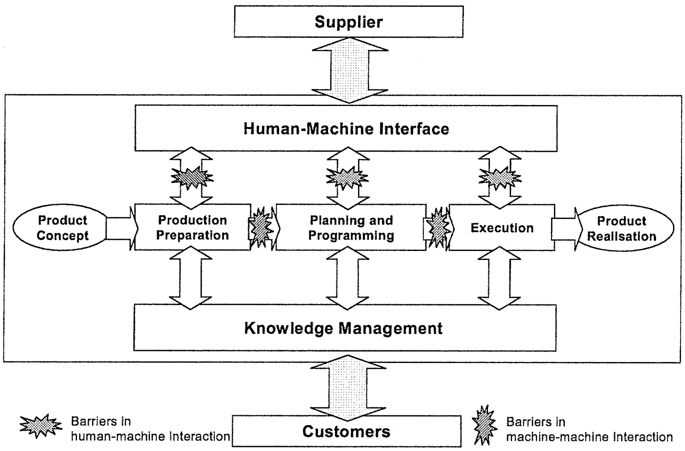


Figure 1: Basic buildings block structure of the knowledge-based enterprise

## 2. INTEROPERABILITY ISSUES

If, on the one hand, the enterprise structure proposed in Figure 1 represents an adequate solution to meet the growing market challenges, on the other hand, it shows to be also ambitious in connection with its functional requirements.

A smooth global information flow between all actors involved in this process is the most important aspect for ensuring the correct process behaviour. However, still too many complications evolve when trying to find standard criteria for interoperability across the entire heterogeneous human qualifications and machine programming languages setting.

As already stressed in (Lepratti and Berger, 2003), on the one hand, possible understanding problems arise, while two persons try to communicate with each other as consequence of discrepancies in their cultural and/or professional backgrounds. They are incline to cognitive perceive and mentally process same situations of the real world in subjective ways, referring these to different models (so called mental models). Thus, also two interaction partners, even though speaking the same language and using identical terminologies, can misunderstand each other, since vocabulary terms represent merely etiquettes of cognitive categories.

On the other hand, in machine-to-machine communication, incompatibilities in data structure or code languages (different syntax and semantic rules) are major reasons of impediments in transferring information from a software system to another one, which uses distinct technology solutions.

## 3. STATE-OF-THE-ART

Some standards enabling interoperability in engineering and manufacturing have been already successfully employed. Some relevant examples are here described:

The KIF (Knowledge Interchange Format) (Genesereth and Fikes, 1992) as well as the KQML[82] (Knowledge Query and Manipulation Language) allow interchange of information and knowledge among disparate software programs - either for the interaction of an application program with an intelligent system or for two or more intelligent systems - to share knowledge in support of co-operative problem solving with the possibility to structurally represent knowledge at a meta-level.

The STEP ISO 10303 (STandard for the Exchange of Product data) (Fowler, 1995) addresses to the exchange and sharing of information required for a product during its life cycle (such as parametric data like design rationale, functional specification and design intent). STEP is nowadays a well-known standard for real world product information modeling, communication and interpretation. Some examples are STEP AP-203 (Application Protocol) (Configuration Control for 3D Design of Mechanical Parts and Assemblies), STEP AP-214 (Core Data for automotive Mechanical Design Processes), STEP AP-224 (Mechanical Parts Definition for Process Planning Using Machining Features), STEP-240 (Machining Process Planning) and STEP-NC (ISO 14649 Industrial automation systems and integration Physical device control) (Richard et. al., 2004).

Finally, CORBA (Common Object Request Broker Architecture) (Object Management Group, 1995) and COM/DCOM83 (Distributed Component Object Model) provide neutral - both platforms and languages independent - communication between remote applications based on object oriented distributed technology, allowing different clients and/or servers connected within a network to live as individual entities able to access to the information they need in a seamless and transparent way. Both solutions aren't standards but are widely used e. g. for the development of agent-based systems.

While shown standard and further solutions have been successfully proved and employed, they are often too strong task-oriented in their applications or remain just one-off solutions. At present, a generic knowledge management concept for architecture as shown in Figure 1 has not been developed. The extent of knowledge and skill transfer in engineering and manufacturing is often strong limited.

New requirements for innovative and generic holistic knowledge-based enterprise architectures such capability in upgrading different heterogeneous systems, transparent data exchange among them, distributed open environments and improved information sharing go therefore beyond the actual state-of-the-art. To

[82] http://www.cs.umbc.edu/kqml/

[83] http://www.microsoft.com/com/default.asp

foster the transition process of European enterprises, big efforts in the research of further suitable concepts are still needed.

In the next Section two approaches, which aim at improving interoperability, will be presented. However, while the first one bases on the use of ontologies and addresses mostly the semantic standardization of computer-supported human-human communication as well as human-machine interaction by the use of natural languages, the second one focuses on overcoming complications in data exchange among heterogeneous software applications of machines and equipments.

# 4. THE ONTOLOGICAL APPROACH

## 4.1 The role of ontology

In today's production systems the development of communication and production technologies becomes not only more efficient but also more complex. The employment of such technologies represents challenges facing professional and cultural requirements of personnel, which has to work with. This stresses the importance of a novel knowledge management solution able to archive semantic standardization of knowledge contents and provide task-oriented as well as user-based redistribution of stored information. A corresponding building block knowledge management architecture concept is illustrated in Figure 2.

However, it is difficult to identify a unified knowledge form, when considering the different nature of tasks needed across the whole value added chain. According to Figure 1, three different knowledge forms are identified: (i) The so called 1-D interaction form, i. e. textual, is for instance still the most common way used for information exchange in scheduling tasks during both product preparation and planning phase. (ii) 3-D technologies of the Digital Factory have gained importance in the last years above all with regard to process & planning activities and represents the most profitable way to design production environments (e. g. planning of human and machine activities and machine programming). Finally, (iii) graphical (2-D) technologies such as interactive platform systems support user-friendly on-line process corrections at shop-floor level.

Under these circumstances the need of standard procedures for an efficient processing of knowledge contents, which are able to acquire, filter and retrieve data of different multi-dimensional sources, is assuming more and more an essential role.

In Figure 2 the core of the architecture is represented by the Ontology Filtering System (OFS). It plays this important role enabling semantic autonomy of different information contents independently of their nature of being. All multi-dimensional data sources mentioned above could be processed in an equivalent manner, i. e. knowledge contents of different forms are stored in the OFS knowledge data base in a standard data structure according to a pre-defined set of semantic definitions and relation rules. This offers a number of advantages: On the one hand, it supports knowledge retrieval and representation in a task-oriented manner according to the specific user requirements and, on the other hand, it facilitates the computer-supported knowledge exchange among humans or between human and machine avoiding possible semantic ambiguities of knowledge contents.

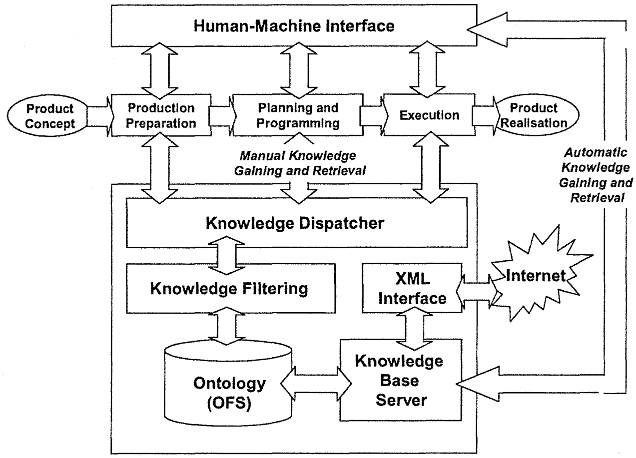


Figure 2: Ontology-based knowledge management architecture

In the next Section, a mathematical description of the applied ontology is presented. It has been developed and already experimentally demonstrated within a research initiative focused on the use of natural languages in the automation technology domain (see (Lepratti and Berger, 2004)).

## 4.2 The Ontological Filtering System (OFS)

Although the use of natural languages still represents an hazard solution approach due to possible misinterpretations, which could arise during the interaction process as consequence of syntactical, lexical and extensional ambiguities connected to their domain of use, they represent the most familiar and understandable communication form for human beings. Following Winograd's theory (Winograd, 1980), assuming that there is no difference between a formal and a natural language, one finds proper reasons for all the efforts to formalize knowledge expressed by natural languages.

The so called Ontological Filtering System (OFS) removes possible ambiguities in natural languages by means of a semantic network, in which words are chained together hierarchically per semantic relations. This network consists, on the one hand, of a set of words selected for a specific domain of application and used as key words, in order to standardize information contents for the machine data processing. On the other hand, it encloses a set of additional words, which could be used from different persons in their natural communication, since there are more ways to express the same knowledge meaning. These words could have different abstraction degrees in their meaning (so called *granularity*). Thus, some words are more general in their expression than others, while others can go very deep with their meaning. A simplified example of this semantic network is given in Figure 3.

According to their specification level all words – key words and additional words - are linked together by means of semantic relations such as hypernymy, hyponymy, synonymy or antonymy. A parser within the OFS processes knowledge contents and leads back words meanings to these ones belonging to the set of pre-defined key words. In this way, one can say, the OFS provides a semantic filtering function. A mathematical description could better explain how it works.

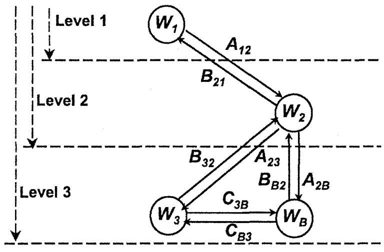


Figure 3: Example of OFS

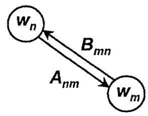


Figure 4: Simple relation in OFS

Considering W as set of chosen words belonging to the natural language:

$$W_{NL}=\{w_1, w_2, ...., w_n\} \quad (1)$$

and a set of key words WB, which represents the basis terminology, selected to formalize knowledge contents:

$$W_B=\{w_{1B}, w_{2B}, ...., w_{nB}\} \quad (2)$$

Using following set R of semantic relations of natural language: hypernymy (A), hyponymy (B), synonymy (C) and antonymy (D):

$$R=\{A, B, C, D\} \quad (3)$$

one can define the OFS network as following ordered triple:

$$OFS=<W, R, S> \quad (4)$$

where W represents the addition WNL $\cup$ WB and S takes into consideration the specification level of the elements of W. According to Figure 3, relations between the elements of W can be included in a relation matrix $\Re$ :

$$\Re = \begin{bmatrix} 0 & A_{12} & 0 & 0 \\ B_{21} & 0 & A_{23} & A_{2B} \\ 0 & B_{32} & 0 & C_{3B} \\ 0 & B_{B2} & C_{B3} & 0 \end{bmatrix} \quad (5)$$

Multiplying R by the transposed vector WT.

$$\Im = W^T \cdot \Re = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} \cdot \begin{bmatrix} 0 & A_{12} & 0 & 0 \\ B_{21} & 0 & A_{23} & A_{2B} \\ 0 & B_{32} & 0 & C_{3B} \\ 0 & B_{B2} & C_{B3} & 0 \end{bmatrix} \quad (6)$$

one attains the system of equations $\Im$, which reflexes the structure of OFS:

$$\Im = \begin{cases} W_1 = A_{12} \cdot W_2 \\ W_2 = B_{21} \cdot W_1 + A_{23} \cdot W_3 + A_{2B} \cdot W_B \\ W_3 = B_{32} \cdot W_2 + C_{3B} \cdot W_B \\ W_B = B_{B2} \cdot W_2 + C_{B3} \cdot W_3 \end{cases} \quad (7)$$

Considering Figure 4 one deduces the simple semantic relation (8)

$$\begin{cases} W_n = A_{nm} \cdot W_m \\ W_m = B_{mn} \cdot W_n \end{cases} \Rightarrow A_{nm} \cdot B_{mn} = \gamma \tag{8}$$

where $\gamma$ represents an empty element, since paths from $W_n$ to $W_m$ and vice versa over $A_{nm}$ and $B_{mn}$ are equivalent. Similarly, it counts also for:

$$C_{nm} \cdot C_{mn} = \gamma \tag{9}$$

Resolving (7) as functions of $W_B$ using (8) and (9) one obtains following results:

$$\Im = \begin{cases} W_1 = A_{12} \cdot A_{23} \cdot C_{3B} \cdot W_B + A_{12} \cdot A_{2B} \cdot W_B \\ W_2 = A_{23} \cdot C_{3B} \cdot W_B + A_{2B} \cdot W_B \\ W_3 = C_{3B} \cdot W_B + B_{32} \cdot A_{2B} \cdot W_B \\ W_B = W_B \end{cases} \tag{10}$$

Every equation of (10) gives the number of different semantic paths, which lead a specific element $W_n$ to the corresponding key word $W_B$.

The structure of the Ontology Filtering System presented in this paper could be easily extended to any other languages or data structures. As in (Guarino, 1998) accurately treated, when considering a further logical language $L$ with a specific vocabulary of symbols $V$, one can rearrange the definition used above assigning elements of a specific application domain $D$ to symbols of $V$ and elements of $R$ to predicate symbols of $V$.

# 5. ENGINEERING DATA EXCHANGE APPROACH

In Section 4, the ontological approach for knowledge management shows how knowledge contents expressed in specific language can be computer-processed, i. e. standardized in their meaning. Also data exchange among heterogeneous software applications of machines and equipment in engineering represents an important issue towards the development of the holistic architecture of Figure 1.

## 5.1 Standard for Engineering Data Interoperability

Nowadays in engineering domains, the data communication process represents a crucial aspect within the digital product creation process. On the one hand, heterogeneous set of software tools is applied. Different data formats and structures describing same engineering object lead to incompatibilities. Furthermore, with development of new information technology, the more digital simulation tools have been used for complicated scenarios, the more complex data become. It ranges from plain text to 2-D, 3-D geometries with semantic information. On the other hand, the data communication within the extended enterprise makes the exchange of data with customers, partner or supplier for a specific engineering object more complex. Therefore, data compatibility of various engineering tools in the extended enterprise represents the essential requirement in exchanging data in different applications.

The following second approach bases on the use of knowledge-derived engineering standards, with which the encompassing architecture of Figure 1 should be composed, its components functions specified and validated in real scenarios.

## 5.2 Knowledge-derived Standard-based Data Exchange Architecture

The High Level Architecture (HLA, IEEE 1516) for enterprise-wide and in external supply cooperation respectively, describes the test platform for performing distributed simulations. As to the data exchange requirements, i. e. engineering data compatibility, engineering knowledge retrieval and application, a corresponding architecture should be built up. The architecture of engineering data exchange using knowledge-based standard is depicted in Figure 5. Its components are:

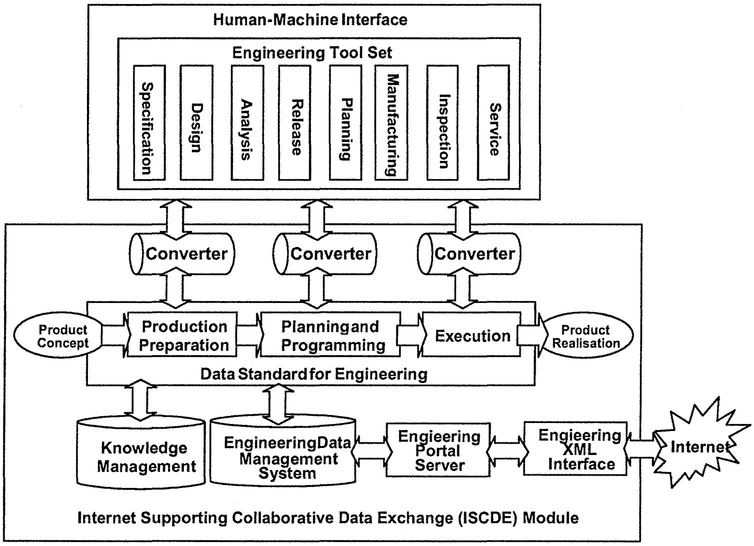


Figure 5: Standard based knowledge management architecture in product creation

1. Engineering tool set: A typical HMI, which is an aggregation of engineering IT tools and computer integrated manufacturing (CIM) machine for engineering i.e. specification, design, analysis, planning, manufacturing, inspection, services, etc. This interface for computer application must support like: (i) access to data, (ii) exchange of information and (iii) Multiple views of product data.
2. Converter: The interface between the software (machine) and knowledge-based engineering standard back-bone. The standard should fit for the entire digital product creation process, i.e. product concept, planning and programming, execution, and finally product realization. For each milestone in this process chain, a universal converter should be available.
3. Engineering data management: It synchronizes i.e. saves/provides engineering data for corresponding tools and realizes standard-specified data management, using data bank functions, i.e. data configuration and interface accessibility.
4. Connection mechanism for external integration: It is based on the net interface to the engineering data management system. This connection includes the engineering portal and engineering XML interface for the Internet application. For building an extended enterprise, this connection is an important element.
5. Knowledge management: (described in the Section 4) Its connection to the data standard for engineering is described in Section 5.3.

### 5.3 Standard as Common Knowledge Representation

A standard is a consistent definition or behaviour established by custom, authority, or consensus. In another word, standard is a higher knowledge level as greatest common denominator syndrome. Standards must be taken into account regarding too many variants or options to maximize performance. The data standardisation is a process of knowledge accumulation, sharing, description, application guiding. Each entity in standard can represent the knowledge in all relevant engineering fields and be directly used in engineering tool set for the intelligent application.

Connection between engineering data standard with knowledge management i.e. ontology-based knowledge management architecture, can be described as follows: i) Knowledge management retrieves the knowledge from the engineering domains, converts the knowledge into ontology through the knowledge dispatching system, then knowledge filtering system, into the ontology data management system. ii) The standard structures and data formats are defined only after standardization of ontologies, especially the ones in the entire supplier chain. Finally, the conversion of standardized ontology into specific standard data formats is to be done.

### 5.4 Scenario Process Planning

In engineering domain, rapid system functional development of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) are progressed. Computer Aided Process Planning (CAPP) system working with 3D-Geometry is far from the engineering interest, because: (i) A CAPP system has the upstream (CAD) and downstream (CAM) application which are at dynamic unbalanced technology levels, this brings the complexity to be integrated. (ii) CAPP itself is very complex. Process planning uses not only planer know-how but also a variety of heuristic rules and logical decision. Conventional computer algorithmic programs can do little with regard to the logic inference. (iii) The most important reason is that there is still missing standard description of manufacturing process. The standard for CAx domain is usually the STEP format. STEP 3D product data exchange has been achieved in an industry-practical way (ProSTEP, 2004). However, STEP is still a development activity and has its limited consideration fields (Michael, 2001). For CAPP system such as AP 240 process planning and STEP standard definition for machine tool is in development. (iv) Due to the application of heterogeneous CAx systems in supplier chain, the process data exchange is blocked (Zhang and Alting, 1994). Thus, knowledge and standard for process planning should be acknowledged through knowledge-derived standard-based data exchange architecture.

The scenario for the process planning can be described as in Figure 6. The OEM planning engineering cooperates with the machine supplier using own planning systems for process definition, and supplier integrates the entire process and orders the equipment and cutting tool from its own sub-suppliers. The Internet supporting collaborative data exchange module (ISCDE) is applied. The connection to the engineering data management system with extension to the supplier using engineering portal server and engineering XML interface is necessary to exchange data with the supplier, finally to build up the extended enterprise.

As to the knowledge management for data standardization of process planning is based on this defined approach is still in progress. This approach promises the interoperability in the collaborative process planning in the extended enterprise. Also this knowledge-based standard makes the entire CAx-engineering in up /downstream application continuously. The next step is to connect the knowledge system to retrieve the data standard for the specification of the engineering data management systems in the extended enterprise for the process planning.

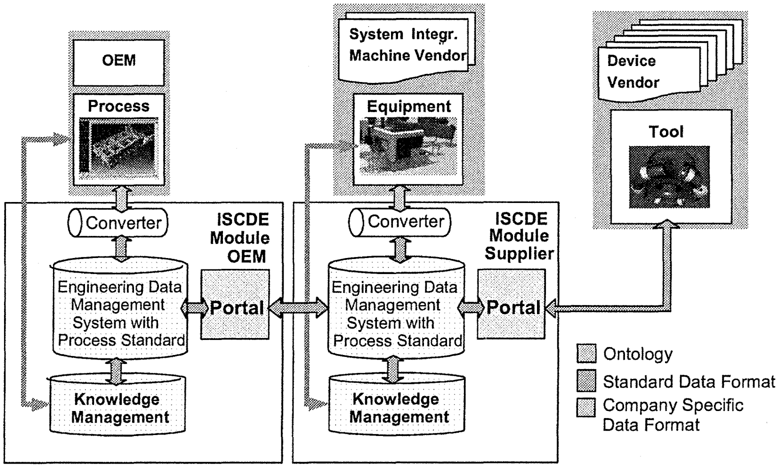


Figure 6: Scenario of collaborative process planning using ISCDE module

## 6. CONCLUSIONS

In product creation process, knowledge acquisition, retrieval and application can be found in every manufacturing and engineering phase. The knowledge management should embrace the entire enterprise structure, giving the necessary structure flexibility to need the growing market challenges such as rapid product creation with higher quality and short time-to-market strategy. As shown in Section 4, ontologies help in standardizing knowledge and data semantic contents in the communication among humans and in the human-machine interaction, while in Section 5 knowledge-derived standard based data exchange architecture is defined. The components in this architecture are described. An application scenario regarding the process planning is developed, further work to realise this architecture is concluded.

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