1

ENHANCING KNOWLEDGE AND SKILL CHAINS IN MANUFACTURING AND ENGINEERING

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Abstract: This introductory paper to the volume explains the DIISM problem statement and applies principles of architecture descriptions for evolutionary systems (IEEE 1471-2000) to the information infrastructure for engineering and manufacturing. In our vision, knowledge and skill chains depend on infrastructure systems fulfilling missions in three kinds of environments: the *socio-industrial domain* of society and its production systems as a whole, the *knowledge domain* for a scientific discipline, and the *sectorial domain,* which includes the operational entities (companies, organisational units, engineers, workers) in engineering and manufacturing. The relationships between these different domains are captured in a *domain paradigm*. For companies, the original scope for infrastructure systems was the *factory floor* and the engineering office. Recently the scopes of *external* collaboration and of *man-system* collaboration have gained importance. Within each of the four identified scopes a system can offer services to different operational levels: *operations*, development or *engineering*, and *research*. The dimensions of scope and service level are briefly explained in relation to the architecting of an infrastructure. Papers are grouped according to their contribution to an infrastructure scenario or to an infrastructure component.

Keywords: architecture, engineering, information infrastructure, manufacturing

1. INTRODUCTION

The context of engineering and manufacturing has witnessed a striking expansion: from the product at the workshop during the workday of the craftsman, towards the portfolio of products and services, the resource base, and the business processes of the globally operating virtual enterprise. Simultaneously, the *set of information-based tools,* supporting the knowledge and skill chain has expanded: from the paper, pen and ruler to computer-and-communications aided applications for a growing range of functions ("CCAx"), with their impacts ranging from the core manufacturing process, over intra- and inter-enterprise integration, to the supply chain and the total life time of the extended product.

Computer-and-communications applications do well support many of the engineering, manufacturing and business functions that are key to manufacturing excellence and product success. But still, the engineering and manufacturing knowledge and skill chain shows many inefficiencies and hurdles. Therefore research and technology development on information infrastructure is ongoing, addressing a.o. information architectures, methodologies, ontologies, advanced scenarios, tools and services. This research is driven by the insight that throughout an integrated life cycle of products and enterprises, the manufacturing knowledge and skill chain sources information from globally distributed offices and partners, and combines it with situational awareness, local knowledge, skills and experience to initiate decisions, learning and action. Hence the top-level objective of the information infrastructure: enhancing knowledge and skill chains.

But how to design the information infrastructure that manages knowledge, information, data, and related services and tools that are shared by the different autonomous entities collaborating in the socio-economic fabric? Because the collaborators are part of different enterprises and economies, the information infrastructure is not regarded as a long-term differentiator in the business strategy of any enterprise. The infrastructure rather is a common enabler for the globalizing enterprise networks and professionals. For these entities, the common services matter at different levels of aggregation: for the external collaboration, for the teams and machine devices working in the factory or office, and for each person working in one or more enterprises. Hence the scope of this book: information infrastructure systems and services for any level of aggregation in the engineering and manufacturing knowledge and skill chain.

2. AN INFRASTRUCTURE PROBLEM?

A series of IFIP TC5 WG 5.3/5.7 working conferences has been dedicated to the design of the information infrastructure systems for manufacturing [1,2,3,4]. At this 5th working conference, building on recent research results and the results reported at and discussed at the previous conferences, contributions demonstrated a rich combination of breadth and depth, academic focus and industrial relevance. As multiple and more capable components are being developed, the gap grows between scenarios that are possible theoretically and experimentally and their practical realization and application. Unless a sound information infrastructure gets deployed, the chaining of the new scenarios will meet problems of quality, of interoperability of data, and of the scaling and combination of knowledge. How to offer continuity of service, the ubiquitous reuse of data and knowledge, and continuous interoperability while seizing new scenarios, as companies compete, stakeholders evolve and new technologies emerge?

Contributions to this volume address components and scenarios of future knowledge and skill chains, as seen from the viewpoints of many expert researchers in engineering, manufacturing and information technology. Traditionally, in industry, the integration of such components and scenarios is performed at companies. Today, and for the future, the globality and connectedness of the economic fabric and its problems oblige the research community to also address these chains supportive of improving the state of "manufacturing industries as a whole".

3. ARCHITECTING THE INFRASTRUCTURE

Architecture is defined in IEEE 1471-2000 [5] as "the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution". Every system has an architecture which can be recorded by an architectural description (AD) consisting of one or more models. The viewpoints for use selected by an AD are typically based on consideration of the concerns of the stakeholders to whom the AD is addressed.

Modelling techniques support communication with the systems stakeholders, prior to system implementation and deployment. Methodologies and tools come available for the model driven building and deploying of information systems and information infrastructures.

The relevance of architecting for the infrastructure addressed in DIISM derives from its life cycle focus: architecting is concerned with developing satisfactory and feasible systems concepts, maintaining integrity of those system concepts through development, certifying built systems for use and assuring those system concepts through operational and evolutionary phases. This is important as the domain of engineering and manufacturing is immensily complex, diverse and evolving. Where infrastructure sub-systems fulfill missions in different scopes, these systems should co-evolve and their architectures be aligned. Their AD's should be based on stable viewpoints.

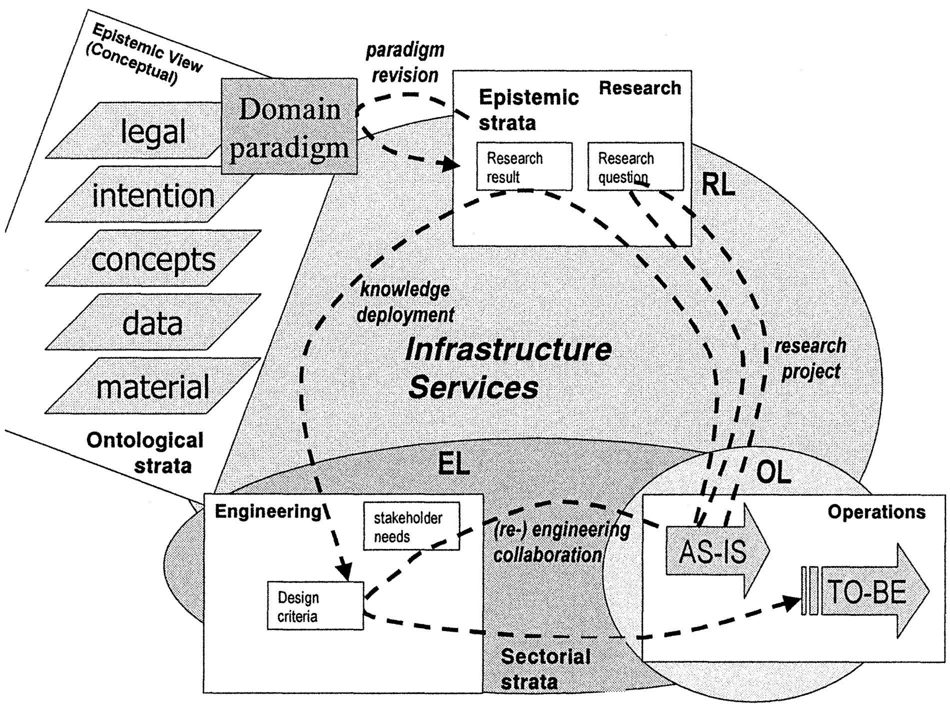

Figure 1. Three operational levels to serve

The four different scopes for which scenarios must be supported are the *natural & socio-economic domain* (DP – domain paradigm), the *external collaboration* (EC) among enterprises, the *factory floor* (FF), and the *man-system collaboration* (MS). In each scope systems evolve: problems and stakeholder needs are observed and analysed in the AS-IS, requirements analysis and design deliver an extended or new specification, development and implementation deliver the TO-BE operational system which is monitored for the occurrence of new problems.

Each of the four views in Figure 1 offers services to the above scenario of systems evolution. The *epistemic view* offers an *ontological stratification* that structures the design space within which intentions, models and operational systems evolve. The *research view* offers *epistemic* *stratification* (one strata per scientific discipline such as logistics, mechanics, chemistry, and ergonomy) that structures the design criteria (constraints) that must be met in modifying or creating the operational system. The *engineering view* merges constraints and contributions from ontological and epistemic strata to obtain new operational capabilities. In the *operations view* repeating tasks are performed, in accordance with the models developed; these models define operations that meet the hard laws of nature, the more soft laws of the socio-economic fabric, and the soft design criteria. Both the engineering and operations view show *sectorial stratification* which is for instance reflected in the STEP Application Protocols.

Assuming that a stable (meta-)model of the epistemic view exists, and that it rarely needs overhauls, the remaining infrastructure services are classified into three levels: *Operations Level (OL):* for the AS-IS operations (engineering or manufacturing processes); (Re-) *Engineering Level (EL):* for the (re-) engineering collaborations linking AS-IS operations and development for certain context to achieve the TO-BE operations; and *Research Level (RL):* research and the deployment of scientific knowledge pertaining to OL processes and EL collaborations.

4. INFRASTRUCTURE DESIGN AT DIISM 2002

Each infrastructure sub-system is a software intensive systems that could be developed using the widely used 4+1 view model of Kruchten[6]. The alignment of the architecture descriptions of these infrastructure sub-systems would benefit from a maximal reuse across those views, in accordance with the subsidiarity principle.

The best opportunities for such reuse are in the epistemic view which covers Kruchten's logical and process views, and in the research view. The domain paradigm would consist of universally applicable models. The domain paradigm embodies the ontological stratification of the natural & socio-economic domain, the epistemic stratification of our (scientific) knowledge, and the separation of operations, engineering and research scenarios in our activities. Part I of these proceedings contains the DIISM 2002 contributions that pertain to the epistemic view, the domain paradigm and the research view. Comparing with the present day best practice, the epistemic view and the domain paradigm could be taken into consideration when developing a 2nd generation structure for STEP's Generic Resources.

With the availability of reusable domain-level infrastructure components, the focus in the scopes of EC, FF and MS is on their differentiating aspects and scenarios. Part II, III and IV contain the DIISM 2002 contributions on

External Collaborations, the Factory Floor Infrastructure and the Man-System Collaboration. In each of these parts both Engineering Level and the Operations Level contributions are included.

4.1 Part I – Generic Infrastructure Components

This part contains the contributions that address viewpoints or services that in principle can be shared by all scopes (society, external collaboration, factory floor and man-system collaboration). It includes papers on the information infrastructure requirements, on the domain paradigm and on the epistemic viewpoint. Papers on research level services are also included because in principle, they can be shared by all scopes at operations and engineering level.

Kimura proposes basic approaches for managing life cycle support information, considering requirements such as flexible extensibility, distributed architecture, multiple viewpoints, long-time archiving and product usage information. Goossenaerts applies an architecting approach to derive specifications of a model-driven information infrastructure.

The domain paradigm is addressed from three different viewpoints. The intensification of service and knowledge contents within product life-cycles is addressed in four papers.

Shimomura and Tomiyama propose a service modelling technique that can represent services with subjective properties. Jansson and Thoben introduce the extended products paradigm and illustrate it with examples from the IMS GLOBEMEN project. Salkari et al. discuss the management of product information of process plants, complex one-of-a-kind products. Mills and Goossenaerts present the architecture of a product knowledge environment that is based on computational contexts.

Two papers focus at software intensity at the shop floor, and how to cope with it. Kanai et al. propose an object-oriented design pattern approach for the seamless modeling, simulation and implementation of distributed control systems (DCS). Matsuda et al. present an interoperability framework and manufacturing software capability profiling methodology.

External collaboration is addressed by Nienhaus et al. who propose a supply chain modelling approach which enriches the SCOR model with product-related and financial information.

The epistemic viewpoint is addressed in three papers with a complementary focus. Itoh et al. illustrate the Multi-Context Map (MCM) and Collaborative Linkage Map (CLM) and interprete these enhanced process-modelling constructs in the collaboration stratum, the workflow stratum and the state-transition stratum. Abramov et al. address ontological stratification and apply it in agent system design. Yagi et al. address behavioural aspects in their paper on logics of becoming in scheduling.

A first paper addressing research level services is by Kryssanov et al. who develop a new theory of communication to explain computer-mediated communication, which in the future will also involve products such as cars. Another paper is by Lee et al. who investigate the relationship between media choice and end-user belief on help desk service. They validate the Mediqual constructs: reliability, empathy, assurance, tangibles, and responsiveness as new belief criteria on media users' satisfaction.

4.2 Part II – External Collaboration

The papers addressing engineering level services for external collaboration cover a wide range of topics.

Two papers address inter-enterprise engineering collaboration. Kawashima et al. describe the Distributed Engineering Environment prototype that was developed as a part of the IMS Globemen project. Ratchev and Medani propose a new STEP AP224 EXPRESS based data model to facilitate the exchange of part and process data during the early design process.

Simulation in external supply chains or virtual enterprises is the topic of three papers. Mertins and Rabe describe a tested platform for performing distributed simulations using the High Level Architecture (HLA, IEEE 1516) while keeping the participating enterprise models private. Hibino and Fukuda describe and illustrate the use of an adapter and user support system between manufacturing simulators and Runtime Infrastructures based on the HLA. Nakano et al. propose a method and its tool to navigate the designers through the engineering process and generate the simulation model automatically from the design results.

The remaining five papers on engineering level services have a focus on the engineering of logistic and engineering networks and related management problems.

Zhou et al. discuss the knowledge management issues in the development of VIEWBID, a web-based system for supporting online bidding document preparation for global engineering and manufacturing projects. Laakman presents a reference model based guideline for logistics engineers. The guideline is supported by a collaborative knowledge management application. Alard et al. describe a framework for the strategic evaluation and planning of the deployment of internet-based procurement solutions for direct materials. Nishioka et al. propose the SUPREME architecture which supports web-based virtual enterprise design and collaborative planning and scheduling. Zhou et al. present a review of state-of-the-art tools and methods that can be used to manage risks in multi-site engineering projects. They then propose a risk management roadmap that can provide guidelines for project managers.

Three papers address operations level services in the context of external collaboration. Kimura et al. propose the ASSIST concept, a manufacturing support system that – for multi-vendor manufacturing systems – combines maintenance services with consulting services by engineering companies and machine tool vendors. Hartel et al. describe a model that will enable service enterprises to team up with external partners and fulfill services collaboratively. Kamio et al. discuss and illustrate a scheme that allows all parties involved in the maintenance of a chemical plant to form a service enterprise, whenever a maintenance service is necessary.

4.3 Part III – Factory Floor Infrastructure

Papers in this part address engineering and operation level services for the factory floor. The architecture of the factory floor infrastructure is addresssed in two papers. Mo and Woodman describe the development of an integrated web-based CIM environment called J-MOPS: based on the MOPS philosophy it can intelligently transform CAD information into machine programs while simplifying system requirements for the user and removing the dependency on platforms. Using the Glue Logic, Takata and Arai design a real-time data gathering system for manufacturing lines. A Scalable Intelligent Control Architecture permits expansion of the control system, in spatial dimension and in intelligence.

Two papers present advanced scenarios in process planning and CAM. Muljadi et al. propose a feature set creator that can lead to the generation of multiple process plans in support of flexibility in shop floor scheduling. Narita et al. propose and verify a two-stage strategy for automatic and interactive modification of NC program using the VMSim cutting process simulator.

Scheduling of distributed production systems is the topic of three papers. Shirase et al. use HLA to achieve a distributed scheduling simulation for dynamic work assignment and flexible work group configuration. Sashio et al. study the data handling mechanism of a distributed virtual factory that is constructed by integrating area level simulators in a manufacturing system. Iwamura et al. propose a new real-time scheduling method to select a suitable combination of resource holons and job holons to carry out the machining process.

To support operators in improving the makespan of an existing Job Shop schedule, created with a heuristic algorithm such as Tabu search, Tsutsumi and Fujimoto propose a tool for sensitivity visualization of the critical path.

Wang and Chu study the requirements of the enterprise-wide integration of managerial and automation systems in a petroleum refinery.

4.4 Part IV – Man-System Collaboration

Papers in this part address engineering and operation level services for man-system collaborations. Mizugaki et al. present a computer aided instruction system (CAI) for NC lathe programming. Multi-media objects including movies, animations, pictures and sound are used in web-browser based training procedures. Following tests with beginners, the efficiency and usefulness of the CAI system is discussed.

Fukuda et al. describe the development and test of a prototype Web-based Instruction system using the wearable computer. The web-applications include time estimation, simulator, active instruction manual system and a posture acquisition system.

Imai addresses the model-based description of human body motions of factory workers performing their work, and how to use the resulting evaluations in manufacturing process design. For the purpose of accurate posture and motion detection by multiple video cameras, Sakaki et al. describe a calibration technique for use in combination with Model based Motion Capture.

Jianhua and Fujimoto propose a Bayesian decision model for the identification of human behaviour in manufacturing on the basis of manufacturing history data. The latter data is converted to a non-parametric distribution over a feature vector by using a binary division method.

5. POST CONFERENCE GAPS

Following the DIISM 2002 conference the research and technology development challenge is to further integrate multiple advanced scenarios and components into true knowledge and skill chains. The engineering and manufacturing infrastructure should support such vertical and horizontal chains, ensuring data consistency, reuse and interoperability as operations, engineering and research proceed within the scopes of man-system collaboration, factory floor and external collaboration.

In line with good practice in software systems development, three milestones could be identified for the information infrastructure: the life-cycle objectives (LCO), the life-cycle architecture (LCA), and the initial operational capability (IOC). These milestones could structure the research and technology development activities that should also include:

- The development and validation of the Epistemic View. Overarching tasks in this validation are the development of a Domain Paradigm and the definition of Research Level services. For these tasks, the papers in part I offer a baseline from where to proceed.
- The scripting of the scenarios from Parts II, III and IV using the conceptual models of the Epistemic View, the Domain Paradigm and the Research Level services (reference models). For available components, the development of application protocol interfaces is recommended.
- The linking of scenarios and components into operational knowledge and skill chains, and their deployment in industry.

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REFERENCES

1. Yoshikawa, H. and J. Goossenaerts (eds.) (1993) Information Infrastructure Systems for Manufacturing. IFIP Transaction B-14. Elsevier Science B.V. (North Holland)
2. Goossenaerts, J., F. Kimura and J.C. Wortmann (eds.) (1997) Information Infrastructure Systems for Manufacturing, Chapman & Hall, London, UK
3. Mills, J. and F. Kimura (eds.) (1999) Information Infrastructure Systems for Manufacturing II, Kluwer Academic Publishers, Boston
4. Mo, J.P.T. and L. Nemes (eds.) (2001) Global Engineering, Manufacturing and Enterprise Networks, Kluwer Academic Publishers, Boston
5. IEEE Recommended Practice for Architectural Description of Software-Intensive Systems (IEEE Std 1471-2000) July 2000.
6. Kruchten, P., Architectural Blueprints - The "4+1" View Model of Software Architecture, IEEE Software, November 1995, 12 (6)