Model-based Adaptive Product and Process Engineering

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Abstract: An approach for model-based adaptive product and process engineering is presented, proposed as an enabling technology to collaborative networks of enterprises. In a model-configured infrastructure, active knowledge models (AKM) of products and processes become the basis for user-composed services available to the users in customisable workplaces, supporting the integration of formal and informal kinds of collaboration between workers of the participating enterprises. Applications in automobile and electronics industries pursued in the MAPPER project have been explained together with a summary of experiences gained from the deployment of the task pattern “Establishing Material Specification” at Kongsberg Automotive AB.

1 Introduction

Manufacturing challenges for 2010 include the need for more effective (i.e. faster and cheaper) manufacturing processes that will be carried out inexpensively by collaborative networks of enterprises and quickly adapt to market demands. Today, the infrastructure and methodologies for enabling the quick formation and adaptation of fast and flexible design and manufacturing processes are missing.

The paper presents the MAPPER project approach that focuses on design and manufacturing phases of the product lifecycle. The approach comprises configurable active knowledge models, a collaboration platform, customisable workplaces, participative engineering methodology, a collaboration infrastructure and a set of practices defined as “task patterns” that result from a collaborative effort of the MAPPER project consortium.

The three industrial use case partners are the driving force of the project and are the origins for requirements that guide the methodology and technology development in
the project. In several cycles, the results from the MAPPER partners providing technology are deployed and used in selected application areas within the automotive and electronic industry.

In the following section the problems and challenges in manufacturing are identified with respect to the state-of-the-art solutions. Further on, challenges are reflected in the MAPPER use cases, focusing on their strategies for applying the MAPPER approach. The core part of the paper presents the MAPPER approach. Finally, a summary of experiences gained from the early modelling efforts and the deployment of one selected task pattern, “Establishing Material Specification” from the automotive supplier innovation process modelling use case, is described.

2 Problems and Challenges in Design and Manufacturing

Manufacturing companies are increasingly challenged by the global competitive environment. Businesses are re-structuring and re-engineering their business models, services and internal structures in order to meet customer demands, like high-quality low-cost products adapted to their specific, rapidly changing requirements. The ability to quickly adapt to changing market needs and to cooperate flexibly with other enterprises has become a key element for maintaining competitiveness on a global market. This is reflected in the increasing importance of approaches, concepts and technologies for agile manufacturing (Gunasekaran 2001) and collaborative engineering (Goossenaerts 2007).

Work in MAPPER is contributing to major industrial challenges and is driven by use cases from different industrial sectors. This chapter briefly presents these challenges (2.1) and the use cases (2.2). Furthermore, a scenario used in chapters 3 to 4 for illustration purposes of the MAPPER approach will be introduced (2.3).

2.1 General Challenges

Current trends of globalisation, mass-customisation and increased competition are leading industry towards networked organisations, such as virtual organisations and dynamic business ecosystems. Increasingly, products must be rapidly adapted to customer needs, leading to faster innovation cycles and more complex concurrent engineering. In many industry sectors, a demand for increased value creation on the supplier and sub-suppliers side of the networks is observed, emphasising knowledge content and services. This requires significant growth in inter- and intra-enterprise knowledge sharing, management services and in collaborative work environments and work management services.

The core problems and challenges in the area of faster and more flexible design and manufacturing concern

- Concurrency in all operations, increasing efficiency and decreasing time-to-market
- Quick and inexpensive formation of networked manufacturing organisations
• Ability for each enterprise in the production chain to have their own production knowledge and product design processes and use their own software and services. Transitions in the production chain must bridge the gaps between heterogeneous knowledge, processes, systems, services and ways of working.

• Processes and products that can be rapidly reconfigured to accommodate diverse and changing needs and opportunities. Change management across the entire production chain requires coordination of individual changes and support for iterative adjustments. Collaborative product, process and service engineering must thus be managed and performed across networked organisations.

• Support for strategic and opportunistic change in networked manufacturing organisations, where new cross-partner knowledge is continuously created and must be shared, executed on and managed. Innovations must be captured, implemented, deployed and combined through cultivation of a Web of shared understanding among the actors in the network.

The paradigm shift from lean manufacturing to agile manufacturing reflects most of the above named challenges. However, the dimension of flexibly adapting not only the manufacturing related parts but the complete enterprise calls for application and adaptation of concepts from (networked) enterprise engineering and (active) knowledge modelling.

Design engineering in collaborative networks constitutes a new engineering paradigm that needs to be supported with new design methodologies, tools and practices. Although concurrent engineering has been advocated for already more than a decade, in practice, it remains typically restricted to engineering groups from large global companies, but even there support for collaboration between dispersed company’s sites proves to be limited.

Jukka Ranta (1999) observed that automobile industry was usually a source of innovation in terms of new production paradigms and the best practices in manufacturing industry (e.g. JIT, TQM or supply chain management). However in categories of management and control of demand-supply chain and industrial structures, electronic industry sets new paradigms through creation of global collaborative (engineering) networks (Salminen 1997). This enables the partner companies to compete against others in terms of time to market, product flexibility and shared knowledge.

MAPPER shares the above observation on innovativeness of automobile and electronics industries as all three use case scenarios address important design and manufacturing tasks in both industries.

2.2 Industrial Use Cases

The general challenges introduced in the previous section are reflected in all three use cases, which drive the project by defining requirements to MAPPER methodology and infrastructure, applying and validating the results. The MAPPER use cases are from automotive industries, industrial electronics and automotive supplier industries.
2.2.1 Collaborative Product Development in Automotive Industry

This use case addresses the portion of the Product Development Process in the automotive sector that describes the first phase of the suppliers’ involvement in the objectives definition and the product planning, namely the Collaborative Product Development (CPD). This is a crucial aspect with high impact on competitiveness and on every performance indicator of a manufacturer. Main partner is the FIAT Research Center and the focus is on the following three phases:

- the CPD process, starting with the target setting,
- the nearly contemporary suppliers integration and choice process or sourcing and
- the product design.

The activities in this area include:

- the analysis of the voice of the customer,
- the technical and economical objectives definition,
- the early supplier involvement,
- the request for quotation and
- the supplier contribution, reviews and negotiations until the final supplier choice.

In the automotive CPD, the collaborative snags include internal and external integration with a heavy exchange of information, sometimes conveyed through the net and sometimes directly transferred face to face during meetings. Data may be managed by IT systems or human action may be needed at one step and it is strongly required to reuse knowledge across different platforms and projects. This requires, as a consequence, to avoid redundancy of databases, the definition of common models, languages and jargons among the actors in the Networked Enterprise as well as among the applications.

The use case will contribute to secure operative and technological integration between the actors of the development of FIAT models and in particular streamline time and resources optimising repetitive processes and re-using knowledge across existing projects and platforms. One goal is to enhance and share the understanding of common objectives and the involvement of suppliers in the enterprise strategies. This leads to a truly stimulating participative partnership. If the suppliers are driven by the enterprise objectives, their role in favouring customers’ needs is clear. In particular it is easier to create a common understanding about the technical and economic specifications and their impact on manufacturing processes of suppliers. Finally, it will contribute to transform and translate the implicit process knowledge acquired during subsequent projects into explicit new requirements for the integration and collaboration processes.
2.2.2 Distributed Collaborative Design in Electronics

In order to face challenges in design and manufacturing of modern electronic systems in respect to their complexity and constraints in time-to-market, engineers need new knowledge-based design methodologies that are enabled by secure and reliable cooperation through the network and by global access to required resources.

This use case addresses challenges in electronics through a demanding design of a System-on-a-Chip (SoC) that requires the development of a sophisticated Intellectual Property (IP) component. This component is being designed in a collaborative network of two SMEs, namely advICo GmbH (Germany) and Evatronix SA (Poland). The advICo - Evatronix collaborative engineering process aims at a Hard IP (USB discrete transceiver with UTMI+ interface) – an IP (virtual) component that is required for hardware implementation of standard serial communication protocols.

The distributed design process commences with an initial, informal specification of the Hard IP design that is agreed upon by both companies and their customers. Once a precise specification exists both companies define their design workflows as active knowledge models and describe the interfaces. These AKM-based workflows span over specification, development, verification and product preparation design phases. In the following, technologies for components manufacturing, tools to be used, and responsible engineers are identified. The common advICo-Evatronix design workflow defines all design steps at both companies that are needed for design and production of the USB IP component. This common design workflow is a result of numerous consultations between managers and engineers of both companies that are supported by the MAPPER infrastructure.

In order to perform the design process the active knowledge model of the Hard IP component design process needs to be executed. Tools in the collaborative network are invoked according to the specified workflow resulting in a design of the IP component. It is foreseen that during different design steps various intervention and collaboration among engineers still are needed. Engineers will be supported in these collaborative tasks with the MAPPER infrastructure. Further needs for supporting collaborative engineering actions will be investigated resulting in requirements for the enhanced version of the collaboration infrastructure.

2.2.3 Distributed Product Design in Automotive Supplier Industry

This use case will support distributed product development and performance of multi-project lifecycles in a networked organisation from automotive supplier industry. The main partner is the business area “seat comfort components” of Kongsberg Automotive (KA). Kongsberg Automotive is an automotive supplier with the main sites in Scandinavia. Today, KA has around 2600 employees within 17 units, working with development and manufacturing of products for the automotive business world wide. The main products are seat comfort products (seat heater, seat ventilation, lumber support and head restraint), gear shifts (gear shifter for personal vehicles) and commercial vehicles (clutch activation, rods, gear shifters and couplings).
The MAPPER project is focused on the department Advanced Engineering within the business area Seat Comfort. In this area the development tasks are concentrating on pre-development of new concepts and new materials. Development of products in this business area includes identification of system requirements based on customer requirements, functional specification, development of logical and technical architecture, co-design of electrical and mechanical components, integration testing and production planning including production logistics, floor planning and product line planning. Within KA, this process is geographically distributed involving engineers and specialists at several KA-locations and SMEs from the region. A high percentage of seat comfort components are product families, i.e. various versions of the components exist and have to be maintained and further developed for different product models and different customers. In this context, fast and flexible product development and integrated management of concurrently performed forward-development processes is of crucial importance. Main challenges for participative engineering and flexible manufacturing in this scenario are:

- To support geographical distribution and flexible integration of changing partners
- To enable flexible engineering processes reflecting the dynamics of changing customer requirements and ad-hoc process changes and at the same time well-defined processes for coordinated product development
- To coordinate a large number of parallel product development activities competing for the same resources
- To allow for richness of variants and at the same time reuse and generalisation of products

The overall target for the product development phases within the automotive business is to enhance the quality and reduce the time to market for new products and functions. This should be achieved with the lowest price with regards to both, development cost and product cost, and weight of the product. Collaboration between people within the company and with external partners is a key success factor to meet these basic needs.

### 2.3 Illustrative Scenario

The scenario used in the following chapter for illustration purposes is taken from the Kongsberg Automotive use case. Within the MAPPER focus area (i.e. Seat Comfort, Advanced Engineering) the Process Of Innovation (POI) has been selected to be the target for creation of solutions based on MAPPER.

The POI shall facilitate the combination of creativity and innovation with detailed system support, flexibility and adaptability. This combination of ensuring a well-structured way of working when developing new concepts (due to many constraints) and at the same time allowing for creative freedom is a key success factor. The POI consists currently of three main phases:

- The idea analysis phase aims at creating and assessing ideas for a given goal.
The visualisation phase concerns the test of selected concepts from the idea analysis phase including design tests.

The reporting phase documents findings and proposals to reach the given goal. Within these phases, the core tasks contributing to the development of innovative products were identified and captured in active knowledge models. One of these core activities is to establish a material specification. The material of a seat heating is an essential element of the product specification as diverse quality characteristics, the manufacturability of the product, suitability for the geometric shape and other customer requirements have to be followed and met by the material.

To establish a material specification comprises roughly the steps of

- preparing a draft,
- testing the material,
- performing process trials and
- releasing the material specification.

In the following, these tasks will be described in more detail.

In order to start preparing a draft, the project manager of the POI project selects a research and development engineer (RDE), to whom is assigned the task of developing the material specification and who is responsible for coordinating this process. The RDE receives the order, the product requirement specification (if available) and specific material requirements from the project manager or design responsible. The order provides information about target of the project, time frame, resource allocation and other frame conditions. The customers’ product requirement specification and the (internal) material requirement are usually described in separate documents. The RDE uses a template to create the draft of a material specification. Furthermore, a material number is created. A material specification describes characteristics and limits of the material. The draft is submitted to the person ordering the material specification, who in turn procures samples of the material for test purposes.

Testing the material is initiated by the RDE when receiving the samples of the material. The test engineer who will conduct the test is identified and informed about the test and also gets the necessary documents. In some cases, suppliers to KA are asked to conduct tests based on test specifications provided by KA. The RDE receives the test results as soon as the test is completed. If the results are satisfactory, the process trial will be started. Otherwise, a new supplier will be selected and new material samples will be ordered for repeated material testing.

A process trial is initiated by the RDE. The engineer who will be responsible for the trial is identified and assigned to the trial process. Again, the necessary documents are handed over. The trial is conducted based on the specifications and experiences of the engineer. After the process trials have been completed, the RDE receives the trial results. If the results are satisfactory, the specification will be prepared for releasing. Otherwise, the RDE has to repeat material testing, i.e. a new supplier will be selected and new material samples will be ordered.

In order to release the material specification, the RDE invites to a specification meeting. The participants of the meeting usually are the POI project manager, the
person responsible for production, the product designer and the material engineer, who get the necessary documents before the meeting. The purpose of the meeting is to receive additional and final input to the specification. The RDE writes the final material specification based on the results of the meeting. The material specification is submitted to the production manager for approval and then to the design manager for approval. After approval from both persons, the released material specification is registered, archived and distributed. The person ordering the material specification is notified that the process has been completed. The specification is made available to the complete POI project team.

3 The MAPPER Approach

The main technologies of the MAPPER project are illustrated in figure 1. *Active knowledge models* (AKM) of products, processes and other enterprise aspects are used for configuring and coordinating both the human and technical aspects of collaborative design. *Customisable workplaces* give different stakeholders access to the information and services they need for performing their tasks. The *secure collaboration platform* enables enterprises to use each other’s engineering tools and product data in a collaborative, yet secure manner, while *participative engineering methodologies* guide joint product and process design, interdisciplinary and inter-organisational collaboration throughout multiple product lifecycles.

![Diagram](image)

**Figure 1: Overview of the MAPPER Approach**

3.1 Configurable Active Knowledge Models

Through visual models that reflect evolving business knowledge, all the other elements can be configured and composed. The models are thus used *actively* to customise and adapt the IT infrastructure and the models are executed through proc-
ess enactment and rule engines. Active knowledge models differ from conventional model-driven architectures (MDA) in that they primarily capture user knowledge about business realities, rather than technical information about how the computerised support systems work. AKM thus lets evolving business needs directly control the IT infrastructure. Its interactive model execution paradigm (Jørgensen 2004), which flexibly merges automatic reasoning and manual decision making, creates IT support for the innovative design processes at the core of the business’ competitive advantage, not just for the administrative support processes. The business logic is liberated from software into visual models, making it available for development, learning, negotiations and decision making.

Product design projects today typically involve a multitude of engineering and other disciplines, often from different companies and nationalities. When such a project is to use the MAPPER approach, methodologies and infrastructure, the first step is to build a scaffolding model for the project. This model should contain the information needed for setting up a collaboration space for the project on the Web, e.g.

- **Product model**: What kind of product is to be designed, what are the constraints and requirements, which components should it use etc.?
- **Organisation model**: Which companies and people are involved in the project?
- **Process model**: which overall project work plan and general procedures should be followed?
- **System and infrastructure model**: which IT applications and services should be used in the project? Which are the overall content models for managing and navigating project information, etc.?

These four POPS dimensions (ATHENA A1 2005) are mutually reflective, in that each model will influence the content and meaning of the other models. There are also many relationships and dependencies among the elements of each dimension. The scaffolding model thus defines the initial structures of a multi-dimensional innovation space, which controls and configures the project collaboration space. As the work progresses, the POPS models will be extended, capturing the current state of the work and the collaboration spaces will automatically adapt to the changed situation, e.g. when a role is assigned to another person, a task is completed, a new product component has been designed and tested, etc.

Figure 2 illustrates some of these dependencies. It presents a model view dominated by the process perspective, defining a reusable task pattern for the design task “Establish material specification” described in section 2.3. Here the product structures are represented as inputs and outputs to the process. The organisation roles that take part in the process are modelled as resources (grey boxes on the left side, below each task), like the infrastructure services needed (yellow boxes on the right side, below each task). Decision control information is captured as roles on the top of each task. The model thus illustrates how all the other dimensions are present in the view of the process dimension used for project planning and business process design. In the following, we will explore how this process can be executed in the model-configured infrastructure, guided by the participative engineering methodologies.
3.2 A Collaboration Platform of Model-configured Services

The term ‘service’ is today used for denoting a wide range of concepts, from a hard-coded software function wrapped inside a SOAP/XML interface (a Web service), to the products and services a company sells and delivers.

To add to the confusion, software professionals often use the term ‘business’ to denote low-level technical elements such as ‘business documents’, ‘business processes’, ‘business objects’ and even ‘business services’. In MAPPER, we develop an ICT infrastructure for model-configured, user-composed services. These services span different layers:

- **Infrastructure services**, accessible e.g. through application programming interfaces (API), as socket-based communication services (e.g., JMS), or as Web services, with explicit XML interfaces and interface definitions (WSDL), accessible over SOAP.

- **User services**, such as interactive portal services and portlets, accessible e.g. as URLs with parameters, pluggable inside HTML frames. Tools and applications, consisting of a number of related software functions, are often used by a specific role to perform a job. Today most applications are hard-coded, non-interoperable software islands. MAPPER aims to replace this with model-configured application services, which can be more easily linked with other role views and reconfigured to local variation and evolution in organisation and ways of working.

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*Figure 2: Example Task Pattern*
• Business services, that are offered, sold and delivered by a company, like products, including generic services (ERP, PLM, application service provisioning etc.), industry sector specific services (e.g. VLSI design) and company specific services, utilising the core, differentiating competence of the company.

The IT industry delivers services across all of these layers. One of the long term contributions of MAPPER is a new way of organizing the IT service delivery value chain. Enabled by a model-configured infrastructure, higher level user and business services can be more easily adapted and composed. During the first phase of the project, MAPPER has concentrated on infrastructure level services, developing Web service interfaces to existing tools. We are exploring how user services can be model-configured and composed from lower level infrastructure services to support generic, technical use cases. During the remainder of the project, the application in the use cases will focus on concrete business services, supported by the participative engineering methodologies.

Figure 3: Layers of Services on Top of an Active Knowledge Modelling

Figure 3 illustrates this approach in more detail. On top of the three infrastructure layers, more complex functionality can be model-configured for individuals, groups, projects, companies, business networks and communities. In particular, generic solutions for methodologies (layer 4) will be operationalised by configuring lower level user and infrastructure services into coherent task patterns.

Each layer filters, combines and contextualises services from the layers below to construct increasingly customized services for business users. In the service teams that perform this customisation, ordinary users and super users are supported by experts on solution and platform modelling. Partners and customers thus extend the platforms on different levels, filling different roles in the service team organisation and forming a software supply chain.
The portal services available in the current MAPPER infrastructure are described in
the Portal Services Model. These services are accessible as parameterised URLs and
may be opened inside the model-configured portal. The way the services are organ-
ised in the model define the navigation menu structure of the portal, so it is easy to
extend and adapt the portal. Each project can define its own local set of services and
so can a company, department, or organisation role. When a user logs into the portal,
he or she is presented with a navigation menu that merges all the portal models that
apply to him or her, i.e. all the projects, roles, groups, companies etc. that he or she
is a member of.

In addition to this model of portal services, the system and infrastructure model
represents the Web services offered by the components of the MAPPER infrastruc-
ture, or by other systems used in each company. Web service description language
(WSDL) files can be imported into models, creating the model structures needed for
later invoking the Web services with correct data. Any Web service can thus be
made available in the collaboration space through simple, automatic model import,
without needing any kind of programming. Users just have to map their data (in the
models) to Web service request and response data structures and the services are
ready for use. As we shall see below, service invocation can also be traced and man-
aged by task execution.

3.3 Customisable Workplaces

This navigation menu described above is the first in a range of model-configurable
workplace components that MAPPER will implement in order to provide each user
with the services, information and communication channels needed for performing
his or her tasks. These workplaces will be available in two main formats:

- **Web workplaces**, easily accessible interfaces for performing well-defined tasks
  and conventional information processing, e.g. through forms and reports.

- **Visual workplaces**, displaying, organising, modifying and interacting with
  active knowledge models, defining and doing work at the same time, handling
  complex and poorly understood problems in innovative ways.

Though the user interface technologies are different, an underlying view manage-
ment engine is used to select the content and context navigation structures to be
included in each role view. This engine interprets the modelled business knowledge,
traversing dependencies and other relationships to generate purposeful excerpts of
the large information base that is the collaboration space model.

3.4 Participative Engineering Methodology

The objective of the Participative Engineering Methodology developed in MAPPER
is to facilitate participative engineering in a networked manufacturing enterprise.
The focus has been on using the modelling approach for the development of a meth-
odology consisting of reconfigurable and customisable knowledge models. The
following aspects are covered by our participative engineering methodology:
• **Collaboration among humans in a networked enterprise**: How should we go about forming and retaining fruitful collaboration relationships with other people, inside and outside our own company?

• **Organisational learning in a networked enterprise**: How should we provide for maximum learning in a networked enterprise? This also involves learning across organisational borders.

• **Multi-project portfolio management**: How to plan and coordinate several parallel projects, where each project may have participants and resources from several companies.

• **Modelling a networked enterprise**: How to plan and perform a modelling effort, covering the whole life-cycle of models, from planning and development to application and management.

The respective sub methodologies are interdependent and therefore integrated in an overall methodology model represented as a graphical knowledge model utilizing the POPS dimensions.

Future versions the methodology will be integrated as Model Driven Application Services (layer 4 in the infrastructure, cf. figure 3). Operational methodology services will be composed from lower-level, model-configured user and infrastructure services. By model-configuration and user composition of the methodology component services, they will be tailored to the user’s need and will be available in the portal as an integrated part of the collaboration workspace.

### 3.5 The Collaboration Infrastructure

In section 3.2, we already mentioned the different types of services that we combined in the MAPPER infrastructure. In the context of the use cases that are supported by the MAPPER infrastructure, we integrated three different tool suites that support different types of collaboration, which are typically required in the task patterns of participative engineering.

From a group interaction perspective, we can classify the needs for group interaction in distributed virtual enterprises according to the dimension of time. Synchronous support is mainly required in the context of virtual meetings. The team needs communication facilities and means for interacting on shared material such as design documents or source files that make up the final product. In the context of the MAPPER project, this kind of interaction is supported by the *ConcertChat* system developed at Fraunhofer IPSI. Asynchronous interaction support is needed to help the team between the different design meetings. It requires that team members are able to share and modify material, discuss and coordinate issues that come up during the design task and stay aware of other users’ activities that take place in parallel to the own activities. The *CURE* platform developed at the FernUniversität in Hagen supports such kinds of interaction.

In both contexts, the users need to have access to the required domain-oriented tools such as simulators or compilers. The tools may in addition require special facilities such as chip test beds or even larger physical installations like a wind tunnel in the case of car manufacturing. The *TRMS* system developed at the Silesian University of
Technology offers means for securely invoking domain-specific tools (Fraś et al. 2004; Siekierska et al. 2006).

In the next paragraphs we will show how each of these tools support collaboration.

The Concert Chat client provides synchronous collaboration services to the users. The user services are accessible by means of the ConcertChat Client, a Java application that can be launched using Java Webstart technology. It offers user awareness, text-based synchronous communication support, a shared whiteboard and referencing functionality using again a virtual room as the metaphor to realize a shared workspace.

CURE (Haake et al. 2004) is a Web-based system that facilitates collaboration in distributed teams using standard browsers over the Internet that is now available under an Apache open-source licence (CURE 2007).

From a user’s perspective, CURE is based on the room metaphor combined with WIKI ideas and communication tools. A user can participate in one or more project by being a member of the rooms that are associated with the project. The actual collaboration takes place in rooms that contain editable Web pages and communication channels. Examples for pages are traditional files (such as spread sheet documents or vector graphics) or wiki pages (Leuf and Cunningham 2001). Each room can have several embedded communication channels. In case of an embedded mailbox, it is possible to send messages to a room using a traditional e-mail client. These messages will be dispatched to all members of a room.

The Tool Registration and Management System (Fraś et al. 2004) enables distance-spanning tool integration. Once registered, tools provide their service for distributed design teams.

The goal of this component is to allow users to offer and make use of tools that are installed at a remote site. An example is the provision of a simulator that is installed at one location and that should be accessed via application sharing from another site. One major design goal of TRMS was to enable access to the tools in a way that the users have sufficient licences. An example for this is a simulator software for that a company has bought only a limited number of licences that can however be used by anyone if no more than the licensed number of users use the tool at the same time. TRMS provides access to its user services via an applet interface.

All mentioned systems provide a unified Web service interface that can be used by any axis compliant Web service client. The Web services allow application clients to modify the domain model of the different tools so that the tools can be model-configured for a specific collaboration context. In our context, these services are invoked.

All the above tools need to be combined to support task patterns for collaborative engineering. On a technical level, the task patterns are mapped to Metis models that represent the plan for the concrete interaction.
Figure 4: The Orchestration Architecture

Figure 4 illustrates how the Metis model is used to configure the different tools. Basically, the Metis model configures the user-defined portal. In the portal, the users find their tasks and the related tools. The tools are configured by the AKM platform model enactment service that uses the tools’ Web service interfaces.

If the task requires, e.g., the creation of a set of pages in CURE, the AKM platform will create the pages using Web services and then point the users to the first page that needs manual changes. If pages should be discussed in a synchronous chat, the AKM platform will create a discussion space at the ConcertChat server and link it with the CURE room in which the documents that should be discussed can be found. Finally, if the task requires the execution of a design tool, the AKM platform will set up a tool configuration in TRMS and trigger the tool execution.

3.6 Applying the MAPPER Approach

We have so far explored how the collaboration space for a design project can be configured and we have introduced model-configured workplaces as the technology to support specific roles, people and tasks. This section outlines how model execution services can be used for activating models, in order to support the real performance of innovative and collaborative design tasks. The first use case application area, establishing a material specification (cf. fig. 2), is executed mainly by the task enactment engine. This engine interactively executes modelled processes, automatically triggering new tasks and performing automatic tasks, while always remaining open to users overriding the modelled flow of work, extending the model while it is being executed, or changing it to reflect ongoing learning and elaboration of work plans. If the task model does not prescribe a sequence of steps, the engine steps back and lets the users coordinate the tasks themselves, e.g. utilising the collaboration services. Any degree of process flexibility, from fixed procedures to completely ad-hoc task pattern, is thus supported within the same model.

In order to make the task patterns model in figure 2 executable, a content workspace must be set up and services accessing this workspace must be selected for imple-
menting each task. Each material specification pattern is supported by a collaborative workspace in CURE, which contains document templates for the different steps (material testing, process trial etc.). The services for interacting with the contents are represented in the portal service model.

What remains to be done then, is to connect the right service for each task. The resulting model is shown in figure 5. In addition to interactive portal services, the solution makes use of Web services from CURE, e.g. for creating a new workspace for each concrete material specification instance. The figure highlights examples of such connections; on how the needed service for communication support (marked

**Figure 5: Executable Task Pattern Model (Process and System Dimensions)**
A) is connected to the CURE service (marked B) and how the needed service for task management (marked C) is connected to the Task Management service “My other tasks” (marked D).

While there are still lots of room for improving this solution, we have demonstrated that model-configured task patterns can support most of the tasks involved in this industrial scenario.

4 Experiences

The work approach in MAPPER has been so far

- participatory in the sense that both use site professionals, researchers and modelling experts worked together – partly synchronously, e.g. in workshops or project meetings and partly asynchronously,
- model-based in the sense that the primary knowledge store and results of the effort exist in the form of an enterprise model in Metis.

This could be achieved on different levels in all sites: In KA, one or more external modellers were available for doing the actual modelling. For most KA domain experts learning how to model would require too much time and effort, hence a mediator who can put their knowledge into the language of the model seems necessary at this point. In CRF, users could model their environment and needed very little support from the external modellers. In Evatronix, the facilitator (SUT) took mainly care of modelling the work processes and user requirements.

In the following we will first describe some experiences from modelling activities in more detail, followed by the very first results from our first application in the area of Establish Material Specification established in KA.

4.1 Modelling as a Cooperative Process

Participation of stakeholders from different departments of a use site and from different MAPPER partners has to be considered a key success factor for creating adaptable knowledge models suitable for use in everyday practice. However, we experienced that different levels of participation were adequate for the different modelling phases. For instance, in KA in the initial phase, scaffolding, nearly all stakeholders were participating all the time during the model development process. In terms of the produced size of models, these model sessions might not have been very productive. But in terms of sharing knowledge and creating a joint understanding of both, the use case subject and the nature and process of modelling, the joint modelling sessions with all stakeholders were extremely valuable. They created a joint ownership of the result. In some other phases, the way of working was changed and the level of participation was reduced: before developing Metis models, we developed textual scenario descriptions for the task under consideration. The scenario descriptions were developed with participation of all stakeholders, but the development of models based on the scenario description was done “in private” by the modelling facilitator. The main reason for this change was the required level of detail of the models. As the objective was to provide executable models, a lot of
detailed and partly technical information had to be included. Joint editing of such models was not only perceived very time consuming but also overloading some stakeholders with technical details considered not relevant for them. However, the models produced by the facilitator were presented to the other stakeholders for validation purposes and in order not to loose the joint ownership of the results. During the modelling of the requirements the participation level increased again, as all requirements had to be qualified and described in joint work of use case, technical and academic partners. Although most requirement model refinements were performed in smaller working groups of three to four people, the participation from different stakeholders was of high importance.

Another experience we had regards the evolvement of models created in MAPPER so far, from handmade sketches on a piece of paper or on a flip chart to traditional flow charts (SADT or UML activity diagrams) and then further to more sophisticated models in Metis. The development of meta-models in Metis resulting in modifications of several model objects and templates has substantial impact on the appearance of users’ models, which users have to deal with (cf. figure 6). Sometimes it was important to refer to old models, to explain relationships between objects, tasks or actors. Sometimes it was easier to see work relations on old maps or scripts to remember circumstances that users wanted to change – starting by modelling their processes, organisations, products and infrastructure from scratch. This enabled reviewing their current situation and reflecting on that, by thinking about problems and potentials to improve, and by making suggestions for future changes.

Figure 6: Fragments of Previous (left) and Current (right) Models in CRF

4.2 Some Experiences from the First Application in KA

The first application of the MAPPER solutions was launched in KA about the task pattern Establishing Material Specification (EMS). The main goal was to create a collaborative design space for users where they can manage their tasks and subtasks related to EMS. The big challenge was to try to integrate two different MAPPER technologies (Metis and CURE) by designing a single interface for user interaction.

Answering to the requirements like integrating different systems, creating one common user interface and hiding the complexity of the technology from its users is a demanding task that has already been subject to several research papers in software engineering. Deploying the first version of task execution in KA made it possible to
identify the complexity of designing and introducing a new system into a work environment, where the work process was also redefined. Furthermore, we could analyse and categorise problem areas to which we are going to provide a solution. For instance, if the complexity of a system is transparent to its users, users are confused. They become sceptical on the necessity and usefulness of the new system and more and more inpatient and intolerant to system errors or delays. The integration of completely different systems is technically very complex procedure. Defining an interface just for exchanging contextual information is a first step towards the goal, but not enough to achieve user satisfaction. User interfaces of and interactions with all integrated systems should be based on one design. Avoiding multiple logins into several parts of the system, avoiding additional popup windows needed by some parts of the system, providing an overall navigation structure and a feedback mechanism are some issues to be considered for improving the integration of different systems. A collaboration space must provide a common context for its members, which is twofold: the information included in the space (content) and the layout of the space (form).

5 Conclusions and further Work

While distributed management, interoperability and appropriate standards are among key prerequisites for strengthening competitiveness in production networks, as observed in a book containing experiences from projects of the AITPL research project cluster (European Commission 2005), the visual knowledge-based approach appears to be a natural and straightforward strategy among ambient intelligence technologies deployed for supporting the product lifecycle. The MAPPER consortium believes that the active knowledge modelling (AKM) technology applied to products, as well as design and manufacturing processes will support reuse of enterprise (also engineering) knowledge and thus will contribute significantly to increase the productivity in collaborative manufacturing networks.

In the continuation of the MAPPER project, based on refined requirements from the experiences with the early deployment and application, enhanced versions of the methodology, services and infrastructure will be deployed and applied at the use cases in the existing application areas as well as in new areas to be introduced. The application in the use cases will be focused on concrete business services, supported by the enhanced participative engineering methodology and based on the infrastructure and user services that are developed early in the project.

Acknowledgements

The work published in this paper is partly funded by the European commission through the MAPPER STREP (Model-based Adaptive Product and Process Engineering) (IST-016527) and through the ATHENA IP (Advanced Technologies for interoperability of Heterogeneous Enterprise Networks and their Applications Integrated Project) (IST-507849).

The work does not represent the view of the European Commission or the ATHENA consortium.
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