20 A DESIGN PROCESS MODEL TO SUPPORT CONCURRENT PROJECT DEVELOPMENT IN NETWORKS OF SMES

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This paper presents a software infrastructure enabling Small and Medium Enterprises (SMEs), working in the mechanical sector, to cooperate in a distributed engineering environment to dramatically save time and reduce product engineering costs. This objective is reached by encouraging SMEs enterprises to systematically apply Co-design techniques, duly supported by this new specially-conceived software. Special emphasis will be put in the Design Process Model, one of the three models that supports the co-operative architecture.

INTRODUCTION

The ESPRIT project EP 25360 – COWORK “Concurrent Project Development IT Tools for Small and Medium Enterprises Networks” is targeted at developing a new software tool enabling Small and Medium Enterprises (SMEs), working in the mechanical sector, to cooperate in a distributed engineering environment to dramatically save time and reduce products engineering costs. This objective may be reached by encouraging SMEs enterprises to systematically apply Concurrent Engineering and Co-design techniques, duly supported by a new specially-conceived software.

The idea of COWORK is based on the following considerations:

- The main success factors of a product in all sectors are short time-to-market and a high quality level since the beginning;

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The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: [10.1007/978-0-387-35577-1_37](https://doi.org/10.1007/978-0-387-35577-1_37)

- Generally, all manufacturing SMEs (and particularly enterprises working in the mechanical sector) need to frequently innovate their products, both to create new products and to enhance the quality of the existing ones; this policy cannot be practically applied because of the long time and the high costs required for new products design. Often these enterprises are compelled to discard new ideas and enhancements because of budget problems, even if this is a suffered choice;
- The market already offers some IT instruments whose aim is to support the organisation of engineering activities; these products are also partially targeted to shorten engineering time but their characteristics of use are absolutely incompatible with SME procedures;
- Some preliminary studies show that the systematic application of co-design techniques based on parity relationships among different enterprises, sometimes among competitors, is particularly interesting for SMEs; unfortunately software tools available on the market do not offer adequate capabilities to support such activities.

The aim of the project is to develop a software package prototype with the following functionalities:

- Helps in the creation of SMEs networks able to strictly co-operate in the engineering sector; supporting the identification of possible collaborators through structured information searching in a SME Competence Repository.
- Manages all the engineering phases even in heterogeneous environments and in different geographical locations, from the initial project planning until the final delivery of the product, thanks to an advanced project model.
- Simplifies and automates the exchange of information as much as possible, thanks to a model of the product having a high semantic content. This model manages geometrical and non-geometrical product information.
- Supports the reuse of previous project and components, as well as the management of changes and different versions during the project life cycle.
- Uses the most advanced Internet/Intranet technologies to support distributed co-operation.
- Provides the possibility to exchange information with non-Cowork users through standardised technology (ISO-10303/AP214 Physical File).

SOME BASIC ASSUMPTION

A high number of countries in Europe present industrial structures characterised by few large enterprises and many SMEs. These companies have presently strongly different features that cannot be changed because they represent some of the success factors of SMEs. For example, SMEs from the mechanical sector are, among others, characterised by:

- Very soft formalism in product modelling (large use of the concept of family, subset) which, even if dangerous from some points of view, allows a significant time compression in the product planning cycle and, thus, a greater aggressiveness in the market.
- Very quick project structures.
- Non-complete availability, within the enterprise, of the know-how needed to lead sub-contractors in the planning area, limit which implies that these sub-

contractors become effective partners, taking part into the definition of product specifications up to the initial designing phase.

- Claim from concurrent enterprises to common sub-contractors for the planning of parts not retained as qualifying from the commercial point of view (for example, concurrent enterprises producing machine tools for wood working, which apply to the same subcontractor for the base planning).
- Claim from non-concurrent enterprises to common sub-contractors for the planning of common parts.
- Impossibility to make a long-term plan because of market behaviour or leaders' innovations.
- Availability, inside the enterprise, of CAD, very often also 3D.
- Skill to project and produce also products of a certain complexity, often also with high export rate of the product.

It is clear that enterprises with these features are naturally oriented to work in a Co-design system and partially apply now, sometimes unconsciously, some Concurrent Engineering techniques. Groups of enterprises with these features are already Virtual Enterprises *de facto*. This way of working allowed SMEs development, helped them to overcome market crises and made them competitive, in some sectors, with respect to very large enterprises.

Taken into account these particular characteristics, the CoWork philosophy is based on a fundamental assumption: *the co-designers are independent companies, collaborating in the design of a unique complex product, but they maintain full autonomy in performing the assigned tasks*. Several consequences mostly distinguish the co-design carried out by a network of SMEs from that carried out within a large enterprise:

- *Autonomous work organisation*. The single co-designer is the only responsible of its design task organisation and planning. With respect to the network, it just must ensure to meet the due dates agreed upon with the other partners and, if possible, to participate in recovering delays and perturbations caused by other co-designers.
- *Preserving know-how*. Each enterprise taking part in a network desires to preserve its know-how. This means that no direct access to its data can be allowed to the partners. The only knowledge made available to the partners should be appropriately selected and prepared by the enterprise starting from its private information. The CoWork system must provide the tools for preparing and exchanging this information.
- *Dynamic network*. A co-design network is dynamic from different viewpoints. For the execution of a single project many different enterprises are involved as contacted co-designers. During the negotiation the enterprises contact each other, some withdraw from their co-operation while new others are contacted. This situation lasts for the whole project. From the single node viewpoint, the participation in different projects can occur simultaneously. Some projects are under discussion (e.g. feasibility studying), some are in progress, and others are coming to an end. Thus, an enterprise can be a well-established node for given networks and only a temporary node for other ones. In general a CoWork network lasts just for the duration of the co-design activity.

- *Technical competence.* Usually the enterprises involved in a project have poor ICT technical competencies. In particular, they cannot divert employees from the manufacturing or design sectors, or engage new ICT specialists. Thus, the user acceptance of the CoWork system is subordinated to the fact of requiring limited investments and training efforts in the ICT technologies.
- *Heterogeneous computing system.* Each enterprise uses a proper computing system and, specifically, a certain CAD system, a certain PDM system (often home made), and so on. Thus, the only common infrastructure of the enterprises taking part in a CoWork network is the CoWork application. This means that, in general, an enterprise cannot directly modify a CAD drawing of a partner by sharing such file and operating concurrently on it.

PRINCIPLES FOR NETWORK ORGANISATION

The idea of co-design in an SME network arises from the need of putting together the competencies that the participating nodes can offer in order to afford a design project that goes beyond the possibilities of the single node. Each partner develops a part of the whole project and exchanges with the other partners the only information of common interest. There is a partner that receives the order from the external customer, while the other partners are involved by it or by intermediate co-designers.

Taking into account the roles that the network nodes play with respect to the other partners, the CoWork approach identifies two basic user types: the *main contractor* (MC) and the *co-designer* (CD). They are abstracted from the user profiles observed in the networks that take part as user partners in the CoWork Consortium.

The main contractor (MC)

Main contractor is every node that assigns co-design tasks to lower level nodes. In particular, main contractor is the enterprise that receives the order from the external customer. Typical roles of the main contractor are establishing technical and non-technical requirements to the co-designers work, and evaluating design results and possible counterproposals coming from them.

The main contractor decision power can depend on the nature of the product to design, the conditions established by the external customer, and even the traditions of the specific geographical region. In some cases the network nodes tend to collaborate on a basis of equality, which means that most aspects are subject to an open and continuous negotiation, in other cases the main contractor fixes constraints that can only be accepted or rejected (observe that this latter case corresponds to the typical sub-contracting relation).

The CoWork models are defined in such a way to support the most general situation. Instead, they do not manage the mutual powers of nodes as they are hardly formalised, can change in time and, after all, remain a private aspect of the single bilateral relation.

The co-designer (CD)

This is any network node that has a co-design task assigned by another node. It receives requirements, performs the envisaged design work and communicates back the results of this work. With respect to its main contractor, every co-designer has the right to:

- Protect its own know-how, that is, fix by contract which information should be delivered during and at the end of the co-design process;
- Negotiate those technical and non-technical requirements, costs, deadlines and other conditions that are considered open aspects of the bilateral agreement.

A co-designer can behave in turn as a main contractor if it decides to involve lower level co-designers. Then, the most general configuration of the node CoWork application includes both the data it must have to interact with its main contractor and that required to collaborate with the lower level partners.

Through this information the single network node realises and maintains its autonomous view of the process, constituted by the state of the ongoing work and that of the open discussions with partners.

The typical co-design network

Taking into account the above profiles, the typical topology through which every network can be modelled is a tree (see Figure 1) where the root is a main contractor, the leaves are co-designers and the intermediate nodes behave as both main contractor and co-designer. This network is dynamically established for each single project and there is no limitations about a single co-designer working with more than one MC.

Figure 1 – The typical co-design network established for one project

THE THREE COWORK MODELS

Based on the user requirements and on the previous considerations, three models have been defined, constituting the core of the CoWork application:

Standardised Product Model (SPM)

This model deals with the product data representation and is specifically devoted to manage the knowledge that is strictly necessary to support the co-design activities of the single node within the network. It means that the SPM model includes all and

only those concepts pertaining to the description of the product whose design is in charge of the node, including the description of the parts it can assign to lower level co-designers.

Hence, SPM will not become a product model to replace that already in use at the CoWork network node. Rather, it constitutes a sort of extension of the present PDM able to manage the only information of interest for the distributed design process. Thus, the SPM data structure will include specific data to support the communication with partners and references to data and documents managed by the present PDM.

Product description involves two main kinds of information:

- Descriptive and quantitative data on product and its components, concerning physical and performance properties as well as constraints, measures, tolerances and alike;
- Project documentation such as textual descriptions, work sheets, graphics and images (e.g. scanned drawings), up to 2D-3D CAD drawings, all possibly marked up with annotations.

Versions, historical information on previous projects, and the trace of product data exchanges are also considered part of the SPM model.

Design Process Model (DPM)

This model must allow the description, in this distributed context, of the process by which the product is designed: activities needed, dependencies between them, rules to follow, time schedules and constraints, planning of work, participant organisation and synchronisation of all of them.

Process description involves three main information classes:

- Project definition, activities to be considered in the project, relationship between these activities and product components that has to be developed using co-design principles;
- Organisation of the network of co-designers and designers involved in the process.

All the negotiation processes established between the participants in all the process phases: previous to the work assignment, during co-design development and getting the final results.

SME Competence Model (SCM)

Each node of the network provides information on company specifics including geographic location, application domain, products and processes, services and capabilities. The SCM represents and relates this information so as to support general facilities for navigating, filtering and browsing. Thus, every organisation accessing the Info Node can select and evaluate the potential candidates for envisaged Co-design activities.

Based on a client-server architecture, SCM functionality is provided through a database accessed via HTML pages. Extended functionality is provided through the SCM client which provides all web browser functionality plus certain SCM specific functionality like annotations or advanced bookmarking.

A DISTRIBUTED ORGANISATION OF DATA

According to the needs expressed by the users, the CoWork system requires a distributed organisation. Network interoperation is assured by an Internet based message passing mechanism, and a centralised server is foreseen for the SME competence repository.

Each node taking part in a co-design network is provided with the CoWork software system. It includes a unique Product & Process database and, possibly, a local SCM data storage.

Figure 2 – The COWORK node configuration

The relations between nodes are defined according to a nested encapsulation:

- Each communication between nodes is bilateral, from the MC to one of its CDs and from the CD to its MC.
- Each node N_i maintains the information regarding both its MC (father node for N_i) and its direct lower-level CDs (children nodes for N_i). It means that, a CD is not aware at all of the other CDs at the same level or in other regions of the network.
- Each communication between nodes is bilateral, from the MC to one of its CDs and from the CD to its MC.

- There is a tracking mechanism to register every change in current co-designed projects and they are marked as pending until the user decide to send them to the involved partners.
- The effect of a change occurred in a given node N_i are propagated towards its MC and towards some of its lower level CDs and, recursively, to their partners. An automatic warning mechanisms could be realised to inform the network nodes of an important change occurred on some technical data.

A DESIGN PROCESS MODEL TO SUPPORT CONCURRENT PROJECT DEVELOPMENT

It is obvious that CoWork DPM requirements drops in the field of those topics covered by the so-called workflow management applications. These type of applications has a wide spectrum of functionalities under a basic common definition; all of them providing mechanisms for coordinating the work of people. Being this the starting point, first task was to consider a mapping between DPM and these common workflow management applications principles. After that, we will present the basic concept included in the model.

The reference of workflow applications

Figure 3 – Relationships between basic terminology in workflow applications

Known workflow applications works on a well-structured processes. Identified the goal for the workflow implementation, first task is to elaborate a complete process definition. The workflow management system will manage the enactment of this process definition implementing process instance as running process. This process instance means the instantiation of activities, which generate work-items as piece of work to be done manually or, automatically, invoke some applications. This is the typical approach for this well defined processes used, for instance, in the order management problem or in similar business processes known as production workflow applications. At these cases, workflow management main objective is the automated co-ordination and control of work processes, both of people and computers. The basic concepts used for this approach are *Process Instance*, *Activity Instance* and *Work Item*.

- *Process Instance*: This is the representation of a single enactment of a process, or activity within a process, including its associated data.
- *Activity Instance*: The representation of an activity within a (single) enactment of a process, i.e. within a process instance.
- *Work Item*: The representation of the work to be processed (by a workflow participant) in the context of an activity within a process instance.

One of the first conclusions of the analysis was that CoWork solution seems to require a different approach as it works with processes not so well defined, are not completed when they start, were long running, change with the time and, finally, are running in a distributed context with distributed data repositories.

Figure 4 – Relationships between basic terminology used in CoWork DPM

These differences introduce some changes:

- Instead of process instance we will have projects.
- The workflow management concept is changed by the project management.
- Project are build up on activities and some of these activities can be grouped to be done under co-design principles. For those activities to be done under co-design principles the concept of co-work task is introduced.
- Instead of process definitions CoWork will use process templates.
- Automatic generation of work items and application invocation are out of the scope of CoWork. The automatic co-ordination of workflow inside the process is not so important being necessary the co-ordination of co-designers as participants in the CoWork task.
- The processes are running in a distributed environment and the knowledge about the processes is also distributed.

Project, activities and task distribution

Any new design work to be carried out in any node of the network will be instantiated under the *Project* concept. The main contractor is responsible for splitting and organising the project in a number of *Activities*. The activity network will be the “process view” of the project, so all the work sequence, precedences, parallel execution and time constraints will be supported by this and it will be based on activities and relationships between them. Different types of relationships can be defined as precedence and decomposition relationship. AND-split and AND-join relations will be used to implement parallel sequences of work. From those activities some of them need to be done under co-design principles and with this purpose a co-design *Task* is defined. The co-design task means a grouping of activities (one or more) to be assigned to some co-designer. For the contacted co-designers this task will be a new project due to start, up to the negotiation process established between them (Figure 5). The project starting at CD node, *Ci.Project*, will have a predefined set of activities, those defined for that task and received from the MC because they have been considered important intermediate stages in the task development; this importance comes from the need of control or because a third partner needs to use these intermediate results.

Figure 5 – Project and task relationship

Those co-designers that have no lower level design activities will present a simplified structure expressing the only relation with the upper level co-designer.

The relation between the activities (process view) and components or parts defined in the product model (product view) is defined by the user, being the task to be co-designed associated to a component using the composition utility of the CoWork software (Figure 6).

Figure 6 – Process and product views

Organisation and task assignment

Once the design/co-design work has been accepted by a partner company, project has been defined and activity splitting considered, the next step will be distribution of work internal or externally. Three different situations can occur:

- A design activity has not associated co-designer. This is the initial situation of most activities, at least of those that have not a predefined candidate partner.
- A design activity has associated the list of candidate co-designer among which the partner will be selected. This is a transient situation that the data structure must handle until the partner is selected.
- A design activity is assigned to a well-identified co-designer. This is the final situation expected for every lower level node, but it may occur only after a search of the best partner.

In general, the data structure of the MC enterprise includes a combination of these cases and only at the end of the negotiation phase all the lower level design activities aimed to be co-designed are in the last of the above situations. The first situation will remain for those activities not done under co-design principles and that must be resolved internally.

Until now the co-designer has been used as an abstract concept, this concept must be represented in each contacted company by an organisation, organisation unit or it could be a concrete person. The same happens with those activities to be resolved internally; they can remain at the organisational level or could be assigned to some organisational unit, a concrete person, or it could be defined a group of persons on the spot.

When a process template has to be defined, the concept of role can be useful for the co-designer or designer assignment. Role is in this sense a typification of something in common between a group of organisations or a group of persons: attributes, qualifications and/or skills.

Negotiation processes

Negotiation processes will be established with different purposes: technical requirements agreement, activity planned times, date for meeting and so on. This negotiation will be based on proposal a counterproposals. Three concepts will be always managed:

- Current and proposed values in the negotiation process.
- Direction of the proposed change. Values as 'SENT' and 'RECEIVED' can be applied.

Process templates

Process templates means subsets of DPM data pre-defined and that can be added to a current process definition.

CONCLUSION

The Esprit Project 25360, COWORK, has been introduced. After the identification of the basic assumption in which the project models are based, the three main models (Standardised Product Model –SPM–, Design Process Model –DPM– and SME Competence Model –SCM–) are presented. These three model conform the core of the Cowork software. Special emphasis has been put in the DPM description. The relation with workflow applications has been considered, as well as the basic concepts of the model: project, activity, task, organisation, negotiation processes and templates.

COWORK is being applied in three different co-design networks: an Italian network to produce fluid powered truck cranes and drilling machines, Spanish network to manufacture machine tools and a German one to design diesel engines for the shipbuilding industry.

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