Implementation of collaborative design processes into PLM systems

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Abstract: Design coordination means project structuring in relation with local objectives identification, resources assignment, task scheduling and performance criteria definition. In small and medium enterprises (SMEs), the design process is generally described at a macro-level which does not fully correspond to the complexity of the real process. A business approach for coordinating design process through the implementation of product life-cycle management (PLM) systems is proposed for improving design coordination in SMEs. Firstly, this business approach is based on a method for analysing informal collaborative practices and modelling detailed design processes. Secondly, these processes are implemented by using PLM technologies. Multi-level workflows are implemented to control progress of design schedule from project management level to document life-cycle management level. Subprocess generation and synchronisation tasks are used to synchronise them from one level to another and 'flexibility nodes' identify choices between different task sequences. An experiment validates the feasibility of this business approach.

Keywords: collaborative design; design coordination; design process management; flexible workflows; PLM implementation; PLM systems.

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1 Introduction

In the worldwide competition between companies, the development of new products has become a challenge where innovation and coordination of design process are two main keys for success. Today, design projects depend on the ability to coordinate and to control the collaboration between the numerous actors participating in such projects, for example designers, experts from different disciplines and with different experiences, and external partners. Design coordination implies scheduling, planning tasks and resources management (Coates et al., 2000). In main companies, the product development process is formalised at a high level and project managers in charge of subprojects or work packages have to respect the identified generic phases and milestones. They have autonomy to structure their subprojects and work packages and to propose tasks schedules but respecting these general constraints. At a micro-level, the coordination of the information flows within design teams is generally managed through product life-cycle management (PLM) processes centred on documents life cycles, without any relation with the project schedule. As a consequence, it is necessary to integrate project scheduling and document processes in order that project managers control all aspects of design coordination.

In small and medium enterprises (SMEs), the design process is also structured and especially when the company is involved in a quality management certification. But most of the time companies undergo external risks and collaboration between designers have a strong influence on the process (Baumberger et al., 2003). Flexibility is the main characteristic of the design process in SMEs even if sometimes this situation leads to time consuming and a lack of coordination. In this context, the formalisation of information flows can lead to rigid processes that can disturb the operations of the company. When implementing a PLM system in an SME, we face two antagonistic problems: first to improve the level of formalisation of information flows and second to keep an adequate level of flexibility (Weber et al., 2002). So integrating project scheduling and document processes through a PLM system must preserve the design processes flexibility.

Our aim is to propose a business approach that allows managing design process from project level to detailed process level through the definition and the control of PLM multi-level flexible workflows (Klingemann, 2000). In Section 2, we focus on design coordination and on PLM systems to emphasise the actual limitations of PLM systems. We then introduce a case study that will be developed all along the paper. In Section 3, an approach based on the analysis of the collaboration among designers and described in Pol et al. (2007) is explained. Its aim is to increase the level of formalisation of design processes, especially at micro-level to describe individual tasks and interactions between designers. Such detailed but flexible processes are implemented through PLM workflows. Finally, in Section 4 we study the impact of this work on the implementation of PLM workflows dedicated to document management as well as design project coordination in order to propose a multi-level architecture that will allow project managers to better coordinate the design process.

2 Design coordination and PLM systems in a small and medium enterprise

2.1 Design coordination

Nowadays, design projects depend on the ability to coordinate and to control the collaboration between the numerous actors participating in such projects, for example designers, experts from different disciplines and with different experiences or external partners. Ensuring the coordination of the whole development of a new product is a challenge for managers, especially into SMEs (Filson and Lewis, 2000). Coordination and control of engineering design implies the need to identify the different situations occurring during the design process. In design project management, the control of the progress of design process can be defined as the understanding of existing design situations (in the real world) in order to evaluate them. Then, project managers must take decisions that will modify and improve the future process, such as identifying the adequate resources, according to design objectives given by customer specifications or issued from the company strategy. The control problem here is a problem of decision-making to support designers in their activities (Girard and Doumeingts, 2004) in order for them to achieve an objective in a specific context (Figure 1).

Design activity has 'input' and 'output' information. Actors use the 'input' information and 'supports' such as human and material resources and knowledge to achieve their activity and to produce the 'output' information. For decision-making, project managers need to identify effective action levers which will influence collaboration thus increasing design performance.

In an SME, design projects have generally different characteristics than collaborative projects supervised by big companies. An SME design project requires a specific study for each customer's specifications. Most of the time, the small structure of the SME does not ensure project management in a routine way and leads to combine various responsibilities. Indeed, there are not enough actors to fulfil each design role, so most of the actors have various design roles in a project. Consequently, the role of informal relationships is very important in the SMEs in order that each design stakeholder may help each other without rigid formalities. Thus, the combination of various responsibilities and the informal relationships lead to a high level of workload because informal tasks are added to the official ones. Accordingly, SMEs have to manage deadlines by setting an order of priorities on design tasks according to the objectives.

Figure 1 Coordination of design activities (see online version for colours)

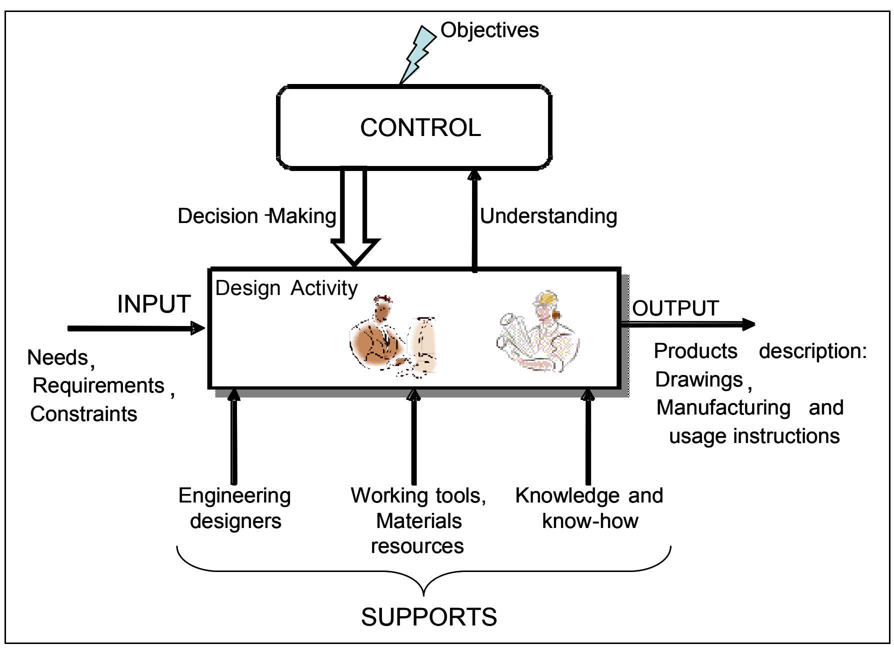
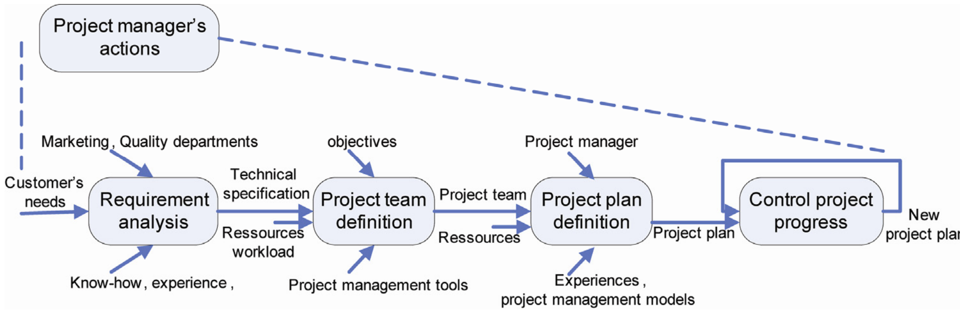


Figure 2 Synthesis of the project manager's actions (see online version for colours)



Another point specific to SMEs is their project structures with a rigid formalisation of their processes at a macro-level and a very low formalisation of the detailed processes which allows informal relationships into the project. As a consequence, design processes in SMEs are flexible and each product development process is different.

In this context, the tasks to be achieved by a project manager have been detailed to coordinate then control the design project in an efficient way. The project manager (Badke-Schaub and Stempfle, 2004) coordinates (Figure 2) by analysing the requirements from the customer, after which he defines the project team with its internal organisation (Mintzberg, 1990). He then defines the subphase of the project plan and activities in each subphase, next he defines a plan to control the project progress and finally he applies this control plan. Periodically, he controls project progress and makes the adequate modifications according to the results and the design objectives.

When achieving these actions, the project manager has to study a lot of information coming from the customer and from designers. The management of this information is essential for the collaboration and coordination in project management. Thus, after having described the actions of the project manager, it is important to define the necessary information to be managed in each phase in order to propose software tools that will help project managers to manage such information. As PLM systems manage part of design information, it is necessary to evaluate their capacity to manage design coordination information.

2.2 PLM systems and design coordination

PLM systems are deployed within companies to support product data structuring and management throughout the product development process. They manage information through document life-cycle management and especially product data evolution using predefined workflows (Liu and Xu, 2001). Other functionalities are available in order to take into account specific needs or viewpoints from the whole company (e.g. classification, integrated views of the Bill of Material, etc.). Actual PLM systems integrate internet-based technologies and offer groupware-like functionalities (Johansen, 1988) for collaboration among actors. Several PLM systems have recently introduced project management functionalities (Saaksvuori and Immoen, 2004). Most of the time, these functionalities allow the formalisation of tasks and milestones schedule. Nevertheless, this project implementation reveals strong limitations (Pol et al., 2005) if correlated with design coordination, because project management functionalities do not use workflow capacities. On the one hand, the management of deadlines and the modifications of tasks sequences can be made dynamically.

On the other hand, it is not possible to 'reuse' predefined tasks sequences or to 'redo' specific ones as compared to workflow capabilities. Main limitation concerns the impossibility to drive documents life cycles from the tasks schedule. If it is possible to associate a deliverable, that is a document at its end of life-cycle, to a milestone, this only means that the end of the deliverable life-cycle must occur when the milestone is achieved, but no synchronisation is possible before the end of the life-cycle. Consequently, in the SME context we consider that it is not possible nowadays to integrate the macro-level project management and the micro-level document-oriented process management, each level being managed through different technologies implementation. Nevertheless, some PLM systems are able to manage workflow without associating them to documents: the proposed business approach will be based on this assertion.

One of the main difficulties for the project manager is to take into account the collaboration into his project schedule. In spite of various works on design collaboration, no generic rules and operational principles have been defined to help project managers in their daily work. As each company and each project is different, the assistance for the project manager must take into account the specificities of the local context of the project and the company. However, it is essential to clearly understand what collaboration is: the study and the characterisation of the types of collaboration used in companies is an important issue for project managers in anticipating design situations during projects and defining the best form of collaboration in accordance with the specific design context.

These considerations highlight the necessary flexibility of a design process in an SME. If the process is predefined at a global level as it is required by a PLM system, this is rather incompatible with actors from all departments working daily in a context of 'mutual fit'. The processes of cooperation are quite unstructured and the confrontation of the various project teams' points of view leads to informal and unofficial information exchanges (Baumberger et al., 2003). When establishing a schedule in a SME, it is an important issue to identify what must be really controlled and so predefined through a workflow, and what must be encouraged and not prescribed and detailed. The management of the product development processes requires greater flexibility in the activities (Weber et al., 2002). The coordination through PLM systems must be studied in order to integrate document workflows and to introduce flexibility into such workflows (Saikali, 2001) for global project coordination.

2.3 Presentation of the case study

The industrial case study has been achieved in an SME which, some years ago, developed a new means of manufacturing structures using honeycomb subassemblies. This innovation confers lightness and significant vibration absorption on products whilst maintaining similar rigidity to steel. The company has captured several markets with products manufactured using its technology and consequently the number of employees grew from 4 to 40 over ten years. Over this period, the organisational structure and internal processes have not been formally revised.

The objective of our study was to help the company to reorganise its product development process and to introduce the role of 'design project manager' in order to manage further growth. Our method of experimentation was based on a socio-technical approach (Boujut and Tiger, 2002). Our role was to participate in a company workgroup and thus introduce an external point of view. In this context, problems of organisation, project management and relationships with suppliers, customers and subcontractors come into play. We have first studied and analysed the company's design and industrialisation department. Then, we have formalised a new organisational structure; the processes of development of new products and the management of technical information and of product data.

After this first phase, we have focused our work on the study of collaboration and relationships between actors and on the design project coordination (Duffy et al., 1997). In Section 2, we introduce this approach and give some results of its implementation.

3 From collaboration analysis to design processes characterisation

3.1 Collaboration analyses: a method to improve design processes definition

In a previous work of the authors (Pol et al., 2007), a model and a software tool have been presented to track the collaboration between designers.

The model deals with the identification of the main relevant elements for the characterisation of the collaborative situations in design. Collaborative situations are defined from a coordination point of view, with scheduling, planning, and the definition of milestones and activities. Alternatively, they are also defined from a human relationships point of view with the persons involved in the collaborative event, their skills, their motivation and their form of communication. Both points of view are considered into an integrated model of collaboration which is built to represent collaborative situations and to record the elements describing each collaborative situation. This model is based on the concepts of events and granularity level:

1 an event corresponds to an identified collaborative situation

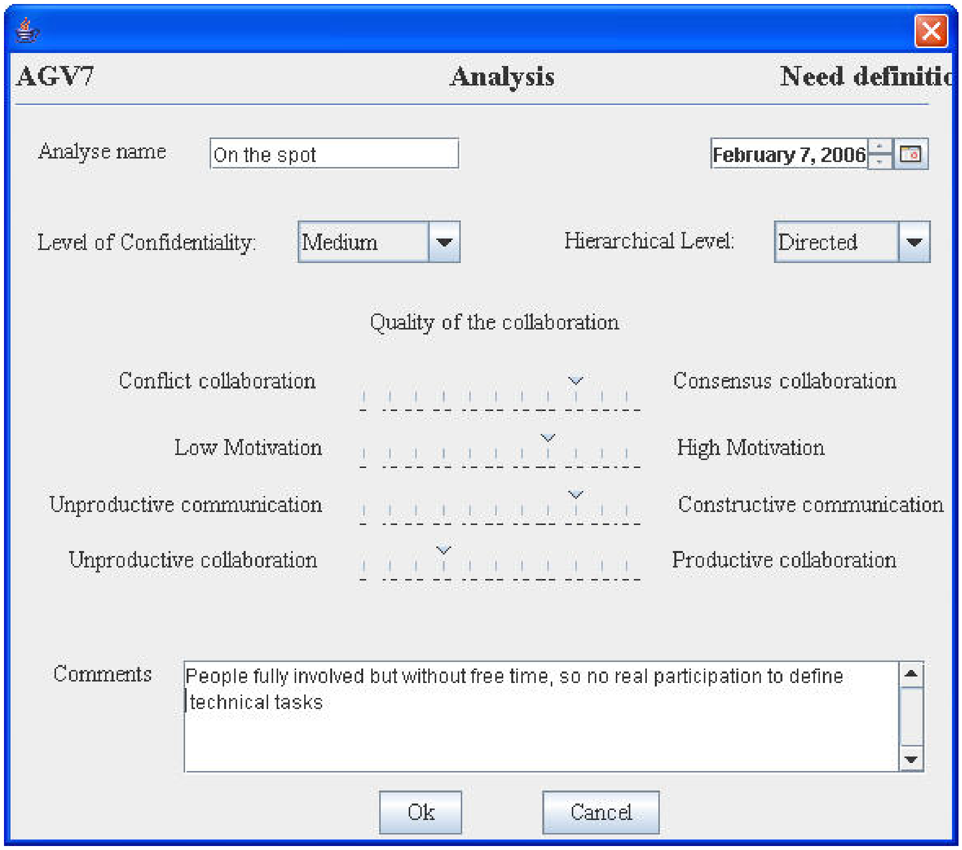
2 depending on its granularity level, an event can be considered as a real design activity or as an element of a more global design activity.

The 'event' class allows the capture of each collaborative event – whether formal or informal by storing the basic definition such as date, actor, expectations of the event, outcomes or taken decisions. The first level of description of an event is its activity type (such as report, scheduling, validation, milestone, codesign, …) and its achievement form (such as meeting, discussion, videoconference, conflict resolution, …).

As a consequence, tracking all the collaborative events during a project allows formalising the occurred design process according to the collaborative point of view. The comparison between the theoretical design process and this resulting process brings benefits to project managers and is a source of improvements for coordination.

To support the tracking of the events, their characterisation and the context of the project, we have implemented a software tool named Collaboration Capture (CoCa) in order to implement the proposed model and to help managers to analyse the collaborative situations occurring in projects for establishing possible improvements. Figure 3 illustrates the characterisation of some 'subjective' parameters dealing with the evaluation of the 'quality' of the collaboration. After having described the event itself with quantitative parameters and general information, this is the beginning of an analysis by an expert. It is followed by the comparison of parameters belonging to several events in order to analyse the reasons of good collaborative results or of existing problems.

Figure 3 Tracking of an event within CoCa tool: analysis frame (see online version for colours)



In the industrial case study, the CoCa tool was used to follow different projects. After six months, four different projects have been deeply analysed and more than one hundred collaborative events have been stored. The chosen examples come from the AGV7 project. The customer is Company A[1] (a global leader in power and rail infrastructure) who demands a quotation to manufacture structural elements of a railway transport engine.

As main result of the analysis of collaboration with CoCa tool, the formalisation of the real design process, the identification of best practices and the resolution of encountered problems lead to the formalisation of improved and very detailed processes (De Vreede and Briggs, 2005). Section 3.2 is introduced a method for integrating such results into a PLM implementation approach in order to help the project manager to control a design project.

3.2 *Introducing collaboration analysis into a PLM implementation approach*

In Pol et al. (2005), a generic PDM implementation method has been proposed in an SME context. Used models are described using UML formalisms. The different steps of this method were divided into two main phases: a modelling phase then an implementation phase (Eynard et al., 2004). The modelling phase generates the required specifications for choosing then implementing the PLM system:

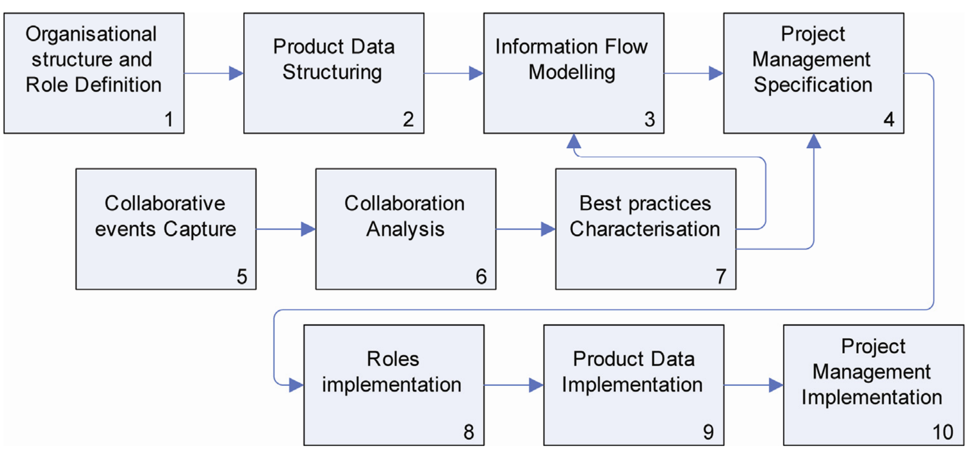
- *Step 1*: a deep analysis of the design process of the company is achieved, and the organisational structure and the different roles of the actors involved into a design project are characterised.
- *Step 2*: the product data are structured using class diagrams.
- *Step 3*: the information flows are modelled using sequence diagrams and state-transition diagrams.
- *Step 4*: the project management dimension is introduced to support design coordination by defining project theoretical schedule: phases, milestones, main tasks and deliverables.

The implementation phase corresponds to the different steps of implementation. Because steps dealing with the introduction of collaboration analysis results will be added, the following steps are numbered differently:

- *Step 8*: as in SMEs implementation is more a configuration work than a coding work, this first step is dedicated to the configuration of the users, roles and teams into the PLM system.
- *Step 9*: the database is modified in order to customise product data attributes and relationships. Then, the specified sequence and state-transition diagrams are implemented as life-cycles and workflows.
- *Step 10*: finally the project schedule is defined.

Considering this generic method, the detailed processes formalised during the analysis of the collaboration with CoCa tool are used to improve the information flows and the theoretical schedule from steps 3 and 4. The following method is proposed to integrate the analysis of collaborative situations into a PDM implementation method, as shown in Figure 4.

Figure 4 Method for improving PDM implementation through collaboration analysis (see online version for colours)



To take into account collaboration analysis, three further steps are now introduced:

- *Step 5*: tracking data about collaborative events and their evaluation with CoCa tool.
- *Step 6*: analysing captured data to identify problems or possible improvements, to establish links between events and to define best practices through good tasks' sequences.
- *Step 7*: integrating existing process formalisation with the identified task sequences.

Step 5 is managed by analysts that are involved in design projects in order to store each collaborative event. In step 6, they have to establish correlations between events in order to identify problems or best practices. One of the expected results is the identification of task sequences corresponding to:

1 the resolution of a problem linked to an inadequate process for a given design situation

2 to the formalisation of an adequate process for another given design situation.

As a consequence, 'good design practices' are formalised in step 7 for specific design situations. As the 'good design processes' are defined through a deep study of real events occurring during a project, their level of granularity is more accurate than generic processes defined after the interviews of experts and managers in step 1. By this way, the added-value of the analyst is then to integrate the adequate 'good design processes' into the generic ones as templates (Gzara Yesilbas, 2005). To do so, he may define nodes of flexibility where the future context of the project will allow the user choosing between several possible task sequences.

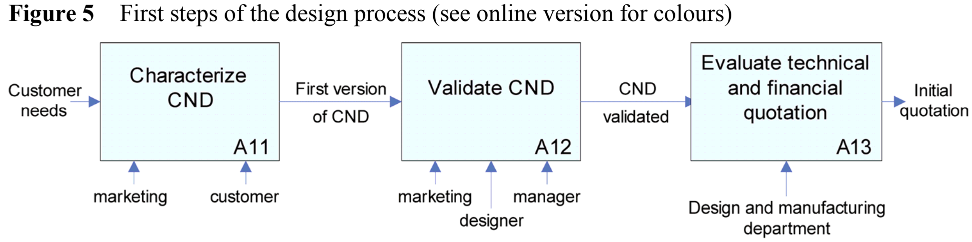
To conclude, this integrated method allows the establishment of links between the analyses of collaborative practices and the formalisation of more complex and flexible workflows. Section 3.3 will illustrate this method.

3.3 First experimentation

The following example is based on the tracked projects from our industrial partner. It illustrates the consequences of such analyses on the project management: the introduction of flexibility and detailed implementation of design processes. The example is based on the customer's need definition (CND) process which corresponds to the first step of a design project: the initial financial quotation phase of the design for the customer.

Initially, the CND document was managed by the marketing person who built the document in collaboration with the customer. Indeed, this step defines the specification of the product on the basis of the need expressed by the customer.

Figure 5 First steps of the design process (see online version for colours)



The first activities of this phase were (Figure 5):

- definition of the CND document by marketing person with the customer (task A11)
- validation of the document (task A12)
- notification that the document is complete (between A12 and A13) to the technical department and that a designer has to make the quotation (future tasks A13).

The analysis of this initial collaborative situation through several projects allows identifying that CND process description incorporates neither details on the way to achieve the tasks nor flexibility. Moreover, the marketing person does not always have the necessary technical skills for all customers, and furthermore he does not have enough time to carry out all the CND processes. So problems of customer data management appear between the marketing and technical departments.

With the analysis of the collaboration with the CoCa tool, the analyst can define guidelines and more detailed processes. In this way, the CND process is updated with an increased level of granularity based on the guidelines from the collaboration analysis.

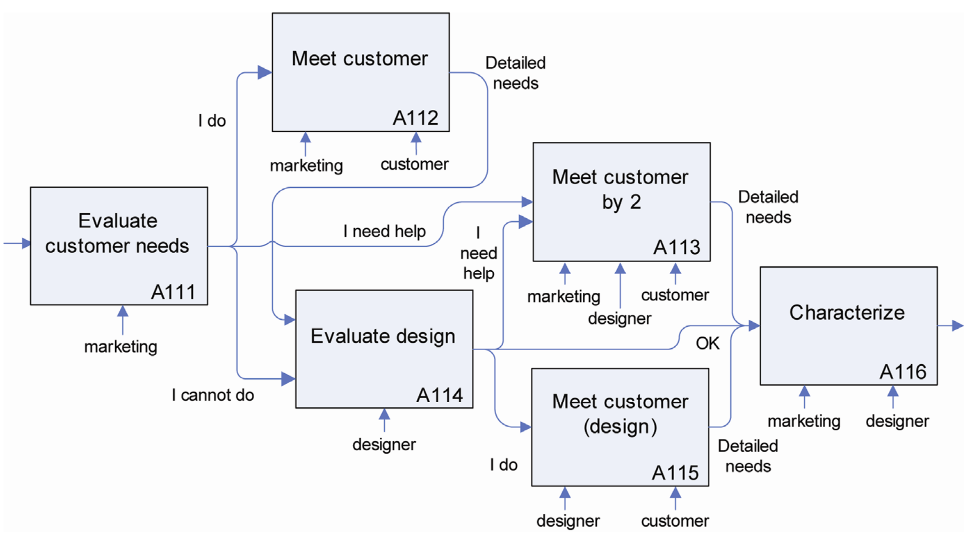
Consequently, a new process is proposed in Figure 6, it is detailed in previous task A11. The marketing person first evaluates the needs of the customer (task A111) then he can:

1 reject directly the customer request, if the customer needs are not appropriated for the company (not formalised)

2 make a visit to the customer: alone (task A112) before sending the detailed needs to the designer (task A114) or with a designer (task A113)

3 directly send the needs to the designer if they are enough detailed (task A114).

Figure 6 Detailed but flexible process for A11 task (see online version for colours)



Afterwards, when the designer evaluates design (A114), he can meet the customer alone (A115) or with the marketing person (A113), or directly characterise the CND document (A116). At each task, marketing person or designer has the possibility to end the process. As a conclusion, the project manager has the possibility to automate the design process by implementing a PLM system with this process. The first node of flexibility is the task A11 because the detailed sublevel may not be scheduled for a specific reason. Next, nodes of flexibility are associated to tasks A111 and A114 as choices exist for the owner of the task. Section 4 develops the implementation of such process into a PLM system.

4 A PLM business approach for the coordination of design processes

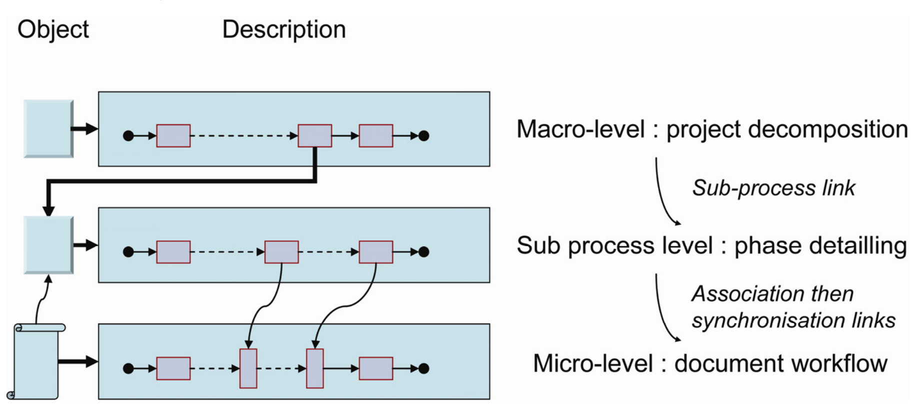
4.1 A generic model for multi-level workflow implementation

In the SME context, design process is generally formalised at a macro-level: the process is decomposed into several phases, and main tasks are defined in each phases. As a consequence of the results obtained with the collaboration analysis method, we are able to specify more accurately sublevels of the main process, for example some tasks of macro-level are decomposed into detailed tasks sequences by the identification of collaborative practices that are linked through flexible nodes.

Our first proposal is to characterise the project phases by using a generic workflow: each phase and each milestone of the project are respectively represented by a subprocess and a task. Then, each subprocess/phase is defined as a traditional workflow, without document association. Each task of the subprocess/phase must specify to the owner what the documents to be created or modified are. A second level of subprocesses is not possible to control document workflow because document workflows are not 'contained' inside a single task of the subprocess/phase, but can be achieved after several tasks of a subprocess/phase, and sometimes after several phases.

Finally, at micro-level, very basic processes that manage document life-cycles are identified. In this case, we need a certain level of correlation between the subprocess/phase workflow and the document workflow in order to synchronise the progress of both processes with the project schedule. This link allows getting information from the document (states, owner, …) during the progress of the subprocess workflow.

Figure 7 Multi-level workflow model for design process management (see online version for colours)



Such document processes are not always necessary: in most SMEs as they reduce the flexibility and they are not implemented. If this is the case, a minimal workflow is still necessary in order to establish the required link. The implementation of such links depends on the functionalities of each PLM system.

Figure 7 illustrates main concepts of the proposed model for the implementation of the proposed workflows from the macro-level to the micro-level. Vertical boxes at micro-level show the possibility of getting document state from the subprocess level.

4.2 Second experimentation

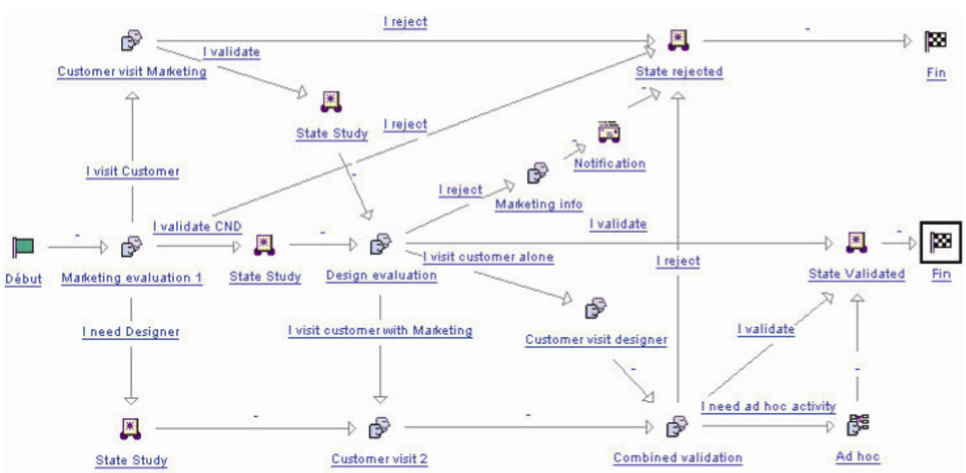
This experimentation is based on Windchill™ (PTC) PLM system. Actually macro-level and subprocess level have been implemented. These two levels can be implemented with traditional workflow configuration.

As an example, Figure 8 illustrates the workflow defined for managing the CND phase as explained in Section 3.3:

- 'State' tasks define the state modification of the CND document according to its associated life cycle.
- All possible ends of the process are also defined as well as the required notifications.
- '*Ad hoc*' tasks correspond to the possibility given to a user to create dynamically new required tasks. This allows introducing more flexibility in the design process for situations that may not be planned.

The different collaborative situations presented in Figure 6 are implemented: in the first task 'marketing evaluation', the marketing person will have the possibility to choose between a meeting alone with the customer, giving the document to the designer for evaluation or a meeting with the customer and the designer. Then, other choices are defined during the two customers meetings, the 'design evaluation' task or the 'combined validation task'.

Figure 8 Customer's need definition phase workflow (see online version for colours)



Moreover, the characterisation of each task allows the project manager to indicate the criteria to be evaluated before making the right choice. By this way, design coordination is automated according to the project manager requirements and the flexibility of the design process is preserved.

The last micro-level is still under development as it requires specific configuration. For example with Windchill™, the possible mechanisms of synchronisation tasks require some Java development.

Such experiment demonstrates that it is possible to implement multi-level-workflows in order to coordinate design management. Nevertheless, the technical aspects of its implementation depend strongly on the openness of the used PLM system and their possibilities of customisation: can document-independent workflow be managed within this PLM system? then can independent workflows be synchronised through their tasks? When validated, these requirements imply that the coordination of design projects is possible using this business approach. Nevertheless, some considerations still remain. The main one concerns the acceptability of such multi-level management into SMEs: our industrial partner has an intermediate size that requires more formalisation while maintaining high level of flexibility. As the implementation of the whole model is not achieved, we still do not know whether the flexibility of the proposed workflows corresponds to this situation of the company with adjustments or not, and *a fortiori* to the situation of other SMEs.

5 Conclusions

In the worldwide competition among companies, the development of new products has become a challenge where innovation and coordination of design process are two main keys for success. In SMEs, design activity is not completely structured and controlled due to the high level of flexibility of processes. At the same time, PLM systems help to rationalise basic design processes. They are the main information systems managing the product life cycle in companies.

In this paper, we have focused on the proposal of a business approach for design coordination implemented through a PLM system. First, we have proposed an adapted method for implementing PLM systems in order to take into account both more detailed process definition and flexibility by using the analysis of collaborative practices. Second, this business approach has been based on the use of workflow technologies. Their implementation has been achieved by elaborating the structure and the schedule of the project phases, then the tasks through different and synchronised levels of granularity. First, results are enough significant to justify the interest of this business approach and future work for implementing all the functionalities of the proposed multi-level workflow model and its experiment in an SME.

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Note

[1]The name of the companies is hidden for confidentiality reasons.