Knowledge-Based Framework for Workflow Modelling: Application to the Furniture Industry*

Juan Carlos Vidal, Manuel Lama, Alberto Bugarín, and Manuel Mucientes

Department of Electronics and Computer Science
University of Santiago de Compostela
E15782 Santiago de Compostela, Spain
{juan.vidal,manuel.lama,alberto.bugarin.diz,manuel.mucientes}@usc.es

Abstract. In this paper, we describe a framework for integrating workflow modelling techniques with a knowledge management approach that enables us to represent the problem-solving knowledge, the coordination of the method execution, and the agents that are involved in the workflow. The case of price estimation workflow in the manufactured furniture industry is described within this framework, that was implemented in a knowledge-based system that is based on a service-oriented architecture that automated the correct execution of the methods needed to solve the estimation task.

1 Introduction

Business process management (BPM) technology [1] allows the explicit representation of the business process logic in a process-oriented view, and is increasingly used as a solution to integrate engineering/manufacturing processes. However, current BPM modelling approaches do not *explicitly* incorporate the problem-solving knowledge in the workflow definition: this knowledge is implicitly used both in its control and organizational structure, but as it is not explicitly represented, it cannot be shared or reused. For dealing with this drawback, a new framework that models workflows at the knowledge-level has been defined [2]: this framework incorporates both the control structure and the participants of a workflow as *two new knowledge components*. The structure of these new components is based on two ontologies: the High-Level Petri Nets ontology [3] and an ontology for process representation and organization modeling.

This new workflow knowledge-based modelling framework has been applied to the price estimation of products manufacturing in custom-furniture industry. This process is strategic since it helps to keep competitive prices, increment productivity, and reduce costs. In the case of many custom-furniture industries this need

* This work was supported by the Spanish Ministry of Science and Innovation under grants TIN2008-00040 and TSI2007-65677C02-02. M. Mucientes is supported by the Ramón y Cajal program of the Spanish Ministry of Science and Innovation.

N. García-Pedrajas et al. (Eds.): IEA/AIE 2010, Part I, LNAI 6096, pp. 175–184, 2010.

is even higher due to the large number of processes that are made following non-standardized manual procedures. A solution in this case can only be approached by means of an automation of the price estimation process that involves great volume of information to characterize the furniture, the knowledge management provided by the company experts related to the manufacturing process, and the coordination between many resources (human and software) that execute activities with different perspectives of the process and in different times.

In this paper, we present a workflow that describes how the price estimation task has been solved in the domain of custom-furniture industry. For it, we have used a framework [2] that integrates workflow-modelling techniques with a knowledge management approach. This new framework enables us to represent *(i)* the problem-solving knowledge through a set of methods that have been selected from the CommonKADS library [4], and *(ii)* the coordination of the method execution, and *(iii)* the agents that participate in the workflow. This workflow has been implemented in a knowledge-based system called SEEPIM that is based on a service-oriented architecture that automated the correct execution of the methods needed to solve the main task.

The paper is structured as follows: in section 2 a brief description of the framework for representing workflows is presented, in section 3 the workflow that models the price estimation task is described, in section 4 the main benefits achieved with the applciation of the new workflow framework are discussed in detail. Section 5 presents the most relevant conclusions of the paper.

2 Knowledge-Based Workflow Framework

The workflow for price estimation of custom-designed furniture presented in this paper has been developed within the knowledge-based system SEEPIM, which aims to model workflows as reusable knowledge components. SEEPIM implements a conceptual framework [2] which facilitates the modelling of workflows as problem-solving methods (PSMs) [5]. Three types of knowledge components are usually referred in the bibliography of PSMs:

– *Tasks* describe a problem to solve but not its solution. They describe the required input/output parameters, the pre- and postconditions, and the task objectives. This description does not include information about how it may be solved.
– *Methods* detail the reasoning process to achieve a task, that is, the way to solve a problem. Methods are described by functional properties and can be split into *non-composite* and *composite* methods depending on whether the method can be *decomposed* into subtasks or not.
– *Domain models* describe the knowledge of a domain of discourse, that is, the facts, rules and axioms that are applied to the domain.

These knowledge components are described independently at the knowledge level. Therefore, the same component might be reused in multiple problems, and this reuse is achieved through *adapters* which define a binary relation between

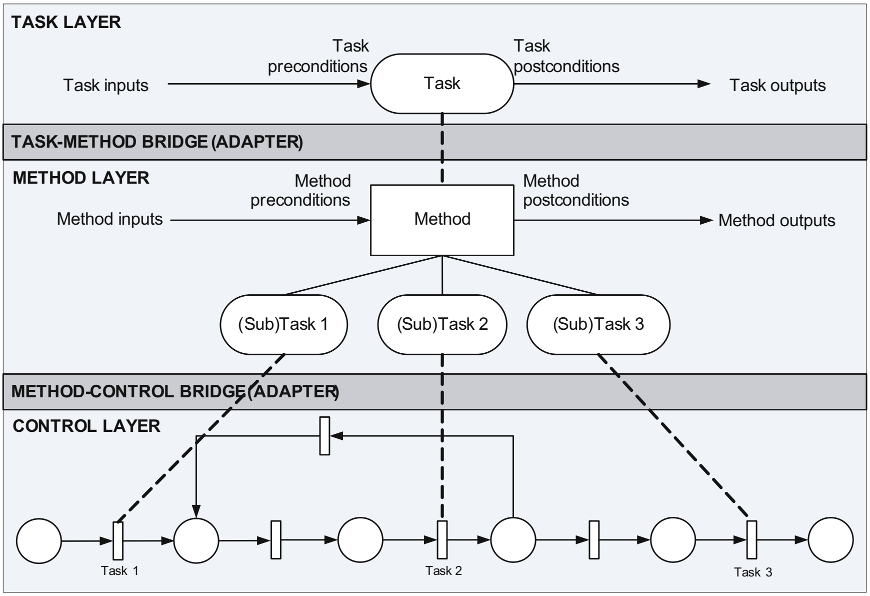

Fig. 1. Task decomposition diagram

two knowledge components. However, it is not possible to model workflows with only these three components, because workflows have two additional features that should be enhanced in the modelling framework: the *process structure* and the *participants*. Therefore two new components are added to the framework:

– *Control component*. Workflow processes are designed with control-flow structures that cannot be modelled with traditional languages of PSMs. Workflows need a language able to deal with parallelization, choice, split, merge or synchronization patterns at least. From the approaches proposed to describe these patterns we selected High-Level Petri Nets (HLPN) [3] because *(i)* they are based on a mathematical formalism and therefore have no ambiguity, *(ii)* they have a graphical representation which facilitates their use and understandability, and *(iii)* they have proven to be one of the most powerful approach to represent the worklfow control [1]. The *control component* is represented through a hierarchical HLPN ontology, and it models the operational description of a composite method; that is, it describes how the execution of non-composite methods is coordinated to solve the task solved by the composite method.
– *Resource component*. Participants play an important role in the workflow specification. Workflow activities are represented in the framework by means of the non-composite methods and will be performed by a (either human or software) agent in the organization. The resource model classifies the organization resources and relates the participants to the activities they may perform.

Within this framework, a workflow consists of a task (problem) to be solved, the method that solves this task, the control of that method, the resources that are involved in its execution, and the domains of discourse of the workflow. For example, Figure 1 depicts the first step of a task decomposition diagram in which a task is solved by a composite method that is split into three (sub)tasks (1, 2 and 3). In this figure, the *task-method adapter* indicates which method will solve the task, and the *method-control adapter* selects the control-flow of this method. The other steps of the diagram indicate how the (sub)tasks of the method are solved in turn by other methods and how these last have associated a control structure.

3 Price Estimation in Custom-Designed Furniture Industry

As an application of the framework described in the previous section we go on to describe here the most relevant aspects of workflow that models the price estimation task in the furniture industry. Other details of context, implementation and validation can be found in [6,7]. The estimation task is a good example for showing the capabilities of the framework since, as it is shown in what follows, it involves a high number of subtasks where heterogeneous sources of different types of knowledge are involved.

Figure 2 shows the first level of decomposition of the solution proposed for the price estimation task. Firstly, using a conceptual model, the method that solves the estimation gets the product description to be manufactured. Based on this description the processing times are estimated using a set of fuzzy rules (TSK type) that had been previously learned with an evolutionary algorithm. This information will be used for planning the workload of the company. Then a *repeat-while* loop is executed. In this loop different technical designs of the product are proposed until the most suitable is found. In each loop iteration the result of the design is evaluated, taking into account the client needs, the technical features of the product, the manufacturing processes necessary to perform them, and the business productivity criteria. For example, at this stage it is decided whether we need to simplify parts of the furniture or look for semi-finished components that can be bought directly without having to manufacture them. The method followed to solve the product design task is called *propose and revise* [4], and is typically used to model constraint satisfaction problems.

3.1 Estimate Processing Times

The resolution of the task for the estimation of processing times is not trivial and depends on the conceptual design and the type of planning to be carried out. Sometimes, it is not possible to obtain a detailed design of the product to be manufactured and therefore to infer the exact operations to be performed is not possible. This situation occurs in the first meetings with the clients for product definition or when they do not have a precise idea of the product they need.

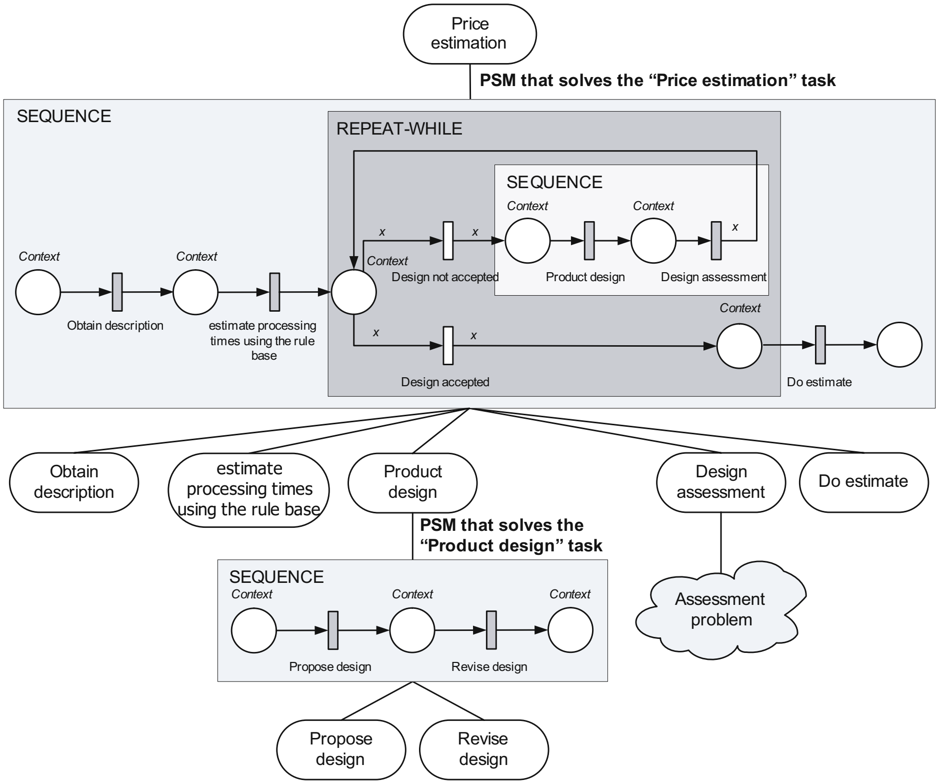

Fig. 2. *Price estimation* task decomposition

However, sometimes the conceptual design can be converted into CAD designs and the operations required to manufacture the product can be extracted in a precise way. In order to address both situations the implementation of the method that solves this task has been performed using a set of TSK fuzzy rules that were obtained using an evolutionary algorithm, which is described in [6].

3.2 Product Design

Figure 3 shows the method that solves the task (*propose design*), in which the technical designs and the final cost of the product are obtained. This task is within the structure *repeat-while* of main workflow and it will be executed while the criteria for completion are not verified.

The first step to solve this task is to create the product design in a CAD format with the aim of *(i)* obtaining the dimensions and materials of the product components, and *(ii)* determining which manufacturing processes will be applied to each of these pieces. To make this design the designers will use standard components and materials, and develop a modular design trying to reduce the cost of piece manufacturing while guaranteeing the robustness of the design.

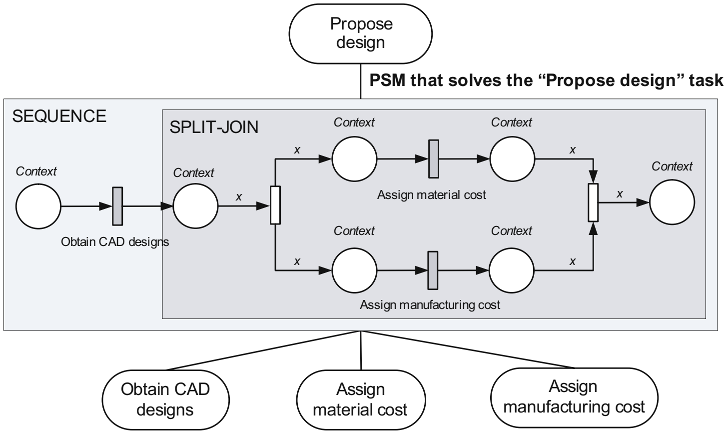

Fig. 3. *Propose design* task decomposition

For example, the product cost depends on the type of joint used to assemble the furniture: some unions require the assembly of the furniture previous to finishing, thus increasing the cost of manufacturing, packing and shipping.

The second step consists of determining the final cost of the product as the sum of the materials cost and the pieces manufacturing cost. These two tasks are performed in parallel and in the following sections we describe how they are solved.

3.3 Assign Material Cost

The task *assign material cost* is responsible for assigning prices to the materials used in the estimation taking into account *(i)* the price and quality of each of the materials used in product design, and *(ii)* the reliability of the suppliers to guarantee that those materials are delivered at the agreed times. The proposed solution to solve this task is shown in Figure 4 and it adapts the general class of CommonKADS library methods known as *propose and revise* to the characteristics of both the domain and the task to be solved. Thus:

– The task *propose material cost* is responsible for selecting the most appropriate price for each material of the product. This cost depends on the direct cost of the material, the cost of the additives (varnish, glues, etc.), and the cost of the wasted material, and it is based on a set of rules/criteria extracted from the company experts in purchases.
– The task *revise material cost* is responsible for verifying the correctness of the proposed price for each material and for modifying the price when necessary. This revision is based on information provided by suppliers about their sales prices, and it checks among other things that the offered price is updated and remains in force at the time of manufacture.

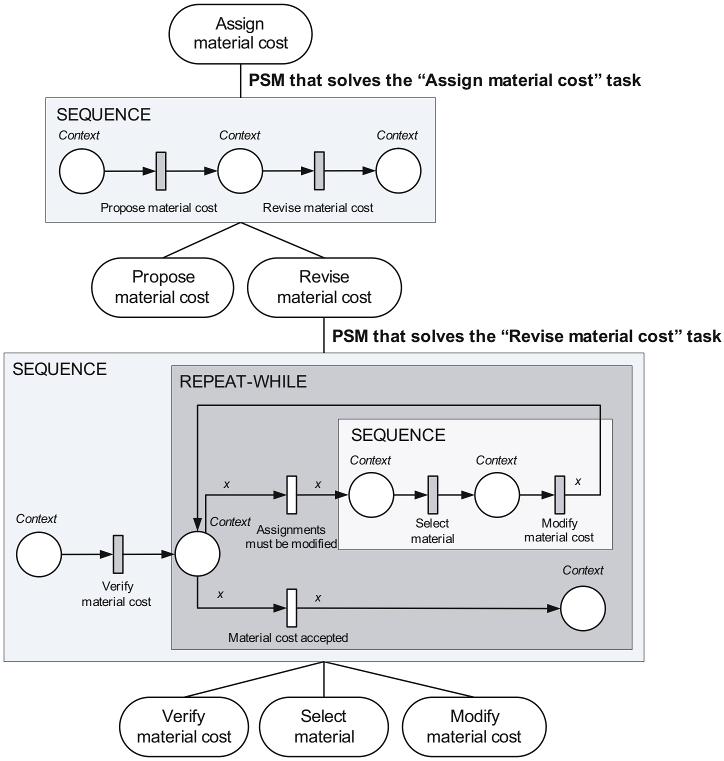

Fig. 4. *Assign material cost* task decomposition

3.4 Assign Manufacturing Cost

The method that solves this task belongs to the general class of methods known as *propose and review*, which is applied to the generation of workplans. Thus, the method that solves the task *propose workplan* executes a *repeat-while* loop until the workplan has been accepted. The loop body consists of a sequence of three tasks. The first task, *Set resource agenda*, is responsible for setting the work schedule of the manufacturing plant. This task takes the work schedule established for each resource and allows to apply changes to allocate/deallocate the resource, assign overtime or include a new manufacturing turn.

The second task, *Set workplan*, is responsible for generating a plan to allocate a work to the resources involved in the product development. This task is necessary to decide whether the plant could support the new workload with the deadline required by the customer, whether a part of the manufacturing is subcontracted, etc. The method that solves this task consists of a sequence of tasks:

- In the first task orders to manufacture are selected. The resource planning is a computationally expensive task and, therefore, the greater the number of orders that are planned, the greater the calculations to be performed and

possibly the worse the results because the search space is of combinatorial size.
- In the second task orders are ranked according to their selected delivery date, its priority, and the client. These criteria rank the orders to perform and will influence the planning. For example, if the product is key to the company, it may be included with a higher priority.
- The third task obtains the workplan, assigning the work to the resources according to a predefined timetable. The resolution of this kind of problem is computationally complex and requires the use of a *scheduling* method whose implementation has been made following an evolutionary approach, which is described in [7].
- In the fourth task the manufacturing director selects the better plan from the set of solutions proposed by the system.

Finally, the task *Revise workplan* analyses the workplan to look for problems: division of labour, overloads, logistic problems, availability of raw materials, etc. From this analysis, manufacturing directors assess whether planning is accepted as is or a new planning is requested.

4 Framework Evaluation

The developed KBS contributed with important improvements in the price-estimation task of the furniture company where the system was introduced. Table 1 contains the average error of time estimations for some machine centers at the start of the project. Some of these estimations have an error greater than 40% which is totally unacceptable in any industry. It must be emphasized that this was not the average error of price estimates: a company with such error ratio would not survive in a market as competitive as furniture industry. The error in price estimates was less than 10% as over and under estimations compensate each other. As result of the automation process we obtained a reduction of the mean error to less than 5% for each machine of the production plant. However, a purely numerical analysis does not reveal the actual extent of the improvement. In this sense, the procedure to achieve the solution and the framework that has been established are as important as the workflow model described here because they led the organization to:

- Restructuring the business process (task, method and control models of the framework).
- Restructuring the organization itself (resource model of the framework).
- A detailed analysis of the business model and of the expert knowledge necessary to perform the product design task (knowledge model of the framework).
- The standarization of materials and the use of methodologies like *Design for Manufacturing and Assembly* for standarizing the processes of the production plant (also in the knowledge model of the framework).

Table 1. Mean error per machine center of the processing time

Machine center	Mean error (%)
Wood preparation	-5,0
Horizontal sawing machines	-8,0
Vertical sawing machines	-22,0
Planer	+11,4
Edge banding machines	-14,5
Sanding machines	-5,5
Edge sanding machines	-33,5
Boring machines	-18,2
Tenoning machines	-40,2
CNC Machine	+7,6
Finger jointing	-26,9
Hand finishing	-15,8
Presses and equipment for gluing	+10,6
Robots for handling, feeding and palleting	+31,0
Packaging equipment for panels	-16,0
Pre-assembly lines for furniture parts	-22,5
...	...

This first phase of the WF modeling already contributed with many benefits. The main one was a major improvement in the processing time estimations: 70% of the error reduction occurred during this phase and the 30% remaining has also a strong dependence on this phase since the variables that influence the processing time of each machine were also identified in this phase. In any case, the automation of this task provided many benefits, some of them intangible from the perspective of the time estimation but of great importance from the organizational point of view:

– *Increased work efficiency.* The work is assigned considering both the agent as the product to design. The work allocation takes into account the role and security permissions of the agent as well as his skills and knowledge to perform the task. In addition, dynamic criteria such as workload and agent work history are also taken into account.
– *Reduction of effort and greater specialization.* The work allocation policy streamlined the effort of agents. In the original procedure tasks were assigned only taking the availability of agents into account. This approach was often not the most appropriate since not all the agents have the most suitable knowledge for a work and consequently the results *(i)* may be of low quality or *(ii)* may take too long.
– *Better use of experts.* The furniture price estimation is a very complex task that usually require the continued involvement of the experts which, due to this effort, neglect their work on the production plant. The acquisition of manufacturing knowledge resulted in a better use of these experts who currently work only in monitoring tasks.

- *Improved scheduling* [7]. In most industries the workload of the factory also affects the calculation of price estimates. It is therefore important to have a tool that facilitates the inclusion of the client orders to estimate in the production schedule and calculate its impact.
- *Continued improvement of processing times* [6]. The processing time estimation was one of the main problems of the original system.In part because each of the experts estimated the time based on their experience but also because the manufacturing of custom made furniture has particular characteristics that make accurate estimations particularly difficult to obtain. To reduce the error of these estimations, the calculation of the processing times was automated by means of a machine learning system.

5 Conclusions

The framework here described allows us to integrate work-flow modelling techniques with a knowledge management approach, enabling us to represent the problem-solving knowledge using methods form the CommonKADS library, the coordination of the methods execution and the agents involved in the workflow. The relevant case of price estimation workflow in the furniture manufacturing industry is described within the framework. Validation of a system implementing this workflow in a real environment show a major improvement in this particular task and also at the organisational level.

References

1. van der Aalst, W.M.P., van Hee, K.: Workflow Management: Models, Methods, and Systems. MIT Press, Cambridge (2004)
2. Vidal, J.C., Lama, M., Bugarín, A.: A Framework for Unifying Problem-Solving Knowledge and Workflow Modelling. In: AAAI 2008 Spring Symposium: AI Meets Business Rules and Process Management, San Francisco, EEUU, pp. 105–110. AAAI Press, Menlo Park (2008)
3. Vidal, J.C., Lama, M., Bugarín, A.: A High-level Petri Net Ontology Compatible with PNML. Petri Net Newsletter 71, 11–23 (2006)
4. Schreiber, G., Akkermans, H., Anjewierden, A., de Hoog, R., Shadbolt, N., de Velde, W.V., Wierlinga, B.: Knowledge Engineering and Management: The CommonKADS Methodology. MIT Press, Cambridge (1999)
5. Benjamins, V.R.: On a Role of Problem Solving Methods in Knowledge Acquisition. In: A Future for Knowledge Acquisition, 8th European Knowledge Acquisition Workshop, EKAW'94, London, UK, pp. 137–157. Springer, Heidelberg (1994)
6. Mucientes, M., Vidal, J.C., Bugarín, A., Lama, M.: Processing Times Estimation by Variable Structure TSK Rules Learned through genetic programming. Soft Computing 13(5), 497–509 (2009)
7. Vidal, J.C., Mucientes, M., Bugarín, A., Lama, M., Balay, R.S.: Hybrid Approach for Machine Scheduling Optimization in Custom Furniture Industry. In: 8th International Conference on Hybrid Intelligent Systems, Barcelona, Spain, pp. 849–854. IEEE Computer Society Press, Los Alamitos (2008)