A knowledge-based workflow to dynamically manage human interaction in extended enterprise

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The research work is also well described. We regret not to have an independent section explaining why the presented development matches interactive engineering topic (the main theme of IJIDeM journal). We invite authors to do it, maybe by redefining the concept of Interaction (often used in the text).
The bibliography is exhaustive, but we can also regret not to have any references coming from IJIDeM's comunity:
- A Tutor Agent for supporting distributed knowledge modelling in interactive product design, Ricardo Mejia-Gutierrez, Xavier Fischer, Fouad Bennis, International Journal of Intelligent Systems Technologies and Applications (IJISTA), Vol4(3), p. 399-420,
- Collaboration based on product lifecycles interoperability for extended enterprise, Farouk Belkadi, Nadège Troussier, Benoit Eynard and Eric Bonjour, IJIDeM journal, Vol 4(3),
- Research in Interactive Design (Springer)
However, the paper is really good and can be rapidly published after light modifications.

Answer:
Three main topics of IJIDeM fit with the proposed research issues:
- the description of industrial problems to identify significant knowledge and variables;
- advanced modelling of design and manufacturing problems;
- interactive computer-based platforms to support collaborative product development.

The first one is well addressed in the paper as it focuses on the development of a knowledge-based platform to support knowledge sharing, process and product content management, role-playing, etc. that deeply characterize the new context of extended enterprise. Moreover, the definition of the platform functionalities just starts from the analysis of the real industrial context of three design and supply chains involved in the CO-ENV project.
The second topic is deepened in section 3.1 where process-modelling techniques have been studied in order to select the best one to represent the complex interactions in collaborative product development.
The dynamic workflow management system really combines the results of investigation of the two topics. It represents a reliable solution to explicit and to formalize the process knowledge distributed across the extended enterprise. It also introduces same self-learning functionalities in terms of events storing, retrieving and proper solution extraction.

The third topic is central in order to contextualize the whole research approach.
At the beginning of chapter 2, where the research context is introduced, a brief discussion of how the concept of interaction is meant is presented. It provides both the requirements for the development of the knowledge-based platform and the criteria for the assessment of the achieved research results. Moreover, it allows understanding how the proposed research matches interactive engineering topics.

"Collaborative product development (CPD) implies three different forms of interaction:
- human-human interaction among team work participants consisting of individuals, teams or even entire organizations. They act in a distributed, heterogeneous and dynamic environment to achieve a common goal. As a consequence, a renewal of the expected shared competences and new governance modalities for the relationships occurred over the supply-chain become imperative [BT1].
- human-computer interaction that refers to the interaction between team members and the computer-based interactive systems used to support collaborative work, to manage knowledge sharing about the design process and the design content, to control all process activities and role playing, etc. Human-Computer Interaction is particularly meaningful in the design activities involving multidisciplinary teamwork. It influences users behaviours, representational and communication modalities [M1].
- interaction between the individual and the collective dimensions. In the context of collaborative design, single components can be individually developed, but some activities require cooperation (e.g. the design of product interface, the assessment of the coherence between each specific solution and the whole design intent, feasibility analysis, etc.). Collective activities are carried

Fig. 1 Flowchart representation of the three CO-ENV chains product development process.

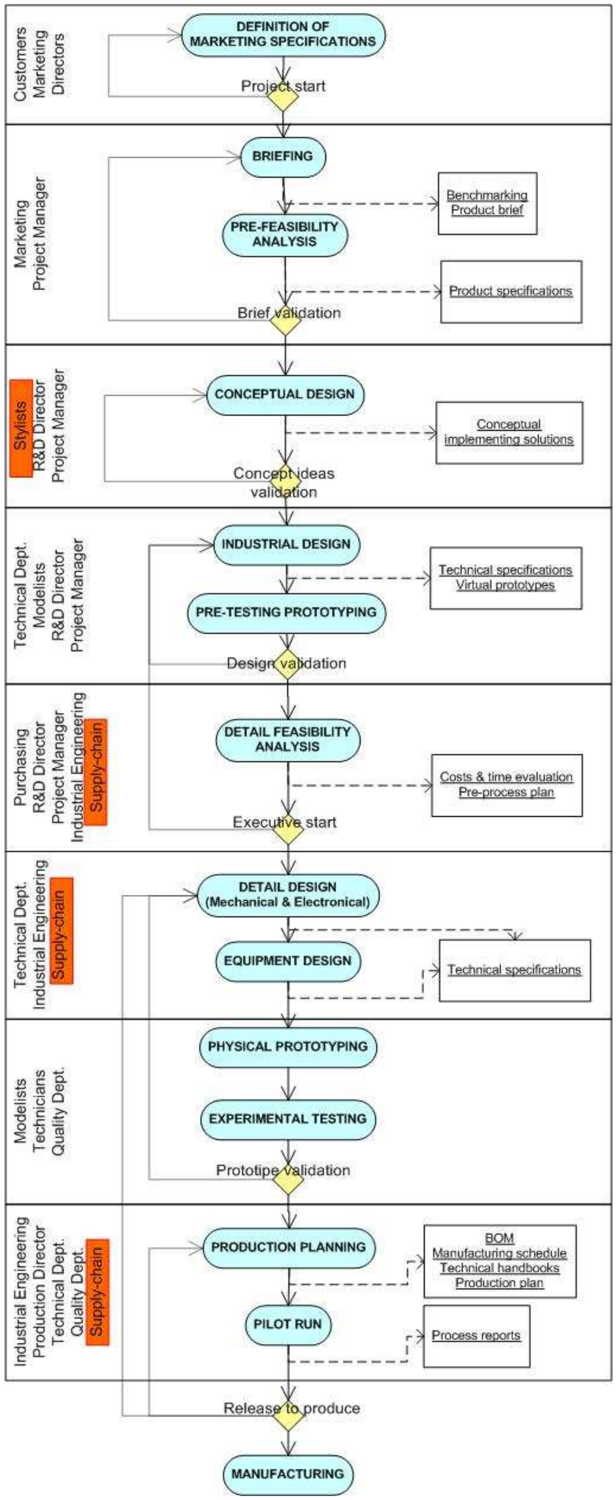

Fig. 2 The dynamic workflow system architecture.

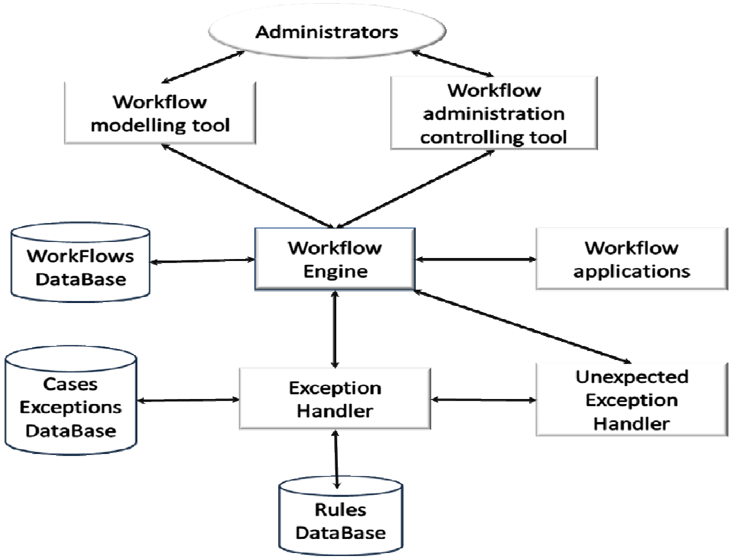

Fig. 3 The unexpected exception handler.

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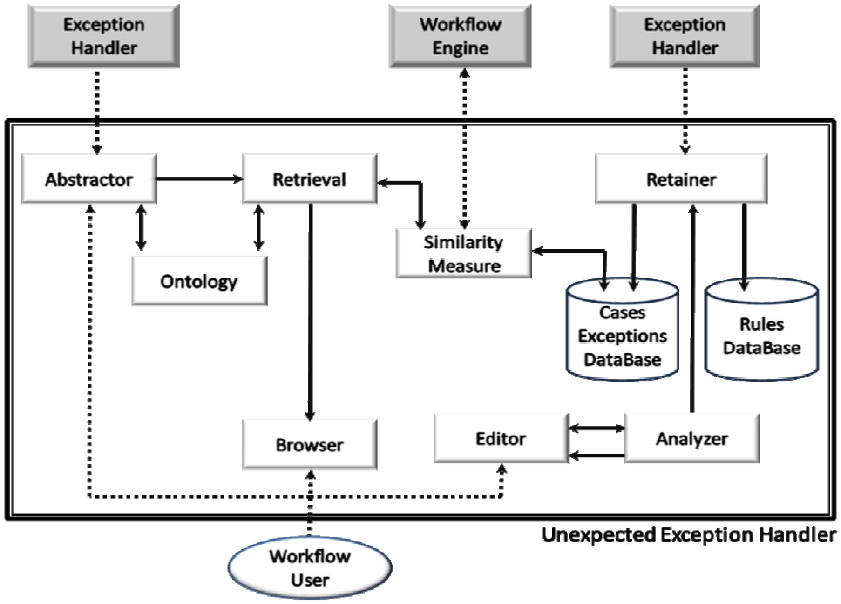

Fig. 4 Differences between the proposed dynamic and traditional static WfMS on managing unpredictable events. UML Activity Diagrams are used to model the sub-process involved in the change.

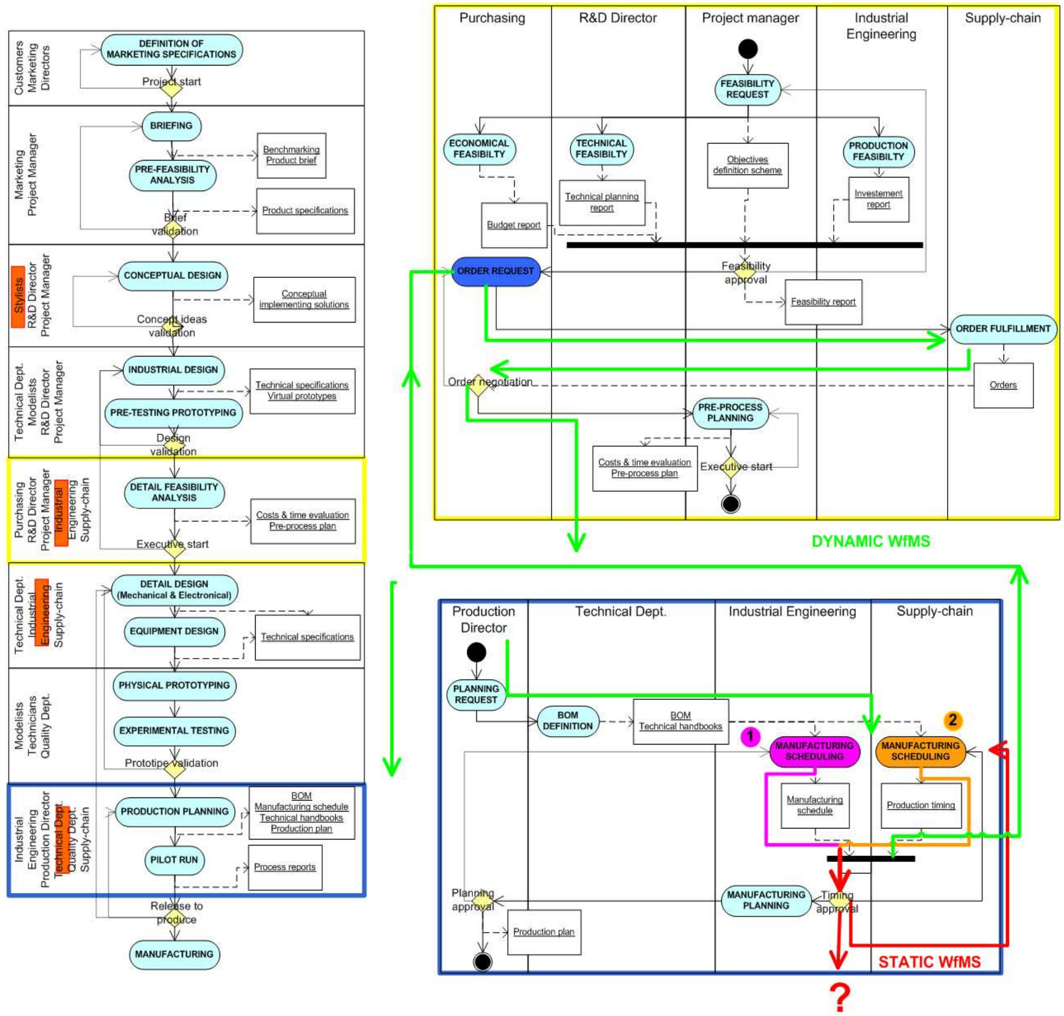

Table 1 Expected exceptions database structure and related generic attributes.

Source	Internal
	External
Type of exception	Technical/technological
	Economical
	Temporal
	Customer-Oriented
	Marketing
Level of importance	High
	Medium
	Low

A knowledge-based workflow to dynamically manage human interaction in extended enterprise

Abstract: Extended enterprises require novel modes of organizing companies and managing collaboration. Although the promise of Information Communication Technologies to connect people, processes and information, it is worth to notice that current implementations are strongly document-oriented and do not enable flexible workflow management overcoming well-known inter-enterprise integration difficulties. The long-term goal of the research is the study of a new methodology and the development of dedicated software tools to facilitate the dynamic collaboration among 21 companies participating to a research project, funded by the Italian Economic Ministry, called CO-ENV. The definition of dynamic workflow system architecture represents the step forwards the implementation of a collaborative platform. Preliminary benchmarking of available systems and techniques, the product development process analysis of the project participant companies and a possible structure of the system are well illustrated. Examples of expected and unexpected exceptions are reported and differences between static and dynamic workflow management systems are discussed.

Key words: Dynamic Workflow, Design Process, Product Innovation, Product LifeCycle Management, Extended Enterprise

1 Introduction

In the last decades, manufacturing industry has experienced important upsets and changeovers as a consequence of the rapid evolution of the global market. Companies are forced to face dynamic contexts that require cut-down lead times, high product quality and lower costs in all product development phases. This framework characterizes the “hypercompetitive” market [D1]. Moreover, the traditional paradigm of product standardization is out-of-date: consumers are becoming more selective, looking for customized products conceived according to their individual needs. As a consequence, companies are seeking ways to introduce research and innovation in terms of technologies, strategies and processes, in order to provide high level of market adaptability and additional functionalities and performances to products. Furthermore multidisciplinary teams are involved in the product design: they consist of internal technical staff and members of the design and supply-chain, often geographically distributed. The management of the whole organization and of all individual training and expertises is not a trivial task.

In order to manage complexity, companies aim at optimizing the processes of the entire “extended enterprise” for rapidly developing new products, processes and services by adopting collaborative environments where all actors can share product and process data, integrate software applications, be supported by flexible tools for business processes management.

Agility concepts represent the key enabler for supporting the dynamic nature of teamwork collaboration. Agility can be considered as a new way of thinking company’s processes, including design and manufacturing. Its implementation allows companies to give a rapid and flexible response to uncertain and unpredictable changes [PG1]. Agility requires collaboration, integration of customers in the development chain, knowledge reuse and rapid configuration of product and processes [ML1]. It represents a novel approach for business organizations in effectively and easily managing the entire product lifecycle.

Agility concepts are mainly based on two key enablers: strategies and exchange Information Technologies (IT). IT technologies are not able to realize the necessary integration in the design cycle, implementing agile strategies is fundamental to supports cross-enterprise interaction. Innovative strategies implementation, such as Concurrent Engineering (CE), Virtual Enterprise (VE), distributed teams, supply-chain integration and lean manufacturing, is then necessary to manage product development and manufacturing processes.

Exchange information technologies guarantee an efficient data interchange and facilitate the product-process-business information flow. Knowledge-based management systems provide structured databases to collect and retrieve information and company best practices. Product Data and Product Lifecycle Management systems (PDM/PLM), Engineering Data Management systems (EDM) and electronic Bill Of Processes systems (eBOP) are well-known examples. Advanced digital technologies aim at improving the whole product development cycle by creating a collaborative environment where data can be visualized, manipulated and modified according to the different viewpoints involved in the process. Computer Aided Design-Engineering-Manufacturing systems (CAD/CAE/CAM) and Virtual Reality technologies (VR) are the most used tools for supporting design processes but they are poorly integrated with the first ones.

Nowadays the PLM systems spread representing the standard technology to create a dynamic extended enterprise for their promising ability to connect people, process and information.

However it is worth to notice that current PLM implementations are strongly document-oriented, have a structured and not much customizable data model and suffer from inter-enterprise integration difficulties [AG1]. Rigid procedures and strong centralization entail two main consequences: first, heavy configuration changes should be made at the server level when enterprises evolve; secondly great difficulties could arise when enterprises wish to collaborate with suppliers and customers. Moreover, PLM tools are generally based on static Workflow Management Systems (WfMSs) that force companies to organize themselves according to predefined structures instead of their needs and practice. Their implementation in industrial contexts implies much effort to represent specific company's requirements and processes, to structure adequate knowledge-based databases and to integrate all existing digital technologies. This is particularly evident in small and medium enterprises (SMEs) for their own limited asset, even if also big industries are affected by similar problems. The difference in the adopted IT technologies for supporting all business processes makes the collaboration between small and large enterprises difficult to achieve.

The starting point is that IT should deal with industrial processes and implement innovation in a new way. Effective product innovation should be pushed through the innovation of the entire product lifecycle management and the improvement of every process inside. Competitiveness and dynamicity demand data integration and effective collaborative environments in order to support interactions among partners, data exchange, unpredicted events detection and solution. Companies can cope with the competitive market and create really innovative products by immediately evaluating the impact of unpredictable events on implemented processes and rapidly reconfiguring them minimising consequences propagation.

The CO-ENV project, funded by the Economic Development Italian Ministry (2007-2009), moves from these general considerations and represents the context of the present research activities. It involves 21 Italian companies arranged into three industrial chains. The objective of research is the creation of a web-based platform to manage interactions in the extended enterprise thanks to the creation of a collaborative environment to visualize and share information. Exchange data will be managed by a dynamic workflow management system (WfMS) that supports the agile product development within the whole design and supply chain. The product development processes of the leaders' enterprise provide the practical test-cases for the research and application of the developed systems.

The research program is focused on:

- the study and definition of theoretical models to organize and concretize the dynamic collaboration that will overcome the identified critical phases. AS-IS processes will be transformed into TO-BE processes and they will be implemented in the developed system;
- the design and development of the web-based platform architecture that integrates dedicated software tools in order to support collaboration, knowledge sharing, co-designing, technical and marketing product configuring and, finally, workflow managing;
- the practical experimentation of the prototypal systems for the validation of the process models and the developed technologies in a real multi-enterprises context.

In this context, the present paper represents a step toward the development of the dynamic workflow system as it discusses preliminary results of the project research activities. It focuses on the analysis of current product development processes of the three involved chains in order to identify the most critical phases in terms of time to market, communication problems, interaction, information exchange, etc. In order to overcome communication problems in intra and inter chains, a new WfMS architecture is proposed to dynamically manage design workflows once unpredictable events occur. The last section discusses the different behaviour of static and dynamic workflows and their performances are compared.

2 The research activity context: the CO-ENV project

In order to be competitive in the global market and to rapidly answer to changing needs and events, companies should be never again conceived as a scene for individuals' interaction but as a system of collective knowledge. Nowadays the design of innovative products demands for collaboration among multiple business competencies, integration of different technological domains, efficient data interchange and dynamic reconfiguration of the product design process. Available digital technologies play an important role in the formalization and management of the industrial know-how, but they are too structured, not-easily open toward customers and suppliers and not flexible enough.

In the context of Collaborative Product Development, three forms of interaction should be taken into account to meet cooperation requirements:

- human-human interaction among team work participants consisting of individuals, teams or even entire organizations. They act in a distributed, heterogeneous and dynamic environment to achieve a common goal. As a consequence, a renewal of the expected shared competences and new governance modalities for the relationships occurred over the supply-chain become imperative [BT1].
- human-computer interaction that refers to the interaction between team members and the computer-based interactive systems used to support collaborative work, to manage knowledge sharing about the design process and the design content, to control all process activities and role playing, etc. Human-Computer Interaction is particularly meaningful in the design activities involving multidisciplinary teamwork. It influences users behaviours, representational and communication modalities [HF1].
- interaction between the individual and the collective dimensions. In the context of collaborative design, single components can be individually developed, but some activities require cooperation (e.g. the design of product interface, the assessment of the coherence between each specific solution and the whole design intent, feasibility analysis, etc.). Collective activities are carried out to share the different aspects of a problem, individually faced, and search for an integral solution that go beyond the limited vision of the involved individuals [BH1].

In this context the CO-ENV project aims to introduce innovation and improve process quality in conceptual and engineering design and in marketing and manufacturing as well, by creating a multi-enterprises aggregation architecture.

The CO-ENV project involves 21 Italian companies, 5 large and 16 small to medium enterprises. All firms are arranged into three different industrial chains whose leader companies are: Biesse, Indesit Company and Teuco Guzzini. They respectively design and produce woodworking machines, household appliances and wellness products. Their structure is quite similar: the leader company concepts, realizes and commercializes the final products, while its partners provide professional advice and supplying services and components.

The three years research activity (2007-2009) is based on the development and experimentation of innovative IT technologies in order to implement concepts such as cooperation, agility and modularity. Starting from the investigation of available technologies, the activity goes forward assessing AS-IS product development processes, identifying critical phases, proposing innovative solutions and setting up a proper platform in order to effectively support companies' interaction.

The definition of a collaborative web-based platform is the main result of the research. Innovation processes are managed by a knowledge-based workflow system implemented in the platform.

The platform will represent the common layer through which companies' specific systems can communicate and share data in order to create a cross-sectional design process that overcomes the single industry's context.

The research program aims at achieving the following goals:

- supporting the collaborative design of innovative product by using dedicated systems for data management, data sharing and data exchanging along every single industrial chain;
- providing real-time interaction among project partners by the developed web-based platform, that will be integrated by software applications for specific design activities and for the sharing of software tools in a remote way;
- managing both inter-chain and intra-chain processes: from the conceptual phase to the technical feasibility, to preliminary and detailed design, still manufacturing activities and to suppliers – customers – dealers interaction, by developing a proper WfMS;
- sharing design, product and process data across the whole design-chain and supply-chain by integrating the developed systems with implemented PLM tools;

- improving the interaction among the different actors of the design-chain, characterized by different insight, tacit knowledge and competencies, and creating a real collaboration among all of them by the project web-portal. The sharing of know-how, expertises, technical laboratories and special equipments, the creation of e-learning environments, the remote use of advanced software systems are the main functionalities of the CO-ENV web-portal that will contain the collaborative platform. It also will contribute to realize multi-enterprises synergies in out-sourcing and in marketing logistic;
- gaining upon marketing and technical areas by developing CAD-based tools to rapid configure product variants to quickly address customer requirement changes. The automatic configuration will be allowed only if modularity concepts will be implemented into the design practice;
- automatic developing and designing of modular products on the specific customers needs by introducing mass customization principles [TJ1]. This new philosophy will help companies to regain those market slices won by emerging and low-cost countries;
- forecasting of the product price by knowledge-based tools that retrieve data from technical documents such as preliminary design models, drawings or CAD models;
- organizing and managing e-learning environments for agility strategies implementation for all CO-ENV partners.

This paper represents the first step forward the project objectives' achievement. It contains effective guidelines for structuring a dynamic WfMS architecture that will be integrated in the web-based platform to support cooperation and interaction among the project industrial partners.

3 The design process management: potentialities and issues of available tools and methods

In order to manage the dynamic changes and the complex aspects of the product development processes of the CO-ENV partners, a proper knowledge-based WfMS should be adopted. The system has to efficiently manage business processes and their real-time reconfiguration once an unpredictable event occurs.

In order to achieve this objective, two main elements are required: a modelling tool able to formalize enterprise's knowledge and behaviour inside a workflow model, and an interactive event handling system for dynamically reconfiguring the process when unforeseen events occur in product's lifecycle. The potentialities and issues of available tools and methods are discussed in the following sections.

3.1 Why to model enterprise processes

A process is defined as a structured, measured sets of activities designed to produce a specified output for a particular customer or market [D2]. In particular, a business process defines the way in which enterprise's goals are achieved [S1]. The product's success is the reflection of the level of "maturity" of a business enterprise. Indeed, the enterprise's maturity directly relies on its ability in capturing and sharing process knowledge and in transferring them from individuals or groups into process standard models. Process analysis and modelling play an important role in making companies competitive: they allow the definition of those activities necessary to achieve the process tasks and the identification of process fails causes [MF1]. This overview explains the increasing popularity of business process management tools and the numerous methodologies and tools developed to support it.

Several techniques for business process modelling have been developed. They can be divided into two categories: static and dynamic. The first enables industrial processes modelling with the flow of information (i.e. UML, Petri-Nets, flowcharting, IDEF0, etc.) while the second enables the evaluation of the processes changes before happening (i.e. Event-Process Chain) [PH1]. Dynamic techniques support the identification and redesign of critical business processes by simulating the expected performance and using a big amount of enterprise's historical data. They are useful tools for performance evaluation but not for their comprehension and representation.

In this research context, the word "dynamic" is not related to the process modelling technique but to the system itself, able to dynamically reconfigure the process workflow. The benchmark of available techniques is based on two essential requirements: 1) the ease to identify the functions, activities, tasks and decision makers, 2) the ease to implement all these aspects into a process modelling software. The adopted process modelling perspective is both *management* and *technical oriented* because it is necessary to provide a quick and intuitive overview of the business process and contemporary to focus on the proper IT set-up for supporting business process management [D3].

The benchmarking results in the UML technique: it allows the quick and deep representation of all business processes and their easy implementation into software tools. It is supported by nine different diagrams highlighting different aspects of the modelled processes: sequence diagrams, collaboration diagrams, state chart diagrams and activity diagrams are the most relevant in the workflow management because they address the system dynamic behaviour. In addition, use case diagrams are very useful in the early stage of workflow modelling in order to identify stakeholders and clarify the exceptions handled by the systems.

3.2 Why to use a Workflow Management System

A workflow is defined as the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules [WF1].

Currently, workflow technology is considered as essential to integrate distributed and heterogeneous applications and information systems to improve business processes effectiveness and productivity [GH1] [SC1] [JB1] [CH1].

On the other side, the level of the integration between document management systems in general and other core transactional systems (e.g. finance or ERP) is still very low. Only few companies are well integrated and only a restricted number extends their workflows to all chain partners. As market competitiveness grows, organizations must clearly define their business goals and increase their reliance on Internet technologies and e-business solutions in goals achieving [VK1].

E-business applications may be classified into *inter-business* and *intra-business*. The firsts are used for the communication among company departments, its industrial partners and customers as well the seconds are applied to collect and share information and computing resources among company's employers.

The main purpose of inter-business application, such as *Business to Business* (B2B), is to manage inter-organizational relationships, build stronger partnerships for realizing an effective collaboration and share knowledge for achieving mutual benefit [AG2]. The most important B2B process is the supply chain integration that provides visibility and access to selected partners or suppliers.

E-business applications aim at improving and transforming enterprise's key processes through the use of Internet technologies. They are supported by workflow system and methods providing some advantages: the transparency, the possibility to make all process participants conscious of all developing activities, the ease of process control and, finally, the capacity of merging customers, information and tasks into an unified environment.

WfMSs are used to support the modelling, analysis and enactment of structured business processes. Current systems are unfortunately too rigid and unable to provide adequate answers to exceptions or deviations that differ from the modelled process. These issues have inhibited the wider implementation of WfMSs [AE1]. Exceptions are referred either to situations not modelled by the WfMS or to deviations between what has been planned and what actually happens. It has been demonstrated that such deviations are really common in almost all processes: their handling appears relevant for improving inter and intra business processes.

Unpredictable exceptions can drastically change process definition and decrease the chances of delivering the desired business result. Industrial contingencies usually determine large wastes of time, need of additional resources and involvement of the workflow managers in order to manually modify the predefined processes.

However studies have shown that the majority of exceptions can be anticipated. So they are not exceptions in the real sense but they represent a sort of deviation from the normal process [SO1]. The recognition, classification and modelling of deviations improve the workflow flexibility.

Exceptions can be classified into [SM1]:

- *Expected*, if they can be anticipated by process analysts or inferred from experience and company's historical data. Specific workflows can be drawn in advanced for handling them;
- U*nexpected,* if they are completely unknown as they are determined by infrequent and non-repetitive events.

In order to realize an exceptions aware system, it is necessary to clarify the nature of exceptions and provide guidelines for their solution during the system development. The exception knowledge space is characterized by known, detectable, and resolvable exceptions. If the exception has not been included in the knowledge system, it can be considered as an unpredicted exception; otherwise, it can be considered expected and the system is able to determine if the exception is detectable. When a known and detectable exception occurs, the system derives one of the predefined solutions and the deviation can be solved. Any position in such exception knowledge space can be represented as an exception point. The exception knowledge of an exception aware system is the set of all those points [LS1].

Actually, the accepted practice is that if an exception can be conceivably anticipated, it should be included in the process model [AH1]. However, this approach can lead to very complex models. Furthermore, much of them will never be executed in most cases and add orders-of-magnitude complexities to workflow logic: mixing business logic with exception handling routines complicates the verification and modification of both [HA1]. In addition it makes the models unintelligible to stakeholders.

As available WfMSs do not implement handlers able to manage any type of unpredictable events, in the last years several researches have been oriented to the management of dynamic workflows. Luo et al. [LS1] introduce a defensible workflow as a framework to support exception handling for workflow management. The authors apply *JECA rules* (Justification-Event-Condition-Action rules) to capture more contexts in workflow modelling: the resulting workflow is based on a situation dependent reasoning to enhance the system capability. Furthermore, a *Case-Based Reasoning* (CBR) mechanism with integrated human involvement is used for improving the exception handling ability. The general approach is based on collecting cases to capture company's experiences, retrieving similar prior exception handling cases and reusing the captured experience in new situations.

Hwanga et al. propose a similar approach where the architecture model deals with both expected and unexpected exceptions [HT1]. Expected exceptions and handling approaches are specified by *ECA rules* (Event-Condition-Action rules) while unexpected exceptions are characterized by their features. The resolute workflow path will depend on the event's features that identify it in a useful way. The unexpected exceptions handling is then assisted by the system providing information about how similar cases have been already solved. Actually, analyzing precedent cases provides useful information in order to handle new ones.

Adams et al. approach is based on the definition of flexible work practices, the so-called Activity Theory [AH2]. A set of principles have been derived from a sound theoretical base and applied to the development of *worklets*, an extensible repertoire of self-contained sub-processes that can be applied in a variety of situations depending on the context of the particular work instance.

Mourão et al. propose a novel architectural framework to handle effective unexpected exceptions where unstructured human interventions are necessary to overcome such situations even when a WfMS is used [MA1]. The problem regards with overcoming thee clash with different types of control exercised by WfMS. The proposed framework uses the notion of map guidance to arrange the human interventions. Map guidance empowers users with contextual information about the WfMS and environment, enables the interruption of model control on the affected instances, supports collaborative exception handling and facilitates regaining model control after the exception has been resolved.

The study of available e-business and workflow systems managing complex and unexpected situations, allow the identification of which proposed approach can be useful for the CO-ENV context characterized by intra and inter business processes and design and supply-chains integration. The complexity and the heterogeneity of the three chains business processes forces the research toward the exploration of a knowledge-based workflows. The use of Case Base reasoning mechanisms for managing useful and unexpected exceptions and the development of ECA rules resulting from the formalization of company practice constitute the basis of the proposed approach to develop the collaborative web-based dynamic workflow management system.

4 How to dynamically manage the product development process

4.1 The proposed approach: product innovation through related dynamic processes management

The success of a product development cycle requires well-planned processes, proper tools and methods for supporting the negotiation phases and managing human resources. In such context engineers, designers and market researchers work together to achieve a compromise between all design aspects creating a product that meets customers' needs. As a result, product innovation process is not a trivial task and the product development process is often rearranged according to all involved partners features. The main goal is the achievement of product innovation maintaining a healthy company internal structure that balances innovation and continuity. The main research issues are the management of the big amount of stakeholders and the necessity to dynamically organize them in order to follow culture and trends shifts.

The use of dynamic WfMSs actually represents the answer to the above-mentioned enterprise's needs only if integrated into a collaborative environment. In order to reconfigure process workflows, once unpredictable changes occur, two activities are necessary:

- business processes modelling applying a proper technique able to identify the main criticalities;
- structuring expected and unexpected events and proper rules databases according to the way usually adopted by the company in overcoming unpredictable changes.

4.1.1 Internal and external interactions in industrial chains

Interactions of different disciplines and viewpoints are key elements in the product development process. Team members (e.g. designers and engineers), should work in a context of positive collaboration that enable them to share individual knowledge for achieving the final task. Furthermore each member generally adopts specific IT to develop product design. The level of technology expertise depends mainly on the involved enterprises dimensions. Achieving efficient marketing, design and engineering interactions during the whole product lifecycle is not a trivial task. The first step deals with the analysis of interactions. The research starts with the investigation of the model of interaction proposed by Hutchins, Hollan and Norman [HH1] focusing the attention on industrial design activities. Four basic cognitive operations (i.e. exploration, generation, comparison, selection) can be identified: they allow correlating cognitive tasks with physical data and vice versa. Each industrial design activity is performed following a cyclic process made of the four basic operations and switching from an individual dimension to a team dimension. An ideal interaction model can be set and an appropriate IT platform architecture identified in order to properly support the transition across different cognitive operations and from individual to collaborative dimensions. In such context an AI approach is useful for speeding up information processing, but it has to be supported by knowledge-based algorithms and structured databases. Indeed the mere AI adoption can cause inefficient solutions when processes have not been analyzed and implemented into the system in a correct way.

As a consequence, before designing the co-design platform and implement the dynamic WfMSs databases, team interactions analysis is fundamental.

In the proposed approach industrial interactions are as *internal* if they involve the company's staff and *external* if they involve also the design and supply chains. Firms generally outsource some activities and make long-term relationships with a stable set of partners to perform critical tasks such as component design, manufacture, assembly and distribution.

A typical product development process is represented in Fig. 1. It synthesizes the main phases of the typical design cycle of the three industrial chains involved in the CO-ENV project. An accurate analysis of the product lifecycle of the three leader companies has been carried out and similarities have been recognized in order to identify a common process. Flowchart representation has been adopted and the main actors of the process and the most relevant interactions with the supply chain identified.

Observations highlight that the main causes of process failure and time delays depend on the difficulty to exchange and share data along the whole product development cycle.

In order to deeply analyze the industrial interaction processes and recognize the main critical aspects, the 21 CO-ENV project partners have been asked to fill ad-hoc questionnaires and have been interviewed in order to collect useful data.
The main problems lie in the difficulty to identify implicit issues in the communication between the leader companies and their chains and to make partners aware of the limits of adopted traditional technologies for managing interaction.
A simple questionnaire has been prepared in order to analyse internal and external interactions. Different questions are submitted to large and small and medium enterprises as the level of computerization is very different and communication mechanisms differ according to the role-played in the chains. Interviews interface is different depending on the structure of the company organization: in SMEs the business manager is also the technical and often the commercial manager. He/she usually highlights cross-respect problems instead of large enterprise where the questionnaire is submitted to different figures. The questionnaire consists of twenty questions, grouped in four sections: 1) the first aims at studying the collaboration with the leader company or otherwise, with the supplier by identifying the product development phases where collaboration is imperative and which actor is involved in the interaction, 2) the second focuses on the analysis of input and output information (e.g. CAD models, technical specifications, documents, etc.), 3) the third deepens adopted information and communication technologies by identifying which tools are used, the level of achievement of communication tasks, the involved companies departments, the quality of interaction, and finally 4) the fourth part asks questions related to possible improvements that partners aims at achieving by adopting a new communication technology.

Fig. 1: Flowchart representation of the three CO-ENV chains product development process.

Process indicators have been defined to carry out performance measurement (e.g. exchange data file formats, file dimensions, preferred means of communication, number of interactions to achieve tasks goal, frequency of similar information transmission with the different means, etc.). Roles and functions of involved partners were recognized and represented in the flowchart below. Main results highlight that:

- the leader company and the supply chain have different levels of IT expertise. The majority of the suppliers are Small and Medium Enterprises (SMEs), whose capacity to use advanced Information Communication Technologies (ICT) is quite limited. They generally adopt phone, fax and physical meetings to exchange data with the leader company. Only few of them have a standalone website and use emails as a preferred mode for exchanging CAD files, digital documents and commercial orders;
- standalone websites are mainly used for marketing purposes and only occasionally for information exchange purposes;
- suppliers are generally not familiar with ICT and not aware of the potential benefits of enhancing websites and data sharing tools;
- suppliers are quite satisfied of the level of their involvement in the leader company's process but they ask for additional supporting tools to allow documents retrieval, updating and approval.

All data retrieved by questionnaires and interviews analysis are used to define the collaborative platform requirements and the main functionalities. In this preliminary phase, the above-mentioned considerations allow the definition of the approach to structure the dynamic workflow system architecture and to identify the proper test case to experiment the latest research results.

4.1.2 A knowledge-based dynamic WfMS

In order to set up a dynamic WfMS able to handle both expected and unexpected events system architecture is proposed.

Expected exceptions are considered as events that can be predicted during process modelling or traced back to the execution of precedents workflow instances. In this research context, two databases are adopted for managing expected exceptions: a *JECA rules Database* and a *Cases Exceptions Database*, formalizing knowledge related to all specific business processes.

Handling unexpected events represents an important research issue: available workflow systems are generally unable to manage them, because such events have never happened before. The problem can be overcome by a careful study of the typical solutions adopted by the company in previous cases when similar events happened. If previous cases and related solutions are classified, they can be retrieved once the system recognizes similar features. Subsequently it will perform the correct actions for restoring the normal business flow and achieving preset objectives according to the retrieved solution. In order to achieve the best solution to the specific unexpected event the system will be able to automatically arrange previous cases and propose to the workflow manager the most similar solution to the current event. If the proposed solution is not accepted, he/she will manually define an alternative path to solve the occurred exception.

Recent studies [HT1] [LS1] about the implementation of dynamic WfMSs represent the starting point of the system architecture. The main novelty the proposed approach consists in developing an exception handler based on knowledge and practice enhanced by the companies participating to the CO-ENV project. The adopted rules directly derive from the formalization of the tacit enterprises' knowledge. They reflect the commonest problem-solving strategies used by companies' managers once an unpredictable event occurs in their everyday work. The developed system architecture (See Fig. 2) consists of two main components, dedicated respectively to system administration and exceptions handling. The Workflow Engine manages each component.

Fig. 2: The dynamic workflow system architecture.

Main system components are:

- *The Workflow Controlling tool*, that copes with activities such as starting new workflows instances, ending other ones or managing the execution of initiated workflows;
- *The Workflow Modelling tool*, that copes with the modelling of new workflow templates;
- *The Workflow Applications*, to perform workflows instances among multiple users;
- *The Workflow Engine* that retrieves workflow templates directly from a *Workflow Database* and structures them into intra-chain and inter-chain workflows. If the workflow is settled as intra-chain, it will be characterized by the internal or external activities flow of the leader company relating to the corresponding industrial chain. External activities deal with specific process phases such as design feasibility, technical design reviews and physical prototyping. On the contrary, inter-chain workflows involve various partners

belonging to different chains which aim to transversally develop product, services or research projects;

- *The Exception Handler*, that manages unpredictable events by interfacing with two databases, the *Cases Exceptions Database* and the *JECA Rules Database*. The Exception Handler performs two types of activities: it checks if the specific exception is included in the Cases Exceptions Database and retrieves the corresponding rule from the JECA rules Database. The workflow is then modified according to the identified rule and the exception is processed. If no one rule can be found inside the database, the exception is classified as unexpected and need to be solved by the *Unexpected Exception Handler*.
  In order to recognize and classify the exceptions, a set of attributes have been defined to identify the exception. Attributes are both generic (e.g. type of exception, resource of the interested activity, etc.) and distinctive of the specific workflow (e.g. product development phases - design, feasibility, manufacturing, negotiation -, inter or intra chains processes). All attributes allow the creation of appropriate events indexing used in rules definition and recognition. For every exception contained in the Cases Exceptions Database, the attributes allow the retrieval of the relative JECA rule. The attribute classification will be discussed in detail in the next section.
  In the JECA acronym, the “J” character (Justification) represents the action that produces the exception, “E” (Event) indicates the type of the exception and “C” (Condition) is the whole of circumstances, tied up to the attributes, that must be verified to perform the “A” (Action). For a determined event “E” and justification “J”, the values of its attributes allow the system to associate the current exception to a previous one or a predicted one and recover it in the *Cases Exceptions Database*. Adopting the corresponding rule solves the exception.
- *The Unexpected Exception Handler* aims at searching for similar case studies to overcome the lack of expected exception in the *Cases Exceptions Database*. The system identifies if the unexpected exception is launched by an external application, interfaced with the workflow engine, or by an actor involved in the workflow (e.g. someone has not performed the task). The system characterizes the exception by defining all its attributes thanks to a predefined ontology (some attributes are assigned by the involved actors and others by

the *Workflow Engine*). The CBR mechanism is used for searching (*Browser*) similar previous cases collected into a *Cases Exceptions Database* (*Retrieval*). The handler measures the similarity between the current event attributes and all retrieved cases. Previous cases are then selected according to the similarity value.

In order to arrange the retrieved similar exceptions from the *Cases Exceptions Database*, proper algorithms are set. They allow structuring a precise attributes' hierarchy by following a tree scheme (e.g. the attribute "date" can be ordered in three levels: year, month and day). Each level could be associated to a numeric value (e.g. year = 2 level, month = 1 level, day = 0 level). Exceptions are ranked on the basis of their particular attributes by considering near cases in the hierarchical staircase. For example, ordering the retrieved exceptions according to their date, it is possible to start from those cases which present same day, month and year (coincident date) as well as those cases with the same month and year (level 1) or finally those cases with only the same year (level 2). Then, the Workflow Engine processes every similar case.

The choice among all similar cases is driven by the impact of the retrieved case solution has on the current workflow. Time to market delay, technical performances of the replaced partners, costs increase, number of additional iterations necessary to restore a regular flow are some of the proposed metrics. The exception handler will be provided with specific algorithms able to automatically assess the metrics for each retrieved case. Otherwise, the assessment of the exceptions' impact can be also evaluated by the company workflow administrator, which can modify the solution (*Editor*) and enter it into the system. The solution proposed by the unexpected exception handler can be restored and adjusted by human attendance. The system also analyzes the solution in order to avoid possible errors during execution (*Analyser*). Then the corresponding exception is automatically included in the *Case Exceptions Database* and the relative solving rule is stored in the *JECA Rule Database* (*Retainer*). The main functionalities of the *Unexpected Exception Handler* are represented in Fig. 3.

Fig. 3: The unexpected exception handler.

The proposed system architecture guarantees a continuous improvement of both databases and increases the knowledge of the whole system by learning from the real practice. The coherence between the experienced practice and the running workflows does not force the company to work according to predefined solutions, assuring complete workflows flexibility.

4.2 The classification of exceptions for design processes reconfiguration

The first step in the implementation of the proposed architecture is the definition of a possible classification of expected and unexpected exceptions in order to structure the corresponding database. The database structure and the adopted attributes reflect the ways of classifying events by all involved companies. The database represents the research core element: if the structure reflects and synthesizes implemented business processes, it can be validated by all project partners and the proposed system can run over more than one firm's application. Exceptions classification starts from the direct analysis of the CO-ENV industrial partners processes. In particular, interviews and questionnaires are used to highlight the main difficulties in managing the product development process. The performed analysis allows pointing out some interesting aspects related to exception handler:

- occurring unexpected events are mainly related to times delays, costs variation and product's requirements changes taking place after the conceptual design stage and sometimes after detail design;
- unexpected lack of human resources (due to dismissal, resignation, changes in executive jobs, etc.) usually determines a time shift that spreads over the entire design cycle. As a consequence, project managers modify the normal workflow and plan again the activities, assigning new roles and tasks;
- occurring errors during the pre-feasibility analysis can spread over the whole design process and the final product design could not meet all initial requirements. As a consequence validation phase fails and time to market stretches;
- technological advances in product design generally require the introduction of continuous changes in design practice and novel manufacturing processes. As a consequence, the management of external interactions and suppliers'

involvement needs to be rearranged. This is true also when the technological advances in ICT systems regard a single department: all other offices are influenced and the adopted technologies must be updated or upgraded if necessary. The whole organization and working conditions change.

It is worth to notice that all types of exceptions are strictly interconnected: a change in product requirements could lead to changes in costs or lead times. Furthermore changes importance is strictly influenced by the product lifecycle's phase during which the event occurs. From the enterprise's standpoint, a change in time during the feasibility analysis is less dangerous than a change during the production phase.

The consequence of an unpredictable event can influence the whole business efficiency according if the event's cause originates inside or outside the company. For example if during the pre-feasibility phase a design aspect is not considered and an error occurs during the detail design phase, the effect rebounds on the internal technical staff. Otherwise if a supplier lacks in a specific activities, the company is forced to negotiate with it and organize the work according to new conditions.

The presented analysis supports the definition of a proper classification of expected exceptions that can be successfully applied for the specific industrial context. The classification is based on three main aspects (see Table 1) corresponding to the generic attributes used to characterize the exception:

- the source of the unpredictable change, that could be *internal* if it is linked to the inner company's interactions or *external* if it is originated within the design or supply-chain;
- the type of the unpredictable change, that is settled according to its nature. *Technical/technological* exceptions are related to adjustments in the ICT systems, evolution in the adopted manufacturing processes and advances in the technologies supporting the development cycle. *Economical* and *temporal* exceptions depend respectively on variations in costs of services, products, or components and on possible delays in the whole product development. Finally *customer-oriented* and *marketing* exceptions concern with changes in product's aesthetical, functional or technical requirements or customers' lifestyle and preferences;

- the importance of the change for business efficiency. It can be *high, medium* or *low* according to the specific process activity and actors involved.

Table 1: Expected exceptions database structure and related generic attributes.

As mentioned before exceptions can also be characterized by distinctive attributes concerning with the phase when the event occurs.

4.3 Differences between dynamic and static workflows

After presenting the general structure of the proposed WfMS architecture, the research examines a practical industrial case in order to describe how the proposed system really works. The test-case allows highlighting the differences between two different approaches: static and dynamic. The chosen example deals with an unexpected event and the way through which both approaches address the problem. As mentioned before unexpected changes in times, costs and product requirements can dramatically lead to the whole design process reengineering. The result is a loss in time if the process is not quickly managed.

The observation of the involved companies' practice highlights that one of most recurring events regards with errors in production planning schedule. Errors can be due both to an internal source (for instance a change in the company's manufacturing scheduling due to a change of the production requirements) and by an external source (i.e. a change in supplier's manufacturing scheduling). In both cases the detail feasibility analysis must be performed again and consequently all design phases reviewed in order to obtain the production plan validation: decisions in the detail feasibility analysis influence the design cycle and the production plan.

The flowchart representation allows the identification of the product development phases involved in the production planning schedule: detail production planning and feasibility analysis stage (See Fig. 4, at left). UML diagram is used to represent the sub-processes in order to highlight actors' roles, performed activities and exchanged documents (See Fig. 4, at right).

The main process activities are contained into round boxes while the shared data into square boxes; black thin lines are used to represent traditional flows, thick red lines static workflow paths and finally, thick green lines the proposed paths

obtained by applying the dynamic workflow. All process entities are arranged into columns (*swimlines*) according to the actors involved in the related tasks.
When the identified unpredictable event occurs, time approval fails and different paths may be adopted in case of static and dynamic workflow. Number 1 and 2 represent respectively the different scenarios: when the source of scheduling error is internal and when it is external to the company's organization.
The first described situation concerns with errors in production planning schedule caused by a company's internal source. In order to manage a possible variation in the production requirements, the company is forced to modify the internal manufacturing schedule defined in the feasibility-planning phase. As a consequence company engineers ask the involved supplier for a different scheduling plan: changes can be in terms of time and resources. The problem regards with the coordination between the old plan and the new one proposed by the supplier. If the supplier is able to comply with the new timing, the process goes on following the normal flow as showed by black thin lines. Otherwise, if an agreement between the company and the supplier cannot be achieved, the approval of the new manufacturing schedule fails. In case of static WfMS application, the system continues to warn the supplier to prepare a new manufacturing plan: it falls in a process loop that forces the workflow manager to stop the process and manually reconfigure it according to his/her expertise (see Fig. 4, at bottom). The problem is generally solved by continuous interactions between partners until either a new detailed feasibility plan has been found or the supplier has been replaced. Interactions are performed via traditional means of communication such as fax, emails, phone, etc. They are difficulty traced and misunderstandings may happen. Once the solution has been achieved the task manager conveys the new plan to the technical staff and to the workflow manager that reconfigures the static workflow according to the received guidelines. As a consequence time to market stretches and subsequent errors chance improves. Static WfMS are not able to agile answer to the unpredictable event: company's actors need to manually modify the process and carry on time consuming activities.
On the other hand a knowledge-based dynamic WfMS can provide a quick response to the unpredictable events minimizing time delays. The proposed system architecture allows the automatic identification of an alternative, the

configuration of a new workflow path that optimizes costs, human resources, number of interactions, etc. and finally allows restarting the workflow by communicating the adopted new plan to the involved actors (see Fig. 4, at right). When the production planning schedule needs a variation, the workflow manager assigns the attributes to the occurring event. Attributes allow the Workflow Engine to identify a proper problem solution automatically retrieving it from the systems databases. The used example deals with an internal exception (source) which is occurred in the manufacturing schedule activity (phase), which is related to technological aspects (type) and which assumes a great relevance (level of importance) due to the fact that it is happened at the end of the product development process. Once the attributes have been set, the *Exception Handler* checks if the exception has already been included in the *Cases Exception Database*. In this case, the corresponding rule is retrieved from the *JECA Rules Database* and a new workflow path is identified for processing the event. Otherwise, if the exception is considered unexpected, it is processed by the *Unexpected Exception Handler* in order to search for similar cases. For instance, the system could identify a new supplier and an "order request" is send to different company's suppliers in order to find the firm that better matches the new requirements. Then, the system automatically communicates the schedule and the chosen supplier to all actors involved in the workflow assigning new roles. Once the process is restarted and the detail feasibility analysis has been carried out, the workflow goes on following the predefined path.

A similar behaviour between static and knowledge-based dynamic workflows can be verified in the case of production planning schedule change due to an external source. In this context the involved supplier may realize that he/she cannot be able to meet the deadline.

This can be due to supplier's internal troubles or problems with other customers. As the static workflow falls into a loop, the proposed dynamic workflow identifies the exception source as external, classifies the event as expected or unexpected and looks for a set of cases and corresponding rules to overcome the problem.

The two discussed examples highlight that exception handling is a very tough problem in the modern industry and requires deep application domain knowledge in order to achieve effective solutions.

The proposed knowledge-based approach has been implemented into a commercial WfMS (softFlow by Metisoft) by developing a plug-in application for the exception handling.

Preliminary experimentations have been carried out to support the development of a project of a new household appliance involving two of the CO-ENV chains. The system performance is evaluated from multiple points of view: interoperability with ICT adopted by the involved companies, time to perform specific workflow tasks, tasks control by all team partners, time for reconfiguring workflows once an event occurs, activities synchronization, time estimation in case of loop cycles, etc.

Achieved results points out some advantages in implementing the proposed research approach and relative dynamic workflow management tools:

- Workflow adaptability without unexpected crash o loop cycles;
- Automation in the rapid configuration of process models according to the occurred event and the retrieved solving rule;
- Support to the system administrator in rapid decision-making based on previous adopted solutions;
- Automation of numerous operations and consequent reduction of time for handling exceptions to predefined workflow.

The analysis of the test case demonstrates that a dynamic WfMS represents a really useful tool for companies in performing critical activities only if supported by a knowledge base that reflect the companies practice in solving unpredictable events. It enables to rapidly react to changes in a well-structured way, support the workflow manager to choose the best solution according with previous test cases and sensibly reduce process workflow reconfiguration times.

Fig. 4: Differences between the proposed dynamic and traditional static WfMS on managing unpredictable events. UML Activity Diagrams are used to model the sub-process involved in the change.

Experimentations, however, point out two main system limitations that need to be overcome:

- the adopted similarity measurement techniques do not completely match with the ways the project manager assesses an unpredictable event during the design process and then retrieve the solution thanks to his/her personal experience;

- the techniques for the evaluation of the changes impact on running workflow in order to better support decision-making during process reconfiguration.

Conclusion and future works

Competitiveness heavily depends on the capacity of industrial companies to quickly react to unpredictable events that can occur during the whole product development cycle. Agility concepts and strategies can be implemented thanks to the creation of a collaborative environment integrated with a dynamic WfMS. It provides a space for improving communication and sharing knowledge. In the 2007 the CO-ENV project arose from these general considerations involving 21 large, medium and small enterprises. This paper is a step forwards the definition of a dynamic WfMS architecture that will be integrated within a co-design web-portal, opened to all project partners. After an overview of the most significant approaches in literature, a possible WfMS structure and its main functionalities are illustrated. The implemented system can be efficient only if expected and unexpected exceptions are handled and the resolving ways are based on rules directly deriving from the formalization of the companies' tacit knowledge and practice. Furthermore, the system databases structure depends on the study of concrete interactions and exceptional cases that usually occur in the three industrial chains involved in the project. Typical exceptions are presented in order to exemplify differences between static and dynamic workflows behaviour. It can be observed that the dynamic one may provide a more flexible organization to companies because problems may be semi-automatically overcome by the system itself. The possibility to evaluate the impact of an unpredictable event is fundamental to improve the business capacity to react to changes.

The main scientific contributions can be synthesized as follows:

- the proposed web-based platform for co-design enhances communication between enterprises at the level of intra and inter chains involving both suppliers, designers and the whole leader company organization. Available information communication technologies generally focus only on collaboration across the supply chain;

- moreover, the supply chain is generally not involved in the leader company processes for the low level of interactivity provided by the adopted communication means. Static workflows are designed according to the specific leader company organization that is very different from that adopted by the supplier. The proposed dynamic workflow platform allows participants to interact without harnessing them in predefined schemas. It does not require the deployment of complex PLM systems difficult to implement in small and medium enterprises as they are strongly document-oriented, have a structured and not much customizable data model and suffer from inter-enterprise integration problems;
- Processes are configured according to practice and unexpected events are handled according to successful precedents. The proposed workflow system is based on knowledge instead of available static workflows;
- The architecture described to dynamically manage workflows; it’s able to formulate different solutions to overcome the unexpected exception, allowing the process manager to customize the solution in accord with specific company’s needs. The best one is stored into the Cases Exceptions Database and the system learns this case, widening its knowledge.

Another interesting novelty is represented by the functionality of the system to assess the impact of the proposed solutions within the workflow. It aims at choosing the best solution among alternative ones. Current commercial systems are not provided with similar functionalities for improving workflows management.

Furthermore, the main contribution consists in the way of put all faced issues together. The effort is to elaborate a web-based platform able to solve communication, interaction, and process management problems integrating the leader companies with its supply chains, enhancing knowledge sharing among parallel chains.

Some novelties need further study, in particular the one related to the implementation of distributed and knowledge-based workflow across complex design and supply-chains. A better development of the platform is required to integrate it within different PLM solutions and commercial WfMS. Future work will be mainly focused on the development of specific algorithms for the evaluation of the changes impact on running workflows.

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