Integrated Approach for Innovation and Problem Solving in Dynamic Virtual Enterprises

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Abstract—**The current business environment pressures companies to be more dynamic and co-operative, to be innovative and to effectively solve existing problems. This paper presents an integrated approach to support innovation and problem solving in dynamic virtual enterprises, based on an innovative and efficient combination of existing technologies. The system under development is described, test results in industrial environment are presented and some directions for future work are drawn.**

Index Terms—**Dynamic Virtual Enterprise, Knowledge Management, Innovation, Problem Solving, Reasoning.**

I. Introduction

The business environment is getting increasingly more dynamic since co-operation across traditional organizational boundaries is increasing, moving beyond the buying and selling of goods and well-defined services, demanding a flexible infrastructure that supports not only information exchange, but also knowledge creation and sharing [1]. This tight co-operation reflects the paradigm of Virtual Organization, which can be generally defined as a network of enterprises that constitute a temporary alliance, in order to share their resources, skills and costs in supporting certain activities [2].

The basic premise of dynamic virtual enterprises is to use the knowledge of outside partners – suppliers, customers, rivals and outside specialists – in lieu of its own [3]. This knowledge should be accumulated and widely shared within the organization, stored as part of the company's knowledge base and utilized in those engaged in developing new technologies and products, generating new knowledge. Producing and retaining knowledge enables organizational learning [4], which is vital to ensure competitiveness. In addition, knowledge management is considered a key part of the strategy to use expertise to create a sustainable competitive advantage in today's business environment [5].

Companies need to innovate, so that they can ensure and enlarge their market segments, but they also need to effectively solve problems to maintain and increase quality of products, while controlling costs. The ability to fulfill these demands (innovate and solve problems) already exists in the form of tacit knowledge, not only within the company's boundaries, but also in all the actors of the dynamic virtual enterprise (suppliers, customers, different subsidiaries of the company etc.).

This paper presents a novel integrated approach to support incremental innovation and problem solving in dynamic virtual enterprises, by supplying the companies with the necessary means to make the best use of their knowledge resources. An analysis of market needs and of the state-of-the-art indicates that an appropriate infrastructure or system to collect and stimulate innovation, providing an efficient framework for problem solving in industrial environment, especially suited to support all actors of virtual enterprises, does not presently exist.

The novelty of the approach here presented consists in combining existing advanced technologies, in an innovative and efficient way, providing an integrated framework, which supports both innovation and problem solving in dynamic and extended enterprises. The approach especially focus on collecting all the relevant knowledge throughout the dynamic enterprise (on products, processes, problems, ideas, innovations etc.), and using it in an efficient way to support companies in innovation and problem solving.

Section II presents the rationale of the approach, describing the common issues and information flows between innovation and problem solving. An overview of the system and respective architecture is presented in section III, and section IV describes the knowledge model used. The main focus of the system is to achieve common modules to be used for innovation and problem solving, especially reasoning methods, which are presented in section V. This approach is currently being tested in an industrial environment, leading to the results presented in section VI. Finally, some conclusions of the work performed so far are presented in section VII, together with future expectations.

II. Innovation and Problem Solving

Innovation and problem solving are two processes with common issues and linked by a strong information flow. In order to understand this, it is necessary to clearly define what is meant by Idea, Innovation and Problem [6].

Idea is a set of information/knowledge that describes a possible measure to be implemented to overcome a problem, to provide an improvement, or to reach an innovation. These ideas can represent different types of knowledge: technical, empirical etc. Every innovation starts with an idea, a rough concept describing something to be implemented.

Innovation is something new that was introduced in an environment, e.g. a new product or a new way of realizing a process. Therefore, an innovation represents the final stage of a development process, representing the result achieved and implemented successfully.

Problem represents an abnormal situation in the enterprise, which requires a solution in order to be eliminated.

Based on these basic definitions, it is possible to state what is meant by innovation and problem solving. The process of innovation represents the complete path realized from an idea until an innovation is achieved. Problem solving comprehends several activities from the detection and identification of a problem to its elimination.

There are clear information flows between the two processes, innovation and problem solving:

- problems may arise during the innovation process;
- ideas and/or innovations can be used to solve and eliminate problems.

Besides these intersection information flows, there is a parallel path in the analysis of both ideas to innovations, and problems to their solutions.

The main common issue in problem solving and innovation is the company context, i.e. the information about the enterprise used to efficiently structure ideas and problems. The presented approach uses a common knowledge base to model all the necessary background information and knowledge, as explained in section IV.

III. System Overview

The main objective of the system is to provide an integrated flexible framework, which can efficiently support innovation and problem solving in dynamic virtual enterprises. This integrated framework comprehends modules realized with the objective of fulfilling the necessary functionality for the two processes:

1. solve problems that arise in the daily life of production and/or product usage (problem solving);
2. generate and/or contribute to the improvement of products and/or processes (innovation).

Providing efficient support to virtual enterprises brings additional complexity to such a system. On one hand, the information/knowledge model has to be adequate not only to structure the necessary information regarding ideas and problems, but also to correlate this information taking into account the large diversity of actors involved in a virtual enterprise. On the other hand, the success of introducing the system in the daily life of the enterprise depends on motivating people to use it. The approach presented in this paper takes into account these considerations, and intends to provide a system which will be widely accepted within virtual organizations, due to its efficiency and ease of use. Enabling an adequate structuring and correlation of information, and providing efficient and clear methods to collect this information is vital to the success of the system. Therefore, the system includes reasoning modules providing functions to find similar information, which are used to support the user in introducing new knowledge.

In addition, the wide diversity of users in virtual organizations demands a clear user interface, containing information that can be rapidly understood individually by each user. As different users can interpret information in different ways and virtual organizations have to be able to efficiently exchange information, it is very important to have the knowledge model and the whole system accompanied by an adequate ontology. An ontology provides a generally agreed understanding of a domain, which can be reused and shared across applications and groups [7].

To overcome these demands, the system includes a flexible graphical user interface (see section IV. B) and an ontology module. The ontology module will enable knowledge exchange among different actors and/or subsidiaries of a dynamic virtual enterprise. A generic ontology will be developed and maintained, related to repositories in different subsidiaries (plants).

The system comprehends several components, as presented in Fig.1:

- common knowledge base, a central repository implemented in Oracle 9i, used by all the components;
- case-based reasoning, realized with the commercial tool ReCall, in C++;
- rule-based reasoning, implemented in Enterprise Java Beans;
- service components, comprehending a collection system, implemented in Enterprise Java Beans;
- client, providing mainly a graphical user interface implemented in java/swing.

As stated before, the system uses existing technologies, although combined in an innovative fashion, as it is described in the following sections.

IV. Knowledge Acquisition/Integration

Knowledge is a fundamental factor behind all the enterprise's activities [5]. Therefore, the presented system approach comprehends one common knowledge base (CKB), which is used by all the components, centralizing all the relevant knowledge.

Besides providing the ability to collect and store ideas, innovations and problems, this common knowledge base has to have background information on the dynamic enterprise, to enable a proper structure for the information to be collected. This background information is in fact quite complex, since it means modeling the virtual organization concerning business entities, function, behavior, information,

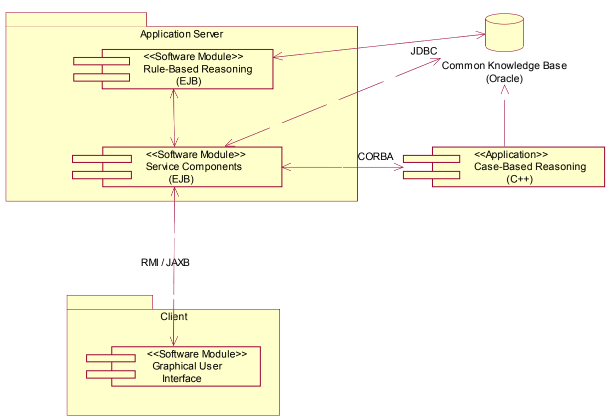


Fig.1 System's modules

resource, organization or economic aspects.

This section describes the knowledge model of the CKB, explaining its two main parts, and presents the collection component implemented.

A. The knowledge model

The knowledge model developed can be separated in two modules: the static data and the dynamic data (see Fig. 2).

The static data comprehends all the information about the physical and process model of the dynamic virtual enterprise, i.e. it is used to store data about product parts, production units, process steps, technologies, resources, states etc., as well as all the interactions among these elements. In addition, the static data also includes types of problems and innovations. This information describes all the processes in the enterprise, and although these will suffer modifications, their information is considered static because it represent components, characteristics and/or parameters, therefore attributes of existing items in the enterprise. The same is true with respect to innovations, which are confirmed improvements that were successfully implemented.

The dynamic data comprises information about what can be called actual data for a specific instant of time, i.e. specific values for any element, attribute or relation defined in the CKB. This set of information is used to store information on problems, process deviations, specific values of state items, probable causes for problems, actions and ideas.

The static data of the CKB represents the complete infrastructure of the dynamic virtual enterprise, and its modification reflects a business decision. The dynamic data of the CKB contains information on the actual state of the enterprise's variables, which is described using components from the static set of the CKB.

The CKB comprehends many relationships that enable to save interactions among elements, which constitute a major source of information in dynamic virtual enterprises.

B. Collection system

The static data of the knowledge model has to be collected during the set-up phase of the system, allowing the acquisition of all the information necessary to properly structure the dynamic knowledge. Therefore, the implemented collection system is divided in the following parts:

- model set-up – component to collect the static information of the knowledge model;
- dynamic collection system – component that provides the functionality to acquire all the dynamic knowledge, e.g. ideas, problems etc.

The graphical user interface (GUI) for the model set-up presents a window with several tabulations, where each one represents one of the main entities in the repository (see Fig. 3). All the tabulations have a similar structure, as uniformity is very important to enable the user to rapidly learn how to use the system. Therefore, each tabulation can be divided in three parts:

1. a main tree, containing all the items of this entity stored in the repository;
2. descriptive fields, containing all the information that characterizes an item;
3. relations to other entities, presenting all the relations of this item to other items in the repository, of different entities.

Following a similar uniformity concept, the dynamic collection systems for ideas and problems are identical. Each comprehends a main window with an overview of all items stored (ideas or problems), centralizing the functionality to add a new item, edit or remove an existing one, search items in the database with several criteria and obtain similar items. Besides this main window, each collection system contains one window to add/edit items.

In order to try to overcome the stated issues related to the diversity of users in a dynamic virtual enterprise, three different GUIs were implemented for the window to add/edit items: easy, advanced and expert. The difference among the three GUIs is the amount of information displayed, and therefore editable. The easy GUI contains very little information, which increases towards the expert GUI. Any user can choose the most appropriate GUI, and this choice can be modified at any moment. This enables an easy use of the collection system, as users do not have to see what they consider unnecessary or irrelevant information.

Fig. 4 presents an example of one of the GUIs implemented for ideas, the expert GUI, which is the most complex one, containing all the information related to an idea.

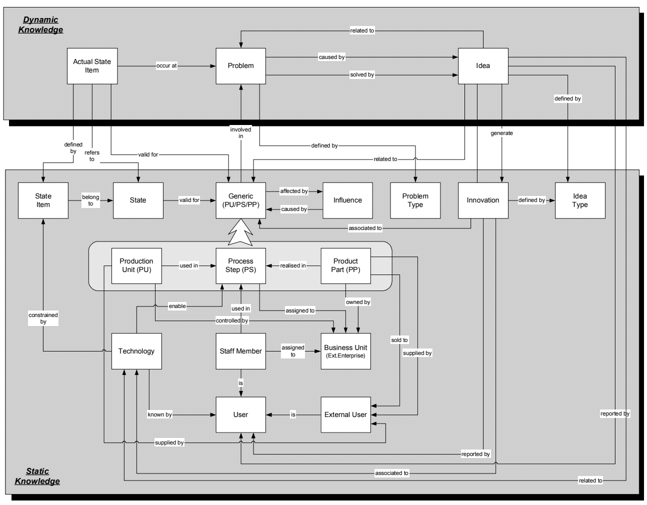


Fig.2 Knowledge model

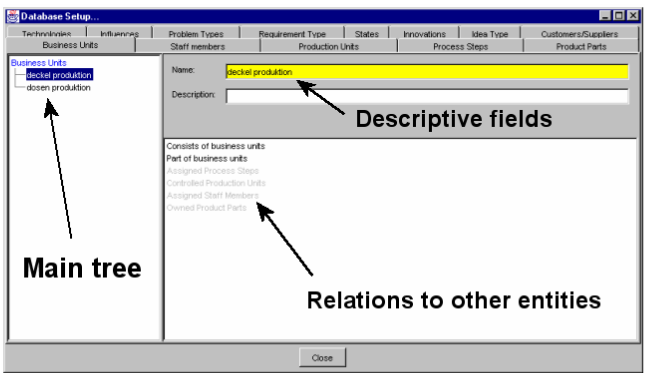


Fig.3 Model Set-up GUI

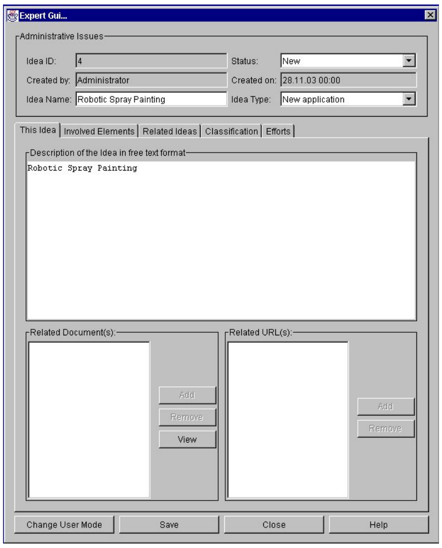


Fig.4 Expert GUI for Ideas collection

V. Reasoning

This section presents the two reasoning components implemented, as part of the system. As will be explained, both components were envisaged in a flexible way, so that their functionality can be used both for innovation and problem solving. The two reasoning methods were then combined in two different ways, in order to provide the appropriate functionality for the two envisaged objectives: innovation and problem solving.

A. Case-Based Reasoning

Case-based reasoning (CBR) means reasoning based on previous cases or experiences. In CBR, solutions are generated by retrieving the most relevant cases from memory and adapting them to fit new situations [8].

The CBR component provides the following functions:

- definition of case structures with the specification of the respective parameters;
- support all types of numerical and alphabetic data, also handling constraints;
- case base multiple indexing, providing fast indexing algorithms to classify cases;
- similar cases retrieval, supporting global and structural similarity, which allows to compare cases according to their structure and their composition;
- definition of weighting for similarity parameters.

The main function of CBR to be used is search similar cases, either ideas or problems. The business logic implemented is used for both applications, where the only difference is the information used, i.e. the case structure defined.

The CBR component was implemented using a commercial tool called ReCall, which is a toolkit that allows the development of a CBR system. ReCall is a set of C/C++ libraries, with multi-language support, allowing calls for embedding the specific ReCall application into other applications.

B. Rule-Based Reasoning

The selected rule-based reasoning (RBR) approach is a probabilistic reasoning since it enables a better representation of uncertain knowledge and manages complex tasks. Probability provides a way of summarizing the uncertainty that comes from ignorance [9]. Probability theory assigns a numerical degree of belief between 0 and 1 to sentences. A probability of 0 for a given sentence corresponds to an unequivocal belief that the sentence is false, while a probability of 1 corresponds to an unequivocal belief that the sentence is true. Probabilities between 0 and 1 correspond to intermediate degrees of belief in the truth of the sentence.

The basic idea of the RBR concept is to split rules into two main groups: 'a priori' static knowledge; and modification rules (dynamic knowledge). The first type of rules will be used to set 'a priori' probabilities for actions. The modification rules will have the structure

If premise
Then if-action
Else else-action,

where the action is a probability modification action, such as: increase by, decrease by, divide by or multiply by a factor, set to a probability and select or exclude.

The RBR component was implemented using Enterprise Java Beans, and provides the following functionality:

- definition of 'a priori' and modification rules;
- evaluation of modification rules, changing the probability values defined by the 'a priori' rules.

As it happened with CBR, the RBR component provides the necessary business logic to realize the appropriate functionality needed for the two applications, as described in the following sections.

C. Innovation

Innovation takes place when different ideas, perceptions, and ways of processing and judging information collide [10]. In the process of innovation, collection of ideas from all the sources throughout the dynamic virtual enterprise is of key importance. In addition, it is essential to be able to identify similar and complementary information, enabling a better analysis of the information and knowledge stored, supporting the innovation process.

On one hand, when a user is inserting a new idea in the system, it is very helpful to be able to see similar ideas, to complete the new one, or to bring a new insight to the information. On the other hand, when a user is processing and elaborating ideas, in the process to create innovations, it is very important to be able to see and combine similar ideas, enabling the user to see the "global picture".

The reasoning methods are used here to provide similar ideas, and they appear combined in what can be called a **cooperative approach** (see Fig. 5). CBR provides the possibility of building cases, from ideas, which are structured information. In addition, CBR provides the functionality to retrieve similar cases, with the ability to define a weighting value for each parameter of the case. Idea cases comprehend the following parameters: type, user who reported the idea, involved generics (elements from the company), technologies and problems.

For each of these parameters, it is possible to define a

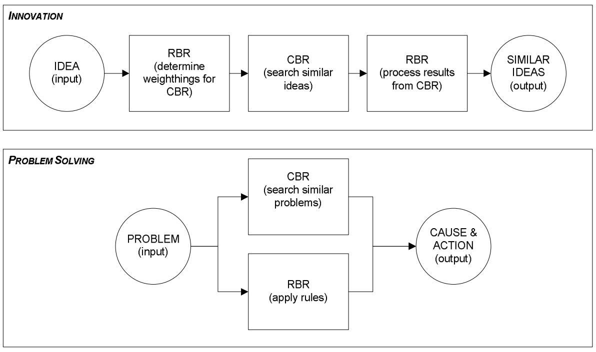


Fig.5 Combination of reasoning methods

weighting from the range lowest, below normal, normal, above normal and highest. However, users have difficulties in defining these weightings and understanding their influence in the retrieval of similar cases. To overcome this, an RBR module is used, to define rules which will "suggest" the most appropriate weighting values to be used for each idea, enabling to get the best results out of CBR.

This is especially important in dynamic virtual enterprises because of the different actors involved in the innovation process, who need to be properly supported in order to realize tasks in an efficient way.

The results provided by CBR consist of a list of ideas similar to the original one. However, if a user is searching similar ideas to support the definition of a new idea, there is no time to analyze many similar ideas, resulted from CBR. In order to support the user in making a quick analysis of the results, RBR can interpret these results in two steps:

1. Identify similar ideas among the CBR results and group them, presenting idea classes with the respective number of occurrences.
2. Determine a confidence parameter for each result, based on the information contained in each idea.

The first item of this RBR system can be considered more as an algorithm, as it is not based on rules defined by the user. For the second item, the idea is to provide the user with some information regarding the "reliability" of the similar ideas suggested. This confidence will be determined based on the user who reported each idea, and his/her success. This "success" will be measured with the support of statistical information, e.g. number of ideas/innovations inserted etc.

D. Problem Solving

In the process of problem solving, reaction time is a key issue. Communication between experts should be made easy and efficient. In [11], it is suggested that using a system to support problem solving should be as natural as using the telephone.

For the process of problem solving, the two reasoning methods realize a **competitive approach**; since both methods are used to determine the cause of a problem and identify appropriate measures to eliminate the problem (see Fig. 5).

In this process, CBR and RBR have different approaches. CBR will search problems similar to the one being analyzed and suggest the cause and measure of the best match found. RBR will determine a cause and measure by evaluating rules, which were defined based on physical elements of the static data of the model (process steps, product parts and/or production units). Rules are defined by users, representing heuristic knowledge introduced in the system.

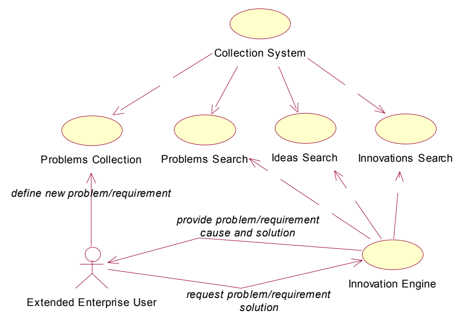
It is very important to enable sharing and reuse of knowledge and reasoning behavior across domains, tasks and actors of the dynamic virtual enterprise. Therefore, it is essential to build an ontology to provide a common vocabulary of an area and to define, with different levels of formality, the meaning of terms and relations between them.

VI. USE CASES AND PRELIMINARY RESULTS

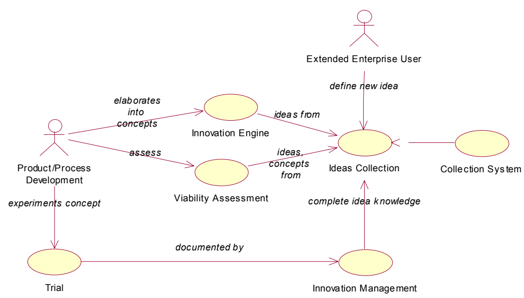
The integrated approach for innovation and problem solving presented in this paper has undergone a first set of tests in an industrial business case.

The present end-user is one of the world's biggest manufacturers of beverage cans, with ca. 8800 employees and plants on 62 locations in 20 countries. All factories work in 3 shifts, 7 days a week. In order to maintain this level of production and to keep shutdowns to a minimal level, the group is strategically interested in introducing this approach, to provide the highest production availability and capture ideas to improve its manufacturing processes. Currently, many ideas from employees are lost as there is no IT system to collect, assess and deliver them to process designers. The special challenge of this business, with manufacturing process distributed over multiple sites, is to enable sharing of ideas among different subsidiaries and co-operate in problem solving.

The end-user has identified two main scenarios in which the system will be applied (see Fig. 6). These two scenarios



a) Problem solving scenario



b) Product/Process improvement scenario

Fig.6 End-user's scenarios

reflect the two main objectives of the system: problem solving and innovation. The goal is to collect problems/potential improvements and innovative ideas from these multiple-site manufacturing plants, i.e. to provide means to put together ideas from actors in different plants.

The end-user's business strategy relating to the system is to collect innovative solutions to improve processes, to reduce process problems, as well as to increase the product quality. The problems in the production floor require the collection of ideas and the integration of IT system culminating in an innovative management system. This is specially needed at the bottleneck machine, which produces approximately ¼ of scrap of the whole production line. Furthermore, similar problems appear in several geographical distributed plants.

Currently, the time needed for collecting and implementing new ideas at the end-user is difficult to assess since every idea needs different time, but it can be roughly estimated that ca. 6 person-years per plant are used to collect and implement ideas. The current number of new ideas generated is around 2000 per year, and the current number of innovative solutions of the identified problems within processes is around 800 per year.

This company expects to achieve the following benefits with the full introduction of the described system:

- expected savings by reducing the time needed for collecting and implementing new ideas by at least 30% (specifically reduction of time and efforts for solving product/process problems);
- increase the number of innovative ideas on processes from employees by 50%;
- increase the number of innovative solutions for identified problems within processes, based on knowledge sharing over subsidiaries, by at least 30%;
- indirectly improve process efficiency by 15% and reduce spoilage by 12%.
- motivate employees to directly contribute to process innovations and strengthen the company culture.

The first set of tests performed in this business case concerns only the problem solving process, mainly to test the efficiency and appropriateness of the reasoning modules. The manufacturing processes were roughly modeled, rules were defined and ca. 100 problems occurred were registered, which took an effort of 20 person-days in the company. The following results were achieved:

- RBR was able to provide a 'robust' assessment for problems' reasons in 50% to 80% of the problems (probability higher than 0.5);
- CBR was able to identify problems' causes for 88% of the problems, with a similarity between 83%-99%.

The results are constrained by the availability and consistency of information, but it can be stated that the reasoning modules can provide a better support with higher number of information and knowledge stored in the CKB.

VII. Conclusions and Future Work

This paper presents an integrated approach to support innovation and problem solving in dynamic virtual enterprises. Some preliminary results in an industrial environment are shown, illustrating the real application and potential of the system. The approach will be further elaborated and more results are expected in the end of the summer of 2004.

In the sequence of this work, the authors are investigating the way knowledge and high-level reasoning mechanisms are created from the history of the enterprise as a whole. Namely, the creation of new rules for the RBR system from the consolidation of cases registered in the CBR system, with an associate confidence level extracted from the statistical analysis of the cases. Additionally, the Boolean detection of symptoms in Problem Solving is quite often too hard and misleading, as they should be interpreted in a Fuzzy fashion. The final goal is to achieve an autonomous dynamic maintenance of the system through the completion and adaptation of the rules with the collected available information.

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