A Global View of Maintenance Management
- From Maintenance Diagnosis to Know-how Retention and Sharing -

TORRES FARINHA[a], INÁCIO FONSECA[b], VIRIATO MARQUES[b], ANTÓNIO BRITO[c], ALBERTO MARIMBA[b], NELSON PINCHO[b], ANTÓNIO SIMÕES[b]
[a]IPC – Av. Marnoco e Sousa, 30, 3000-271 Coimbra, Portugal
[b]ISEC - Instituto Superior de Engenharia de Coimbra, 3000-Coimbra, Portugal
[b]FEUP – Facul. Eng. Da Universidade do Porto, Porto, Portugal

Abstract:- This paper describes some state of the art maintenance management systems - from information systems to fault diagnosis and know-how retention and sharing - as devised by a Portuguese research group whose members have a considerable experience in the academic and industrial fields. The research team has developed and improved various aspects and models whose usefulness and versatility have been validated both in hospitals and industry. Currently, efforts are centred on systems integration for the development of a new generation of maintenance and knowledge management systems based on a new classifying method of maintenance objects, Case-Based Reasoning (CBR), Intelligent Tutoring Systems (ITS) and e-learning. First, current concepts are discussed and a new one is introduced. Next, two methods for maintenance state diagnosis is presented. Then, SMIT(H) - a maintenance management system developed around the concept of maintenance objects - is described. A maintenance database and web-based security plans, HMANUT, is presented. A fault diagnosis system (that will also become available on the web), SADEX, is introduced as a fundamental piece of the future MKM - Maintenance Knowledge Manager - under development, which aims to integrate CBR, ITS, e-learning and virtual reality. At last, is presented the new approach for SMIT(H) that is under development, SMIT(H)– 2G a subject for a new PhD Thesis.

Keywords:- Maintenance; Reliability; Scheduling; Knowledge Management; Fault diagnosis.

1 Introduction

Traditionally, maintenance always referred to non planned maintenance. however, concepts like terotechnology, total productive maintenance (tpm) and reliability centred maintenance (rcm) have completely changed this scenario.

The first author of this article, some years ago, introduced in his PhD thesis a new concept: terology. It is defined as the combined use of techniques of operational research, management of information and engineering, with the goal of accompanying the life cycle of facilities and equipment. it includes the definition of the acquisition specifications, installation and reception, as well as the management and control of its maintenance, modification and withdrawal during its accompaniment in service [1].

Nowadays there is an integration of several points of view concerning the management of maintenance. For instance, TPM is compatible with Terotechnology, but emphasizes the human role. RCM looks at the equipment in its operational context. Finally, Terology is a global point of view of maintenance in all its various aspects.

In this paper the author's perspective is illustrated and emphasized in the information maintenance system summarily described in this paper. Also, some other work in interrelated areas where the authors have been collaborating is also discussed.

2 Diagnosis of the maintenance state

2.1 The method for small and medium size enterprises

The first step in the reorganisation of a maintenance department should be an exhaustive diagnosis of the *maintenance state*.

The methodology summarised here is mainly used in small and medium size enterprises. This is a progressive process, proceeding according to the real situation of the maintenance department and referenced in [2].

The method considers essential to traverse eight stages to make the transition from the state of poor maintenance management to the state of an adequate maintenance management:

- Management of equipment;
- First level maintenance;
- Management of stocks and spare parts;
- Management of work;
- Analysis RMRS (Reliability, Maintainability, Readiness, Safety);
- Analysis of costs;
- Database;
- Planning and prevention.

The evaluation allows to describe the maintenance state by means of a position in a radar graph, as in the original method (Fig. 1).

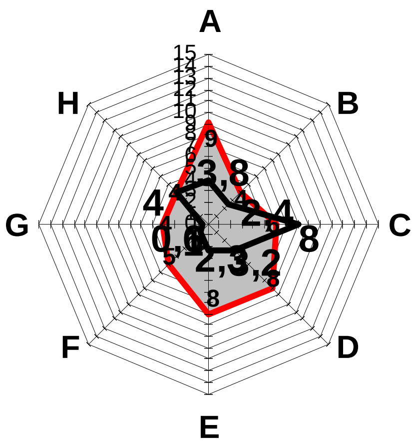

Fig. 1. Radar graph

The original method was modified and managed in order to adapt the relative values and to automatically print a report with each diagnosis. This method was used in some industries with good results. The results met the high administrative and maintenance manager expectations.

The weak points were improved by this method and the SMIT(H) information system was successfully introduced afterwards.

2.2 The method for large organisations

The method described here covers medium and large organisations, [3]. The previous method in conjunction with the present one allows the management of all organisation types.

The analysis of how maintenance is managed and performed uses five basic components that are further subdivided into key elements. These five components are:

- Organization
- Workload Identification
- Work Planning
- Work Accomplishment
- Appraisal

The maintenance management audit is carried out with the aid of several inquiries structured according to the five components referred to above, with each component subdivided into its key elements.

At the moment, the team is developing a new method to manage all types of organisations. This method includes the aspects referred to in the last two methods, but in a more versatile way, and also includes new concepts that are the result of industrial experience and the current vision of maintenance management.

3 Information systems for maintenance management – SMIT(H)

The main subjects of an integrated maintenance management system are the following: Equipment, Working Orders, Planning, Spare Parts, Suppliers, Purchase, Outsourcing, Overhauls and Costs Control.

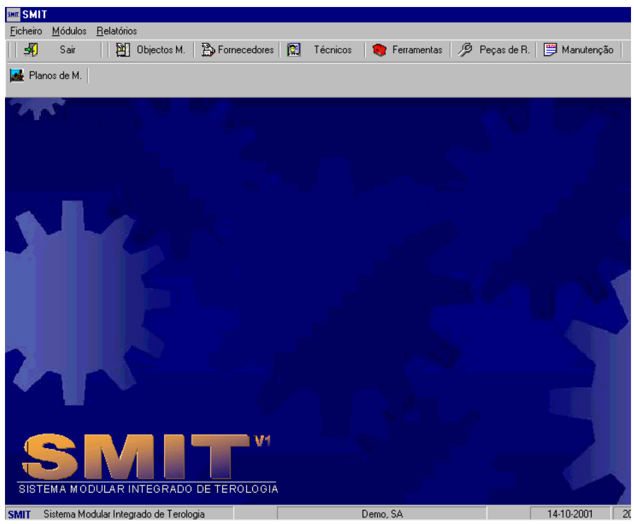

Fig. 2. Main form of SMIT

SMIT - Modular Integrated System of Terology - (Fig. 2), SMIT(H) for hospitals, is an information system that begins with the equipment and facilities or, in other words, with the Maintenance Objects (MO), common entities to all enterprises. They are, of course, the aim of maintenance [4] and [1].

SMIT includes the following modules: MO, Working Orders, Planning, Suppliers, Spare Parts, Technicians, Tools and Fault Diagnosis.

The MOs are structured in a tree model with parent-child relations, but with great versatility: each module can be a parent or a child; and all have similar information that can be managed both individually or inserted into the tree (Fig. 3).

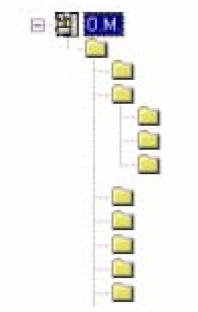

Fig. 3. Maintenance Object (MO) tree

Each MO has a complete store of categorized information:

- Physical Characterisation
- Functional Characterisation including annual historic
- Technical Characterisation
- Spare Parts
- Maintenance Interventions
- MO of Lower level

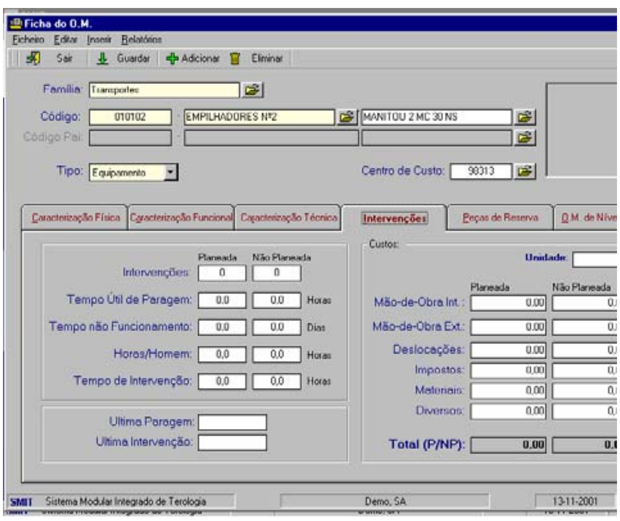

Fig. 4. Maintenance Object (MO) form

Fig. 4 shows the MOs form with the sub-form that characterises the interventions.

The WO module is the only document indispensable to SMIT. It carries both the planned and non-planned interventions.

For the non-planned interventions, failure description is stored along with its cause and confirmed solution. Keywords can be introduced to better describe and locate the failure.

For planned interventions, and instead of the data above described, control parameters such has hours of functioning, kilometres, etc. are stored, plus the intervention data in itself. When the WO is closed, the next planned intervention is automatically generated.

The maintenance-planning module permits management of several maintenance and security plans, because each MO can have several plans.

Maintenance plans can be created either for periodic or non-periodic intervals. Compared to other systems, this is a powerful advantage [4]: for example, a machine can work *W* hours in a week, but next week it may work $W\text{-}\Lambda$ or $W+\Lambda$; thus, the interventions can't be periodic from the calendar time point of view, even if corresponding to the number of working hours.

The maintenance plan obviously includes sections for labor, materials and the checklist of procedures. Fig. 5 shows part of the fields of the form that manages maintenance plans.

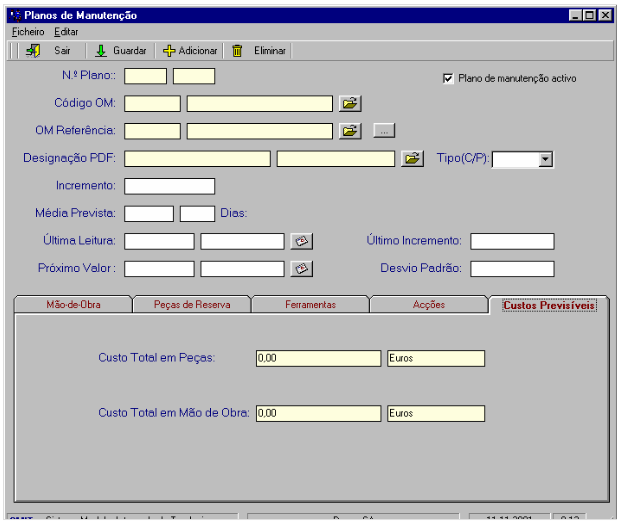

Fig. 5. A maintenance plan form

Today, SMIT(H) is becoming a Second Generation Information System, meaning that the tree structure will be changed to a net structure in order to delineate a more realistic structure of the MO. This will be discussed later.

4 Database of maintenance and security plans for equipment and facilities

Maintenance data and security plans can be characterized by the following items:

- Procedures check list;
- Parameters of use (hours of functioning, time, etc.);
- Kind of maintenance (scheduled, on condition, etc.);
- Reliability parameters;
- Duration of intervention;
- Security checklist;
- Interval between security checking.

Using some information sources, it was developed a Web Page, www.baltico.ipc.pt/hmanut, that provides maintenance and security plans for more than 200 types of equipment (in Portuguese and English languages) and also to most facilities (in this case only in English language (Fig. 6, 7 and 8)).

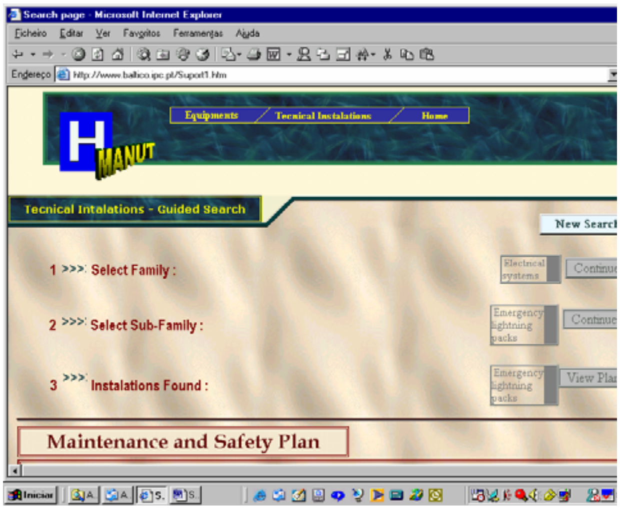

Fig. 6. Maintenance and Security Plane of a facility

The final goal is having all Portuguese facilities and medical equipment maintenance and security plans in the database that the Web Page accesses. The final step is to maintain this information, namely to upgrade it with new data about reliability and planning - result of the technician's experience and acquired know-how - information about new equipment models and so on.

At this moment the Web Page is being improved and, in the near future, it shall be possible to download the plans directly to SMIT(H).

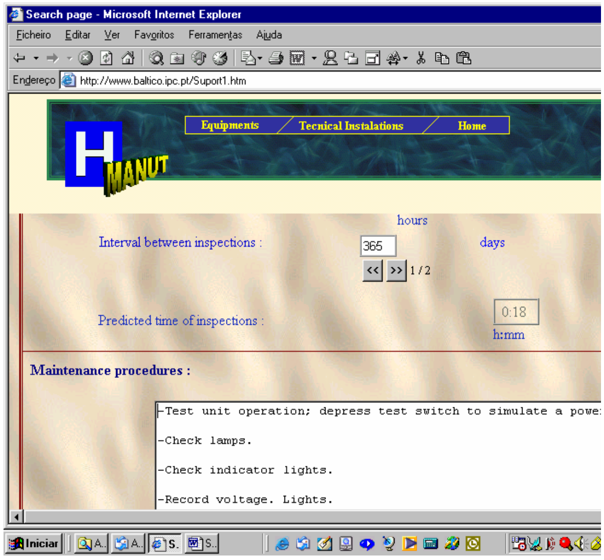

Fig. 7. Maintenance and Security Plane of a facility (continued)

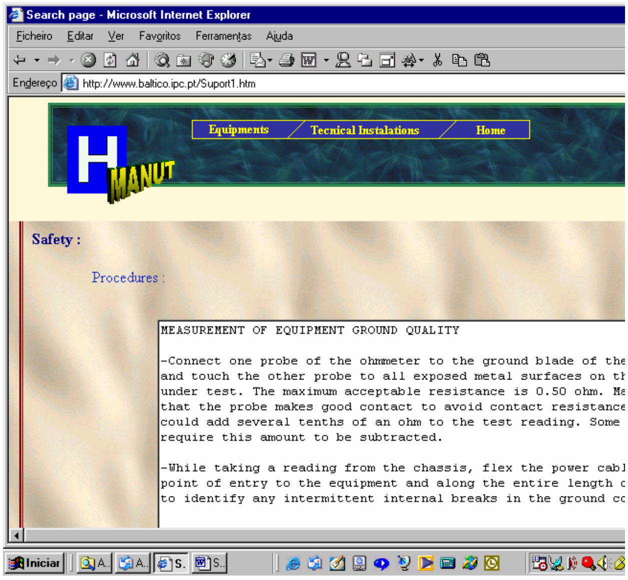

Fig. 8. Maintenance and Security Plane of a facility (continued)

5 Fault Diagnosis systems

The easiest and perhaps the most pragmatic system for fault diagnosis is based on the information of the Work Orders, namely the fault, cause and procedure fields, structured in a hierarchic way (Fig. 9).

Failure i	Keyword i	Technical opinion i	Cause i.1	Procedure i.1
			Cause i.2	Procedure i.2
			...	...
			Cause i.n	Procedure i.n

Fig. 9. Structure of the attributes in the fault diagnosis system

SMIT(H) can integrate a module of fault diagnosis based on the information of the Working Orders (failure, cause and procedure) and the technician’s opinion, based on fuzzy logic. Fig. 10 shows part of the actual forms of fault diagnosis.

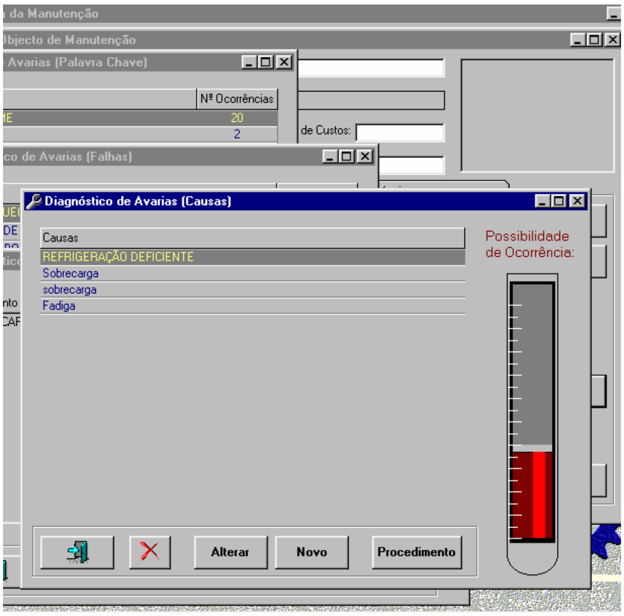

Fig. 10. Forms for failure diagnosis

Making use of part of those resources, a new project was developed and validated, being the result of the PhD. thesis of [5]. He has developed and implemented a fault diagnosis system based on CBR - Case-Based Reasoning and Fuzzy Logic.

This system, a CBR Expert System Shell named SADEX, uses a graphical interface to collect case descriptions and build the Case Library. Basically it operates in the four phases cycle of [6]: Retrieve, Reuse, Revise and Retain (Fig. 11).

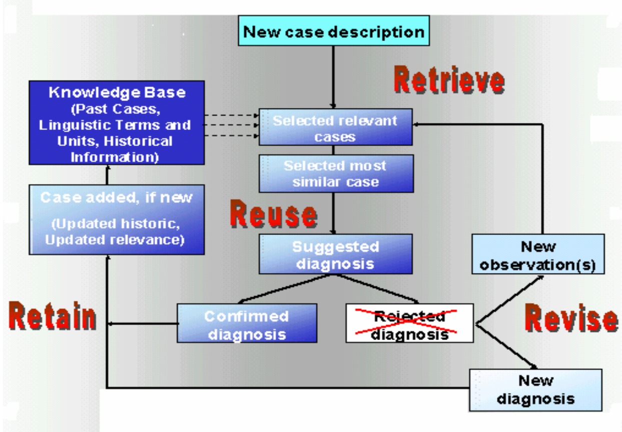

Fig. 11. The four phases of SADEX CBR fault diagnosis system

The principles and architecture of SADEX may be organised into 5 sections:

- Classification, composition and taxonomic similarities;
- A three level model for attribute representation and handling (3L Model);
- Knowledge representation;
- Similarity function;
- Relevance and information cost matrix.

Fig. 12 shows the main form of SADEX/SADEH and Fig. 13 a part of the diagnosis phase.

Fig. 12. Main form of SADEX (SADEH)

The system has been designed to offer an information load as small as possible so that even administrative tasks may be carried out remotely with a traditional dial-up connection.

The system is being used in the hospital field and the results are promising.

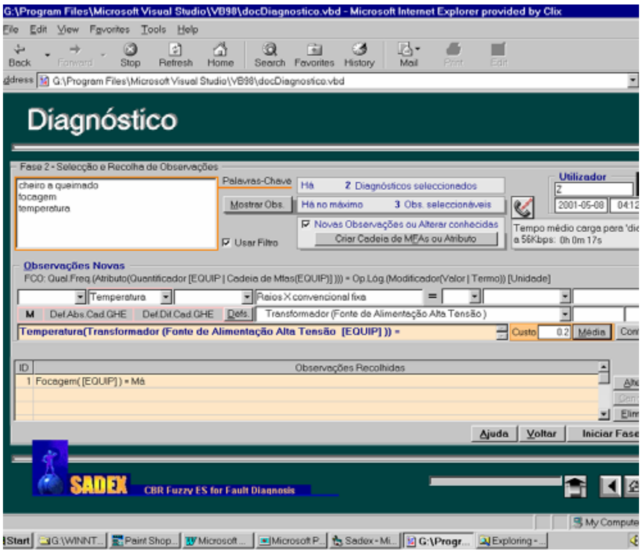

Fig. 13. SADEX: a diagnosis in progress

6 A Global View of Maintenance Management – anticipating the future

As shown, during the last few years we have developed complex models and systems concerning the maintenance field. However, and as Fig. 14 shows, all these systems are no more than pieces of a kit.

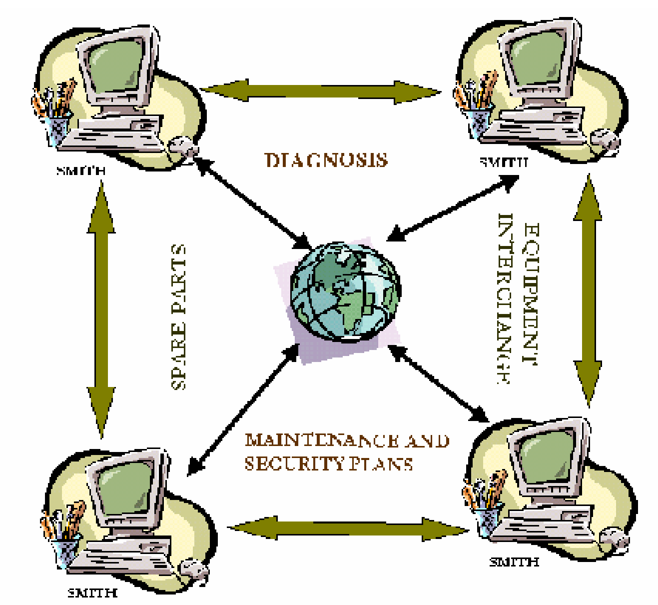

Fig. 14. A Global View of Maintenance Management

Thus far we have discussed the systems integration currently under development. But we are also developing models that will support some new approaches.

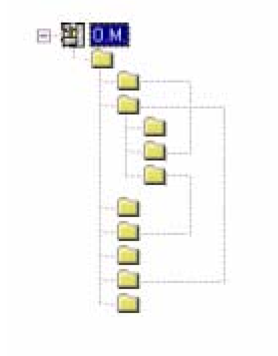

Fig. 15 – Interconnections among the modules of a real MO

MO modules	**Module 1**	**Module 2**	**...**	**Module N**
Module 1			✔	✔
Module 2			✔	
...	✔	✔		
Module n	✔			

Fig. 16 – The new MO Matrix Structure

It was highlighted that the salient feature of SMIT(H) is its development around the MO. Therefore, when the interconnections among the modules of an MO are not well represented by a tree, a better translation of reality is needed, so that SMIT(H) can more precisely translate the real world. Fig. 15 and 16 illustrate this problem. Fig. 15 shows the diagram of an MO with more complex connections that in a tree and the Fig. 16 shows the matrix that supports the solution for the referred problem, what we call the next generation of SMIT(H).

This new concept is now leading to SMIT(H)-2G (Second-Generation Modular Integrated Terology Management System), at this moment under development as a subject of a new PhD Thesis.

SMIT(H)-2G is using the new MO Matrix Structure concept for interconnection between MO and, in parallel, the same concept is also used on the PM module, to represent dependencies between Maintenance Plans (figs. 17 and 18).

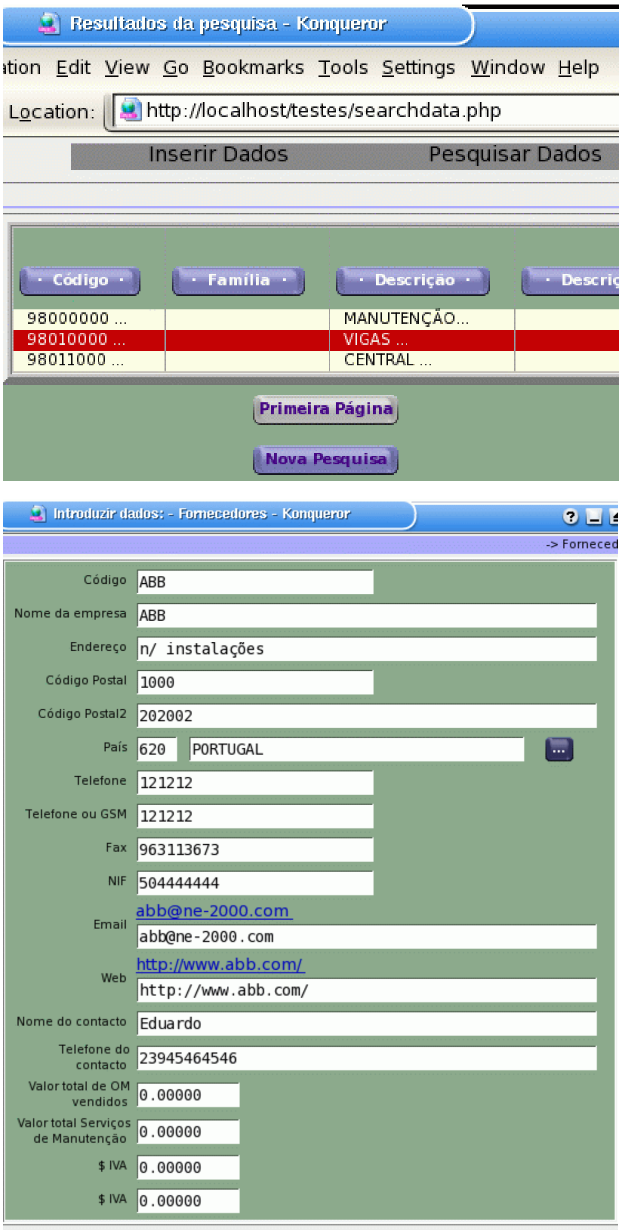

Fig. 17 – SMIT(H)-2G still under development

The final version will work using a web explorer, giving a web-based access for users. SMIT(H)-2G is programmed in PHP, using an Apache Server. It is possible to install this new version on Windows or Unix machines.

Additionally, the PM module is prepared for scheduled planning and for on condition (predictive) planning. As an example, planning based on ambient pollutants from the automotive vehicles, the WO's are generated in function of measures made trough specific variables, for example, CO_2, PM, NMHC and NOX.. When some of these parameters reaches a limit, or when some combination of its values, based on a specific methodology that is under development, reaches specific condition, a WO is automatic generated. This module is part of the work of another PhD Thesis.

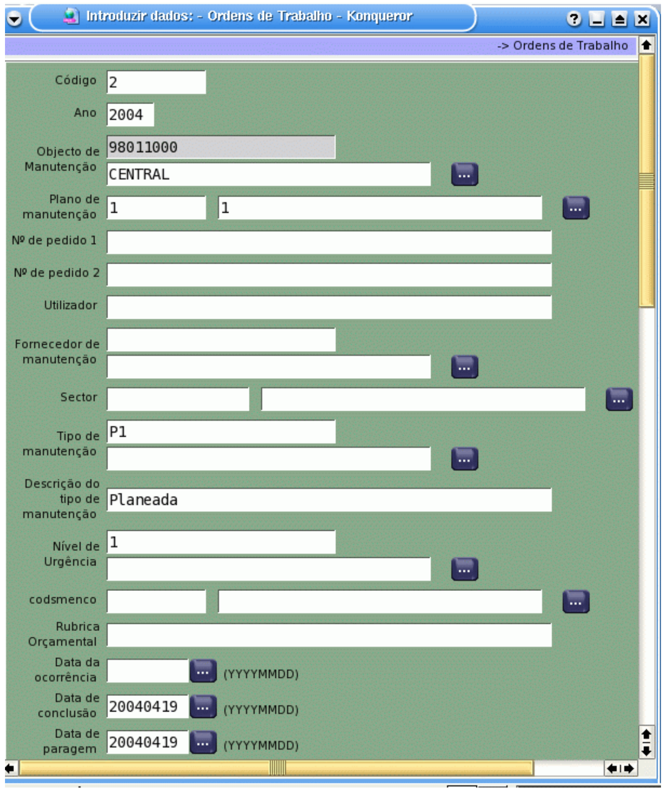

Fig. 18 – A Planned WO using a PM.

7 Maintenance Knowledge Manager – Into the future

7.1 IS's, CBR, *e-learning*, ITS's: Abstract of characteristics

An important component of knowledge is the acquired know-how by means of experience. A CBR system like SADEX can retain experiences [7].

However, retain and reuse is no longer enough. The integration of CBR, IS's - Information Systems-, *e-learning* and ITS's - Intelligent Tutoring Systems - all working together in a maintenance context is, certainly, a desirable solution.

- E-learning platforms resemble sites with access authorization and a series of associated services (text and multimedia; interchange of information; etc.).
- ITS's have more sophisticated means of knowledge transmission, using Artificial Intelligence (AI) techniques and simulation.

- IS's (Information Sytems) and ES's (Expert Systems) based on the CBR paradigm are essentially repositories of information and knowledge, ready to be used or treated for posterior dissemination. They lack a specific way of knowledge dissemination to complete the cycle of Fig.19, an important means of implementation of TPM, Terotechnology and Terology.

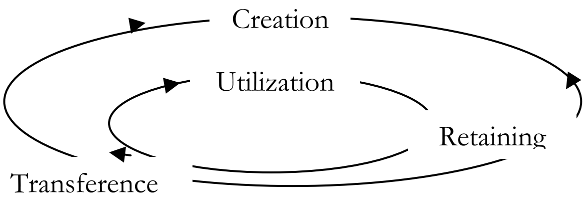

Fig. 19 - A General Model for Knowledge Management (Newman & Conrad, 1999)

	Knowledge					Role in the Formation		Pedagogy	
	Creation	Acquisition	Retention	Utilization	Divulgation	Active	Passive	Present	Absent
e-learning			X	X (1)	X (2)		X		X
ITS			X	X	X (3)	X		X	
CBR	X	X	X	X	X (4)		X		X
IS		X	X	X	X (5)		X		X

(1) only as aid to dissemination

(2) in great scale

(3) in the base from 1 to 1

(4) under the queries format

(5) queries, reports,*datawarehouses*

Fig. 20 - Comparison between the characteristics of e-learning, ITS's, ES's, CBR's e IS's

The fig. 20 shows why these systems are mutually complementary. Some opinions and work already developed strengthen this point of view, although the focus has been, up to now, on the integration Web / ITS. It is the case of [8], [10] and [11] that describe approaches to the availability of the technology of ITS in the Web (the last ones integrate a CBR component, too); of [12], that describes an integration scenery between CBR and e-learning; of [9] that describe a diagnosis system, adaptative, in the Web; and of many others.

7.2 A little beyond

Fig.21 shows the aspect of a control panel and a 3D (three dimensions) picture created by a tool of ITS's development called RIDES / VIVID (USC, 2003). Tools of this type allow the creation of work environments extraordinarily interesting, from bi-dimensional images to virtual reality scenarios where agents act.

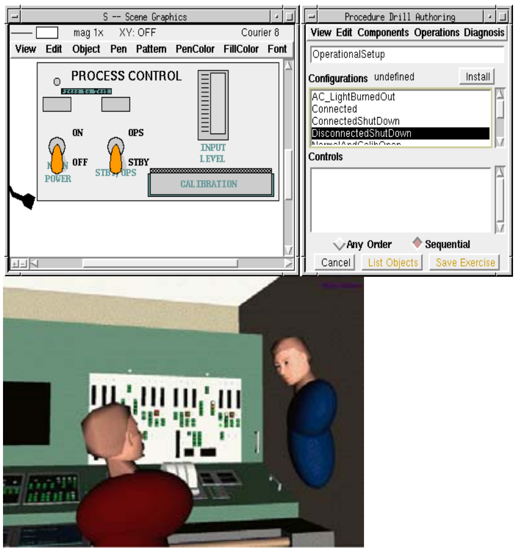

Fig. 21 - Simulation: a control panel and a 3D world where two agents act. (tool RIDES / VIVID - University of Southern California , USA)

The result of the integration of IS's, ES's of CBR type, ITS's, e-learning, simulation and virtual reality in an stand-alone system tailored to education and training in the industrial and hospital maintenance fields, is MKM - Maintenance Knowledge Manager - a system under development. Its validation should occur in a collaboration frame that will involve higher education colleges and some Portuguese companies in several areas, from hospital to industrial field.

Just as the e-learning provides courses when integrating services, MKM will provide experts when integrating systems. These are the synergies that our team is trying to reach.

8 Conclusion

The paper presented some results of the research and development carried out by the team referred in its header. It relates several fields, namely: maintenance; diagnosis methodologies; information systems for maintenance management; maintenance and security plans in the Internet, two kinds of fault diagnosis systems and the first step in a new approach to the on condition maintenance in an ambient perspective.

The paper presents some new directions taken by the research team. These include a new vision of the MO structure; a first glimpse of the second generation of information systems for maintenance; integration of spare parts into the life cycle of an MO; withdrawal of an MO; the full integration of these systems; the three dimensional simulation of the maintenance tasks; finally, a maintenance knowledge management system that closes the cycle of the present research.

Today we are not only in the era of global economy but also in the era of global maintenance… And the future will be based not in the destruction of natural resources but on the wise stewardship of resources, what implies a future not primarily based on industrial production but on the maintenance of goods... Economic and social progress will be based on respect for nature, striking a balance between the maximum recycling and the minimum use of natural resources.

This may seem a virtual world, but keeping what we have is, in fact ... just a matter of maintenance!

References:

[1] Farinha, *Uma Abordagem Terológica das Instalações e Equipamentos Hospitalares*, Editora Minerva, Coimbra, Portugal, 1997.

[2] CETIM, 1994, Vous Êtes une PMI, Faites Votre Auto-Diagnostic Maintenance – Un préalable à la GMAO dans une demarche de qualité totale, CETIM, France.

[3] Kaiser, H. H., 1991, Maintenance Management Audit – A Step by Step Workbook to Better Your Facility's Bottom Line. R. S. Means Company, Inc. Kingston, USA.

[4] Farinha, J. T., 1994: Uma Abordagem Terológica da Manutenção dos Equipamentos Hospitalares, PhD Thesis, FEUP, Porto; Portugal.

[5] Marques,V., Diagnóstico de Falhas em Equipamento Baseado em Informação Difusa Oriunda dos Técnicos de Manutenção, Tese de Doutoramento, Fac. Engª. Univ. do Porto, 2002.

[6] Aamodt,A., Plaza,E., Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches, AI-Com, Vol7, Nº1, 1994

[7] Marques, V.; Farinha, T.; A. Brito, A; Pincho, N., 2003: CBR+IS+ITS+e-learning = MKM - Maintenance Knowledge Manager - Sinergias no Contexto da Manutenção Industrial, 18º CBM - Congresso Brasileiro de Manutenção / 12º CIAM - Congresso Ibero-Americano de Manutenção, Porto Alegre, Brasil, 2003

[8] Seridi-Bouchelaghem, H., Sellami, M., Design of an Inteligent Tutoring System on the WWW to Support Interactive Learning, Int. Conf. on Engineering Education, Oslo, August 6, 2001

[9] Brusilovsky,P., Cooper,D., ADAPTS: Adaptive hypermedia for a Web-based performance support system, Second Workshop on Adaptive Systems and User Modeling on the World Wide Web, Toronto, Canadá, 1999

[10] Brusilovsky, P., Schwarz, E., Weber, G., ELM-ART: An intelligent tutoring system on World Wide Web, in Frasson, C., Gauthier, G., & Lesgold, A. (Ed.), Intelligent Tutoring Systems (Lecture Notes in Computer Science, Vol. 1086). Berlin: Springer Verlag. 261-269, 1996

[11] Aleven,V., Ashley,K.D. Automated Generation of Examples for a Tutorial in Case-Based Reasoning Argumentation, Proceedings of the Second International Conference on Intelligent Tutoring Systems, Spring-Verlag, Berlin, 1994

[12] Cornicholi, T., Uma Arquitectura Baseada em Agentes para Suporte ao Ensino à Distância, Tese de Doutoramento, Universidade Federal de Santa Catarina, Florianópolis, Brasil, 1999