APPLICATION OF KNOWLEDGE-BASED SYSTEMS IN STRUCTURAL INTEGRITY ANALYSIS: EXPECTATIONS, TRENDS, RESULTS, EXAMPLES

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Abstract: The paper gives a lecture-type survey of what has happened in the field of knowledge-based systems applied in the last decade in the area of structural integrity analysis. The survey includes the software and hardware development trends and it is complemented by a series of representative examples and results taken from the fields like remaining life prediction and other power plant applications. The use of techniques like production rules, object oriented programming, and, in particular, the issue of integration of knowledge-based systems with hypermedia, numerics and data bases are discussed more in detail as an important practical alternatives. Several European and US knowledge-based systems relevant for the structural integrity analysis in the field power plants are given as examples.

INTRODUCTION

As structural components in various engineering systems (e.g. power plants, bridges, etc.) get older, degradation mechanisms such as creep, fatigue, corrosion, and erosion, possibly leading to cracks and structural failures increasingly appear. Sophisticated engineering analytical techniques have been developed in the last years to estimate the failure susceptibility and (e.g.) residual life, and schedule repairs and replacements of these components. Many of these methods are computer-based and give quantitative and qualitative estimates of the required values, but engineers often experience difficulties in coping with the complexity of the analytical methods, of data and information, of record keeping requirements, and of governing standards and regulations. This paper is devoted to the sub-class of these computer-based solutions, namely to those known as knowledge-based systems - KBS (also "expert systems").

AI, KBS AND STRUCTURAL ENGINEERING IN THE LAST DECADE

INFORMATION GLUT

Last three decades of the development of electronic data processing (EDP) methods and techniques have been marked by two factors (Fig. 1):

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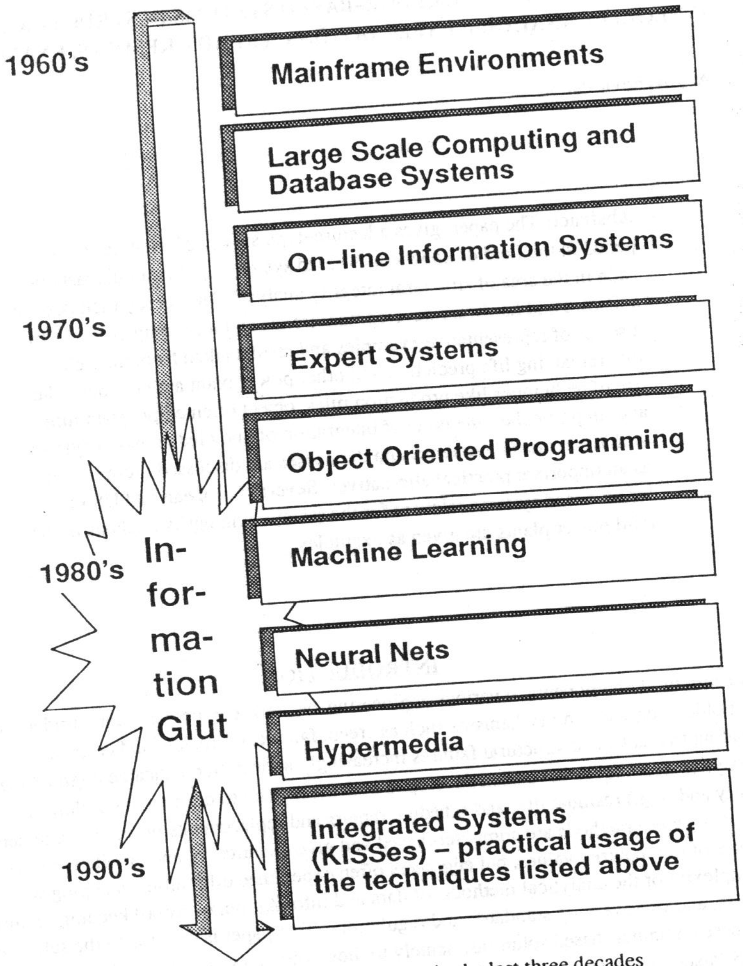

Fig. 1- Development of EDP-tools in the last three decades

a) fast development, diversification and multiplication of available tools, and

b) information glut (overflow).

The two factors are strongly dependent: the development of the tools has been one of the causes for the glut (the new systems produce new data - e.g. stresses calculated in thousands of points of a structure) and, on the other hand, the glut has put more emphasis on tools enabling to cope with huge amounts of data in a more "intelligent" and more user-friendly way. Areas of materials and structural engineering (MSE), as well as those of structural integrity assessment (SIA) are not exceptions in this sense: the above mentioned problems are present there, too (Jovanovic, Bogaerts 1991 and 1992).

GENERIC TRENDS IN THE DEVELOPMENT OF KBSs

Knowledge-based (expert) and related systems, like hypermedia and neural nets can substantially improve the current practice in the domain of materials and structural safety assessment engineering. They can help (e.g.) when dealing with limitations imposed by unavailability of data, time, resources and/or highly qualified personnel, or when dealing with uncertainty in material properties, local changes of material properties (e.g. those caused by welding or heat treatment) and similar factors.

The main difference between the KBSs and conventional programs can be described as the KBSs' ability to exploit the powers of association and inference when dealing with complex tasks. Knowledge in the sense of a KBS means primarily structuring and systematic management ("definition, manipulation and exploitation of relationships") of various pieces of information. If a computer system pretends to be "intelligent" it must posses at least a subset of the abilities listed hereafter, i.e. it is supposed to:

- solve complex and/or ill-structured problems
- be responsive and adaptive
- provide nonlinear program navigation
- make effective use of all available information
- be user-friendly and interactive

The trends in the area of KBS development and applications in the last decade are marked by two major waves (Fig. 2) and by the tendency to use computers which "bring the power to the desktop" - workstations and powerful PCs (Fig. 3).

Furthermore, the second wave of the "AI enthusiasm" (the first one registered in late sixties crashed in disillusion, but left the area of engineering unaffected) seems to be approaching its end too, leading to a sort of an "AI identity crisis" (see for instance BYTE, Jan. 1991). The practical consequences of this crisis are "extermination" of many KBS-shell manufacturers, reduction of number of available successful shells and disguising of shells into "intelligent CASE-tools" (CASE - computer-aided software engineering) or hiding under other market names.

Although the engineers might be confused with such a development, there is no reason at all to "abandon" AI and/or KBSs: not because today's AI is so good but because a whole class of problems (especially in engineering) cannot be solved without systems exhibiting an "intelligent behaviour". In other words, the time has come to show that the academic questions like "if it works can it still qualify as AI" must face the requirement of the practice which can be formulated as "only if it works can it survive".

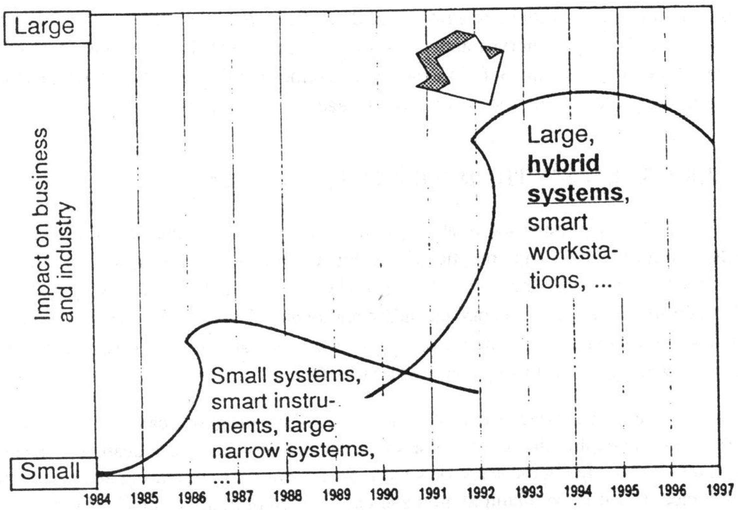

Fig. 2 Two waves in application of expert systems (adapted from P. Harmon, D. King EXPERT SYSTEMS, J. Wiley and Sons, 1985)

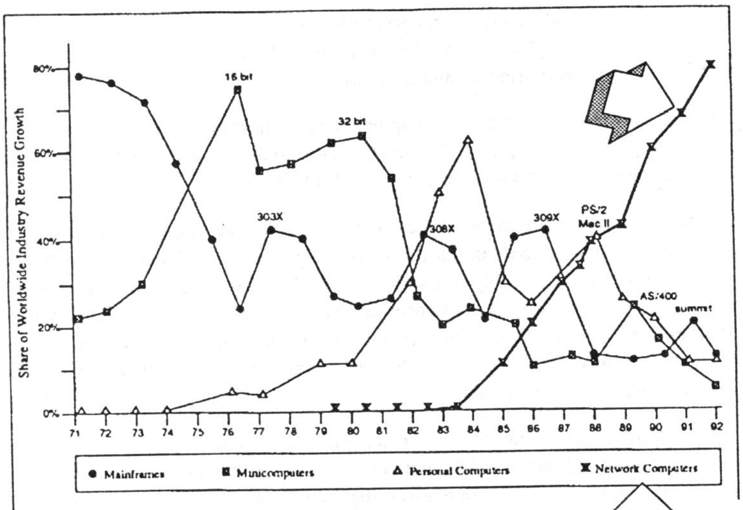

Fig. 3 Two waves in application of expert systems (adapted from INTELLIGENT SOFTWARE STRATEGIES, February 1991)

REQUIREMENTS REGARDING THE SUCCESSFUL APPLICATION OF KNOWLEDGE-BASED SYSTEMS IN THE AREA OF S I A

The basic issue from the practical standpoint is the definition of the requirements which have to be met by an "intelligent software system" applied in MSE/SIA. The most important ones

a) data availability: make data which already exists in some electronic form (EDP) more readily available

b) data correlation: interrelate and correlate data of different types and coming from different sources

c) information dissemination: turn the available and interrelated data into information which can be used in practice

d) knowledge extraction: extract knowledge which is hidden in the information and make it available to the user

e) intelligent consultation: improve the end-use of the knowledge by providing intelligent assistance during consultation.

These requirements are similar to those initially imposed on (but never fully met by) the conventional expert systems. Practical experience (Jovanovic et al., 1989; Jovanovic, Bogaerts,1991) with expert systems has namely clearly shown that conventional (production rule based) expért systems alone can deal successfully only with a very limited range of practical problems in the domain. In addition these systems are almost always interactive (dialog-based) and as such they often tend to "block" the dialog at the moment when the user is not sure what to answer the system, either because he needs an explanation of the question or because he is asked to provide (to the system) some additional information which is currently not known/available.

KISS - POSSIBLE ANSWER TO THE IMPOSED REQUIREMENTS

Some of the above listed required abilities obviously call for integration, e.g. "effective use of all available information" means in practice "use the databases, spreadsheets, ... that are already there". The same remarks are also valid for the hypermedia systems (Begoray, 1990; Woodhead, 1990).

Possible practical answer to this and similar requirements is the MPA's approach called "KISS" - Knowledge-based Integrated Software Systems, or Knowledge-based Intelligent Integrated Software Systems, so it is good to precise what an integrated knowledge-based software system (e.g . developed within KISS) could mean for the engineering practice directly, for instance when dealing with structural problems related to structural assessment of a power plant component.

The component may be dangerous, people who built it may be long gone, a lot of data is missing, documentation is in a poor state, ... still, the new component may be very expensive, its delivery time long, and, after all, why should one replace it if it still works, or can continue to work after a minor repair! The answer has to be provided by an engineer who should presumably be supported by a KISS-based system. The answer would then contain the following steps:

a) Retrieve necessary data / information regarding
- material
- operational history
- loads
- applicable standards, codes, etc.,

KISS-support: "conventional" databases.

b) Retrieve necessary background data / information regarding
- applicable standards, codes, etc.
- similar cases (case studies)
- relevant literature

KISS-support: e.g. from hypermedia databases.

c) Make necessary calculations / analyses (e.g. finite element ones)
KISS-support: use numerical programs

d) Recommend necessary further actions involving (a), (b) or (c), ask for missing information / data
KISS-support: use knowledge-based systems

d) Make all necessary warnings recommend solutions and support the decision
KISS-support: use knowledge-based systems

e) Communicate with the user and record the work in the most appropriate way **KISS-support:** use knowledge-based systems and hypermedia

In addition a KISS can help to meet (the usually very high) expectations in each single subarea tackled by an integrated system. In each of these parts one regularly meets the same dilemma: to program these parts in the expert system shell (and thus avoid the compatibility problems) or to integrate off-the-shelf solutions (and thus avoid the problem of developing in unoptimized environment); e.g. one can program a database also in Lisp but at what cost and with what performance. There is also regularly the need to optimize the system ("a system preferably as big as possible on a machine as small as possible") and this objective can practically be reached by using, i.e. integrating the software already optimized for particular tasks. The second option, to integrate off-the-shelf solutions, is the approach adopted by MPA within its KISS.

A KISS can thus help to integrate two basic elements of each engineering decision: knowledge AND information.

TECHNOLOGY - TRENDS AND KEYWORDS OF INTEGRATED SYSTEMS

The "hardware/software technologies" to be used in an engineering application must be: reliable, available (on the market) and proven. In the area of knowledge-based systems these technologies nowadays are available in the form of PCs and workstations, as well as the DOS / Windows 3.1 and Unix operating systems. As the PC-based solution appears to be of a particular interest for the on-site applications, the paper will tackle these ones more in detail further on.

The list of important keywords which are relevant for the today's and tomorrow's integration can be compiled in many different ways, but in its essence it should contain at least:

- networks ...
- PCs, Workstations ...
- DOS, Windows 3.0, Unix ...
- Graphical User Interface (GUI, user-friendliness) ...
- Object oriented
  - · programming (OOP)
  - · databases (OOD)
  - · interfaces (OOI)
  - · languages (OOL)
  - · tools (OOT) ...

The enabling technologies for achieving the integration of knowledge-based, hypermedia and conventional software systems are:

a) the widespread availability of local area networks, which allow one to interconnect software running on different machines

b) the move towards similar computing power in both PCs and workstations, which makes it possible to develop and deploy integrated solutions on both

c) the increased acceptance of a graphical user interface, which allows the design of more user-friendly and task-centered interfaces

d) the adoption of object-oriented software technologies, which allows the development of systems which are more portable and maintainable

Together they provide necessary tools and techniques for integrating knowledge-based, hypermedia and conventional software systems in engineering applications. The integration of these three types of systems offers both short-term and long-term advantages to system developers in the field of structural engineering:

Short-term: Integrating already existing applications allows the developer the opportunity to offer an additional level of functionality, by simply exploiting the different ways in which existing software can be made to work together.

Long-term: Once a first level of integration has been achieved, the functionalities of the different applications can be extended and an additional level of integration can be achieved. As one becomes more familiar with this higher level of integration, it becomes easier to incorporate new expected developments in the field of AI and other adjacent fields. This is very important because some of these developments (multimedia, pen-based computing), now still in a research stage, can quickly become the standards of tomorrow.

PRACTICAL ISSUES OF THE PC-BASED INTEGRATION

Main practical issue in any integration is probably the way (ways) in which the integrated elements can communicate with each other (the so called IPC - interprocess-communications). A presumably comprehensive list of IPCs available at the PC/DOS level today should include the following ones:

1) exchanging data via intermediate files
2) including functionalities from other programs through "static" linking of (e.g.) libraries
3) starting other processes (execute) from within the master program (process).
4) Cut-and-Paste facility ("Clipboard")
5) Dynamic Data Exchange (DDE)
6) Dynamic Link Libraries (DLL)
7) Object Management Facility (OMF)
8) Object Linking and Embedding (OLE).

In most of the existing computer operating systems the IPC were limited to (1) to (3). As a subclass of the last case (offered only by some programs - not by the operating systems themselves) one could identify also the possibility to start some programs with predefined scripts (i.e.the new process can be started from different points, as specified in the script). All these IPCs are very static and are, therefore, often designated as "cold" ones.

The processes communicating in such manners remain independent and virtually unaware other ones. A true integration requires better tools and many of them have been offered with the new version of Microsoft's Windows 3.x. These new options like DDE, DLL and OLE "open the horizons" in the programming of integrated systems. Virtually all of them have been exploited in the ESR System of MPA Stuttgart (Jovanovic and co-workers, 1991).

APPLICATION EXAMPLES

US RESEARCH - E P R I SYSTEMS

U. S. electric utilities have had success in applying expert systems to power plants in areas such as mechanical diagnostics, plant performance monitoring and control, maintenance, failure analysis, construction, coal quality impacts, and environmental control system operations. These applications reflect the industry need for increasing the productivity of valuable corporate assets, including power plants and the people who run them. A representative subset of the US research is certainly the research performed at EPRI (Electric Power Research Institute - Palo Alto, Ca.) - presented more in detail in the work of Gehl and Jovanovic (1992).

EPRI's approach to expert system development has been to concentrate on the needs of the utility users. This philosophy has led to an emphasis on problems that have a high consequence for the industry, easy-to-use computer programs running on desktop computers, and the incorporation of engineering analysis functions along with expert systems in the final product. Both off-line and on-line expert systems have been developed: two off-line systems, the Boiler Maintenance Workstation (BMW) and the Vibration Advisor (VIAD), and one on-line system, the Generator Expert Monitoring system (GEMS): the BMW-system can illustrate this approach.

Boiler tube failures are the leading cause of availability losses in U. S. fossil power plants. Each year, the industry averages nearly 4% lost availability in large fossil plants due to boiler tube failures. The causes of most of these failures are understood in sufficient detail to allow the specification of operating practices and plant modifications to minimize the occurrence of future failures. EPRI has integrated the available knowledge base, and supplemented it with new research where necessary, to develop a comprehensive program for reducing boiler tube failures.

The BMW computer system (Valverde and co-workers, 1989) contains modules that:

a) maintain a data base on failures, repairs, and tube replacements;

b) analyze and display data on water wall, superheater, and reheater tube thickness and predict the occurrence of stress rupture failures in these components;

c) predict long-term creep failure of superheater and reheater tubes; and

d) diagnose the causes of boiler tube failures. The expert system that performs the diagnostic function is called ESCARTA.

EUROPEAN RESEARCH – M P A SYSTEMS

Characteristic examples of European expert systems discussed in the work of Jovanovic, Gehl (1991) are those of TU Graz (boiler tubes, material selection), the prototype developed within the so called Interest Club (JRCs Ispra and Petten, participation of UK, Belgian and Italian utilities and MPA Stuttgart – the prototype tackling headers), the RAMINO system being developed within the BRITE project, the systems developed at KU Leuven for corrosion analysis (ALC/ESCORT/PRIME), and the ELBA and ESR systems of MPA Stuttgart tackling leak-before-break analysis of piping and damage assessment of the high temperature piping in power plants, respectively. The highest industrial potential have probably two of them: ESR and ALC/ESCORT/PRIME (Vancoille, Bogaerts, Perdieus, 1989).

The ESR project (Jovanovic, Maile, 1991) of MPA Stuttgart (ESR – Expert System for Remaining life assessment, or Expertensystem für Schädigungsanalyse und Restlebensdauerermittlung) addresses the problem related to possible failures of high temperature pressurized components (piping, pipework subcomponents, etc.), in power and other industrial plants. The system is envisaged as a way to summarize, structure and make reusable human expert experience gathered in current practice, in an engineering environment where the regulatory requirements are numerous and tough and where the tradition to rely on deterministic and numerical calculations is very strong. The major generic requirements imposed by the utilities are:

- improve safety and availability of piping systems
- support and help personnel in performing usual maintenance tasks
- support and help personnel when dealing with specific sub-problems
- provide recommendations during the annual inspections (revision)

The ESR project has been started at MPA Stuttgart in 1989–90 (Jovanovic 1989). Initial requirements were imposed by five south German utility companies (Badenwerk, EVS, GKM, Neckarwerke and TWS) and the lessons learned though the MPA's participation in the ARTIC project (Lucia, Servida, Bressers, 1990) shaped the initial lay-out of the ESR project and ESR system. Laborelec form Belgium and IVO joined the project in 1990, and utility consultants ISQ from Portugal and SGP-VA from Austria did it in 1991. The project is thus now sponsored by nine power engineering companies from Austria, Belgium, Germany, Finland and Portugal. Some other countries expressed their interest to join the group, too (e.g. EPRI).

PRACTICAL DEPLOYMENT

A hypothetical example of deployment of above mentioned systems in a power plant, using EPRIWorks or some other, similar, integration framework is shown in figure 4.

CONCLUSIONS

The power of computer and KBS technology applied to MSE/SIA has caused significant changes in this field. Dedicated expert systems are likely to be used much more in the future. These expert systems are likely to be transparent to the user, so that the user will be conscious of all the functions performed: like e. g. analyzing inspection data, or planning for the next maintenance outage, but will probably be unaware that a powerful expert system is operating in the background to check data and calculations. These systems should markedly reduce the chances for human error in critical activities. Another class of systems (like ESR – expert systems for experts) will support the experts by making the access to all necessary data, information and knowledge sources available in the "computerized form"easier.

Three principles should guide the selection of areas for expert system application. First, sufficient expert knowledge should exist to allow the generation of consistently reliable solutions to actual plant problems. Second, the application should provide improvements in performance parameters that are not readily obtainable by traditional computational approaches. Third, the application should address knowledge domains in which human expertise is expensive or scarce. In addition, it is important to give consideration to the user perception of expert system technology; early failures can cast doubt, while dramatization of successes can overstate the true capabilities of the technology. Even with this caveat, it is clear that most well-designed expert system applications have been successful, and the industry response to these successes will insure the future growth of the technology in real world applications.

First experiences with installations in power plants have clearly shown KBSs are suitable for a whole series of sub-problems in the field of MSE/SIA (e.g. remaining life assessment, failure risk assessment, crack susceptibility, etc.).

Deployment of KBSs will help in achieving a series of economic and technical benefits. Improved availability of systems and plants, shorter and better utilized maintenance periods, reduced costs of scheduled inspections due to the optimized inspection strategy– re-

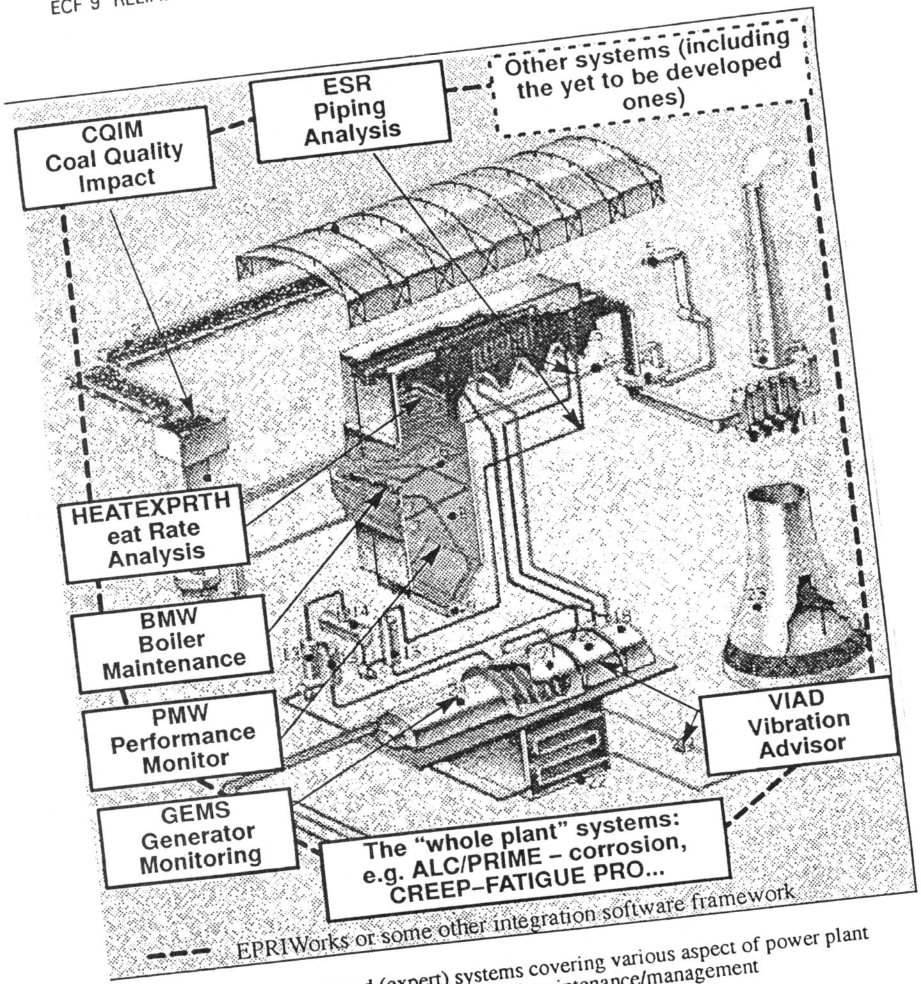

Fig. 4 – Knowledge-based (expert) systems covering various aspect of power plant operation, engineering analysis and maintenance/management

duced costs of daily operation (specialists called only when necessary), reduced unplanned costs, or improved possibilities for the life extension of the plants, are only some of the goals to be mentioned. Quality of decision and advice, the human-computer interaction, the system efficiency and the cost effectiveness will be imposed as the main verification criteria.

REFERENCES

Begoray, J.A. (1990). An introduction to hypermedia issues, systems and application areas. International Journal of Man-Machine Studies, **33** (2), 121-147.

Chandrasekaran, B. (1990).What Kind of Information Processing Is Intelligence in *Foundations of AI: AI Source Book*. Eds. D. Partridge and Y. Wilks, U.K. Cambridge Univ. Press

Gehl. S. M., Jovanovic, A. (1992). Trends in development of computer workstations for operation and maintenance of power plants. Proc. of the VGB Conference "Residual Service Life", Mannheim July 6 and 7, 1992

Jovanovic, A. (1989). ESR project: Expert system aided assessment and management of remaining life of pressurized high temperature components (in Expert System in Structural Safety Assessment. Jovanovic, A., Kussmaul, K.F., Lucia; A.C., Bonissone, P., Eds.), Springer-Verlag

Jovanovic, A., Bogaerts, W. (1991). Hybrid knowledge-based and hypermedia systems for engineering applications, Avignon '91 Conference Expert Systems and their Applications (vol. Tutorial Nr. 13), Avignon, May 27-31, 1991

Jovanovic, A., Bogaerts, W. (1992). Integrated knowledge-based and hypermedia systems for engineering applications, Avignon '92 Conference Expert Systems and their Applications (vol. Tutorial Nr. 8), Avignon, June 1-5, 1992

Jovanovic, A., Kussmaul, K.F., Lucia; A.C., Bonissone, P., Eds. (1989). Expert system in structural safety assessment, - Lect. Notes in Engineering, vol. 53, Springer-Verlag

Jovanovic, A., Maile, K. (1991). An integrated knowledge-based system for structural assessment of high temperature power plant components, Proc. of the Avignon '91 Conference Expert Systems and their Applications (vol. 3 - Applications), Avignon, May 27-31, 1991

Lucia, A. C., Servida, A., Bressers, J. (1990). Expert system for creep damage assessment and headers management, Proc. of the "High Temperature Structural Design" Conference, Venice, Oct. 24-26, 1990

Valverde, J., Gehl, S., Armor, A., Scheibel, J., and Divakaruni, M. (1989). Fossil Power Plant Applications of Expert Systems: An EPRI Perspective. Proceedings of the American Power Conference, Chicago, IL, April, 1989.

Vancoille, M. J. S., Bogaerts, W.F.L., Perdieus, F. (1989). AI-based corrosion risk analysis in oil refinery operation. In Expert Systems in Structural Safety Assessment (Eds Jovanovic, A.S., Kussmaul, K.F., Lucia, A.C. and Bonissone, P.P.), Lecture Notes in Engineering, Vol. 53. Springer-Verlag, Berlin, Heidelberg, New York

Woodhead, N. (1990). Hypertext and hypermedia: Theory and applications. Sigma Press, Wilmslow, Addison-Wesley Publishing Company, Wokingham, Reading, Menlo Park, 231 pp.