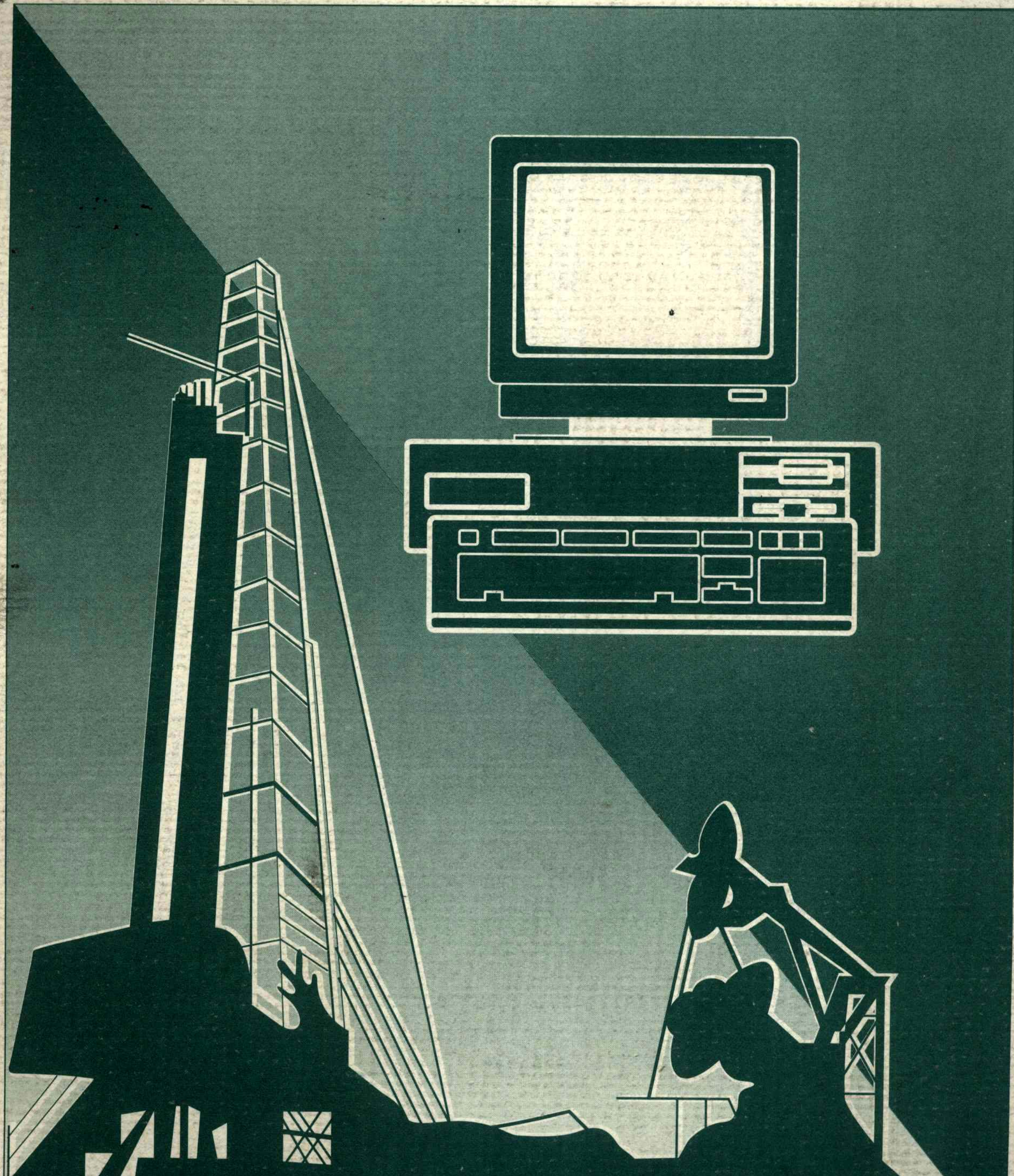
SPE REPRINT SERIES

NO. 41

EXPERT SYSTEMS IN ENGINEERING APPLICATIONS



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EXPERT SYSTEMS IN ENGINEERING APPLICATIONS

1996 Edition

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Editor's Note: Although reproduction-quality copies were unavailable for a few papers in this volume, they appear because the technology they present is central to the content of this book. We regret that the affected pages do not conform to SPE's usual standard.

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PREFACE

This book is intended to provide both an overview and a reference on the use of expert systems in engineering applications for the petroleum industry. The organization of this book was planned to help the reader focus on the specific interest that provided the attraction to this collection of papers and references. The Overview section includes two papers that give a perspective on the use of expert system technology in the petroleum industry. While the industry survey paper by Braunschweig dates back to 1989, it demonstrates the serious investment made by the industry in this technology by estimating that as of 6 years ago, approximately $300 million had been spent on expert-system development. The more recent paper by MacAllister *et al.* describes the experience of one company with this technology over a 5-year period. The Technology Milestones section includes two papers describing projects carried out in the early 1980's, both of which are considered classics and helped set the direction for development that followed. The other sections in the volume include papers that describe projects in the various disciplines of petroleum engineering; these sections cover Drilling Applications, Formation Evaluation Applications, Production Engineering Applications, Reservoir Engineering Applications, and Related Technology Applications. The committee reviewed approximately 200 papers before choosing those that are included in this volume and referenced in the Annotated Bibliography.

The use of expert systems is still a comparatively young technology, with the oldest paper in our references dating back to 1983. As demonstrated by the number of papers that were reviewed for this book, the technology has been embraced with fair enthusiasm by a number of companies in the petroleum industry with varying degrees of success. Papers are included that describe expert systems costing many hundreds of thousands of dollars to build that are not being used today, and papers are included that describe expert systems built for a few tens of thousands of dollars that are being widely used and returning their building cost many times over. Some papers describe projects that never moved beyond the prototype stage, while others describe systems that have been fielded successfully. Some expert systems are reputed to have been so successful that the companies have not allowed their developers to publish papers on them or even disclose their existence. From this spectrum of results, it is apparent that the selection of appropriate applications, development tools, and development teams is not a simple process, and success cannot necessarily be guaranteed by a large budget. Accordingly, one objective of our committee has been to provide a sufficient survey of various projects so that, by careful analysis, criteria can be developed to help ensure more successful projects in the future.

An area of complexity is that expert-system technology has undergone a significant evolution during the past 10 years or so. Early expert systems were often developed in computer languages like LISP on specialized single-user computers called LISP machines that cost more than $100,000. Today, most expert systems are developed with expert-system "shells" that run on commonly available PC's and workstations with modern graphical user interfaces, such as Microsoft Windows and OSF/Motif. In addition, many expert systems are losing their identity as they are embedded as "smart" components in conventional software systems. In spite of this evolution, the expert knowledge that is captured in an expert system has significant value and can often be used in subsequent systems, as described in one of the papers in the Annotated Bibliography. We hope that the observant reader will be able to observe this evolution of technology while reading this book.

Those working on this book endeavored to seek out every publication on this topic, to evaluate them, to retain them as references in the Bibliography, in some cases to annotate them, and in exceptional cases to include them in this book. If relevant papers and articles were missed in this process, their omission was unintentional, and we offer our apologies. There are related technology areas, such as neural networks and genetic algorithms, that are sometimes classified with expert systems that are being used with success in petroleum engineering applications. The committee decided not to include papers on the use of these technologies with the view that they are sufficiently significant that they will soon justify a separate Reprint Series volume.

Occasionally, someone will take offense at the term "expert system." A sometimes more palatable and equally valid term is "knowledge-based system," and we ask any reader who is bothered by the title to make this substitution.

I want to thank the members of this Special Reprint Committee for doing their job in a commendable and professional manner. It has been a pleasure to work with you on this project. Finally, I want to thank the Society in general and the Reprint Series Committee in particular for recognizing the need and commissioning a critical coverage of this important body of knowledge.

James W. Bridges, Chairman

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ARTIFICIAL INTELLIGENCE IN THE PETROLEUM WORLD

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ARTIFICIAL INTELLIGENCE
IN THE PETROLEUM WORLD

This paper shows the main results of a survey conducted by the *Institut Français du Pétrole (IFP)* on the applications of artificial intelligence (AI) in the oil industry. The survey was made in 1989 by interviews with specialists from the petroleum industry and from the academic world. This investigation produced as a result a synthetic document which presents, on an anonymous and statistical basis, the major trends of research and applications involving artificial intelligence in the oil industry. All organizations which agreed to participate in this study are in possession of one copy of this document.
This paper will try to highlight the major trends identified by the survey, and show some detailed results. The figures present the interview data base, which consists in 150+ application questionnaires and 30+ questionnaires on organizations.

I LIMITS OF THE SURVEY

A. Geographical

The interview forms were sent to selected specialists all around the world. The majority of answers we received was from **Europe, North and South America.** There does not seem to be much AI work neither in the Middle East nor in Africa. However, there are well-known projects in the Far East (mostly in **Japan**) and in **Australia.**

B. Domains

As the research domains of IFP cover **all activities of an oil producing and refining company,** the domain of the survey was the same. That is, we were interested in getting interviews on applications in geology, geochemistry, geophysics/ seismic processing, reservoir engineering, drilling, completion, onshore and offshore production, physico-chemistry and thermodynamics, kinetics and catalysis, refining, petrochemistry, process engineering, safety, regulations, transportation and uses of oil and gas. We did not collect data about non-technical projects such as accounting, personnel management, strategic planning, which are of interest for large oil companies but were not selected as critical for the IFP survey.

We obtained more information about exploration and production-related applications than refining and petrochemistry. This is mainly due to a larger number of projects in the first domains, and to the existence of more specialized international conferences on petroleum exploration and production. This paper gives both general (including refining and petrochemistry) and specific views.

II GENERAL REMARKS

Artificial intelligence is applied, successfully and unsuccessfully, to the whole spectrum of petroleum industry. From fundamental research on geological knowledge representation to application software for indicating how to better clean an empty tanker, hundreds of projects were started — and often completed — by petroleum engineers and AI specialists. Some of the most frequently mentioned expert systems were initiated by major oil companies and oil services firms. Lots of academic research is sponsored by the petroleum industry, be it theoretical or applied to petroleum-related subjects. Almost every oil company has a few AI groups, although sometimes very small compared to other industries such as electricity, transportation or finance. In this survey, which is limited to Europe and America, more than **one thousand man-years** were identified as spent by the petroleum industry on AI related projects. As we interviewed only half of the large companies, our estimate is that the overall amount spent during the last ten years is somewhere **between 2000 and 3000 man-years,** that is not too far from $300 million.

It is worth to notice that the second wave of expert systems (the so-called « second generation expert systems ») seems to take place together with an equivalent second wave of AI applications, initiated not only because of this methodological step, but also linked to the oil crisis of the late eighties. This crisis had conflicting effects on the AI teams and projects within major companies : some teams were closed due to a lack of research funds, but new projects started because of the need to do about the same job with less and less-experienced people. As long as the price of crude oil will remain close to $20/bbl, there will still exist some development and research money available for AI.

The petroleum industry is extremely contrasted, as observed though an AI lens. A very small number of companies made some major advances, and decided that knowledge-based systems were now an ordinary part of information systems, and kept the research teams on more advanced subjects. Others started with the second wave, and have still to prove theses techniques' usefulness. As mentioned in Feigenbaum's famous book "The Rise of the Expert Company", the development of AI within an organization relies on the existence of one or few "champions", enthusiastic people who strive for demonstrating the new technology to interested but careful managers. The oil companies who possessed such champions are now ahead of the others. They are now looking into neural networks, as many other industries are, realizing that the investments are much lower and that the benefits are measurable.

III WHAT ARE THE MAIN DOMAINS ADDRESSED ?

In this chapter we will look at what can be considered as the most typical AI developments made in 1989. The oil industry likes to address almost every activity by the means of AI, but there are some themes that are met frequently. Most of them are very technical themes : until recently, the oil industry was a world of technical people, which is now looking into finance or other subjects, and the people tried to apply AI methods to technical problems :

A. In Terms of Application Domain

• In **geology, geochemistry, geophysics** : several sorts of log interpretation and correlation, based on either rules, pattern recognition algorithms, structural geometry, neural networks or bayesian classifiers; several approaches on basin and prospect appraisal, using vision algorithms, data analysis, rule induction, deep modeling, large object-oriented networks; analyses of rock samples, chromatography or pyrolysis data by either rules or neural nets; semi-automatic generation of code or data for the use of various kinds of software, most often with rule-based object-oriented tools; expert systems for diagnosing the hexadecimal content of seismic tapes; rule-based seismic velocity picking; interpretation of local seismic signals by neural networks; interpretation of multiple seismic signals by large object-oriented systems; interpretation of a whole seismic section by constraint-propagation algorithms together with declarative knowledge.

• In **reservoir engineering** : fluid properties characterization by rule-based systems and thermodynamic models; reservoir models identification by analysis of well tests with rule-based systems or neural networks; intelligent, front-ends for reservoir engineering software packages, either rule-based or object-oriented; several types of technical analysis of reservoir (formation damage, waterflood monitoring, enhanced recovery, other reservoir characteristics) with expert systems; knowledge-based planning and execution of a whole reservoir engineering study.

• In **drilling and completion** : directional drilling preparation (selecting tools and choosing a path) with expert systems; knowledge-based mud selection; drilling tool selection and monitoring by means of expert systems or neural networks; several systems for controlling the drilling process, diagnosing dangerous situations and proposing means for recovery — all these systems based on signal preprocessing and ruled-based analysis; expert systems for giving advises on the most appropriate cementation method for a specific well and for analyzing it after it is made; automatic planning of a drilling campaign, using weak constraint propagation algorithms.

• In **offshore production** : large knowledge-based systems for designing treatment modules and tools such as separators, pumps; expert systems and qualitative reasoning for controlling the production process at various stages (whole production process, gas lift, rotating machines using vibration data, specific equipment monitoring and diagnosis); diagnosis/maintenance of all kinds of equipment, and alarm filtering, most often with model-based reasoning; expert systems for helping enter data in finite elements software for offshore structures calculations; many rule-based systems for safety studies : risk monitoring, automatic planning and scheduling of security tasks, selection of methods to use in emergency situations.

• In **transportation:** pipeline design with motion planning techniques and geometrical reasoning, expert system for pipeline scheduling; knowledge-based systems for different applications for tankers.

• In **refining and petrochemistry:** some applications on process design, usually with traditional rule-based expert systems (distillation units, hydrocracking, several types of separators, corrosion problems) combined with numerical calculations generally in FORTRAN; object-oriented system for designing flowsheets; intelligent helps for modeling these processes and their chemical reactions; lots of process control systems for all kinds of equipment, although very few pretend to be on-line and almost none works in closed loop; all these systems use both rules and causal or functional models, often with object-oriented facilities; lots of applications for the diagnosis and maintenance of the same equipments: alarm filtering, optimization, troubleshooting, signal processing for rotating machinery; sometimes these systems are developed together with a simulation model of the plant, in order to validate the knowledge base before installing it on the real unit; automatic scheduling systems for the weekly program of a refinery.

• In **utilization :** lubricant formulation with knowledge-based systems linked to existing products databases, associative memory for estimating properties of products with neural networks, fault detection in engines.

• In **safety studies :** several kinds of knowledge-based systems for helping supervision personnel to apply the sets of existing regulations when preparing security tasks or in emergency situations; hypertext facilities for browsing among large contractual, technical or legal documents. Rule-based systems linked to conventional algorithms for risk analysis on all types of equipment; intelligent front-ends for the use of risk analysis packages.

B. In Terms of AI

• **Expert systems and knowledge-based systems.** Expert systems are the most popular AI technique applied to the whole spectrum of the petroleum industry. Knowledge acquisition techniques, however, are seldom used: almost all knowledge elicitation is made by traditional means, that is, interviews of experts, readings of books and articles. When knowledge acquisition tools working on PCs will become widely available, the picture will change. We would like to underline that the availability of such tools would be an incentive for developing the large knowledge bases that are needed by our industry.

• **Vision.** A few systems pretend to do some sort of artificial vision; most of the time, they use pattern recognition algorithms or simpler transformations for recognizing features in images or graphics. This field of AI is not very popular in the petroleum industry.

• **Robotics.** The robotics applications are not developed by the AI people, but rather by specialists who try to automate the installation of subsea modules, or the safety tasks in large plants. These applications are not part of this survey.

• **Natural language.** No questionnaires mention any natural language interface.

• **Man-machine interface.** It is difficult to isolate applications whose main goal is to improve the communication between a user and a computer; almost every knowledge-based system pretends to do so, even if it does not use windows, icons, mouse etc. The few applications which were mentioned as "man-machine interface" applications are not different from the others.

• **Plan generation.** Automatic planning techniques are applied in the oil industry to various domains : for safety exercises, for project planning, for resource allocation, for generating sequences of software calls, for refinery production scheduling, and some others. Knowing what the state of fundamental research is in the field of plan generation, it is rather surprising to find so many attempts. However, only simple and conventional planning methods are used; the well-known difficulties of developing general planners are left out by using diagnostic-like planners on very precise subjects, apart from one or two more ambitious applications.

• **Classification.** Lots of classification-like problems are approached with expert systems or neural networks techniques : classification is an important part of a petroleum engineer's activity and therefore has been subject to several AI developments : oil basin appraisal, well-test models identification, well-log data interpretation, microorganisms recognition, reservoir models selection etc.

• **Intelligent Data Bases.** Rather than developing so called "intelligent data bases", practitioners integrate the use of existing databases in their knowledge-based systems : applications are not standalone anymore, and all available data and programs are taken as major knowledge sources for the second-generation expert systems; some examples : chemical products properties database to be used in thermodynamic models adjustment, technical database for monitoring and diagnosing rotating machinery, existing wells database to be used for the planning and control of directional drilling, attempts to induce rules from database of cases in several domains (geology, production, process etc.).

• **Simulation.** Once again, AI applications do not

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change the way in which simulation programs are made or used, but rather try to use existing simulation software as additional procedural knowledge. This approach is found in almost every subdomain, due to the existence of simulation models of all sorts.

• **Neural Networks (NN).** As neural networks are becoming more and more popular, the oil industry is evaluating this new paradigm of computer programming. Almost every major oil company or oil services firm has some NN projects, although some are more advanced than others. NN research started in the oil industry with exploration and production projects (in geology, geophysics, reservoir engineering, drilling and production), and new attempts are now expected in downstream activities. This is encouraged by the fact that NNs are cheap compared to knowledge-based systems, where a typical demonstrator takes some months and a prototype some years, whereas constructing a backpropagation network for a specific set of data takes days or weeks, and the currently available development software cost between five hundred and five thousand US$. We will see dozens of small applications in less than one year, but no-one pretends to have fielded one NN system until now.

• **Others.** We have seen some developments in the following AI fields : Qualitative physics, model-based reasoning, hypertext, constraint propagation networks.

There are much less applications using these techniques than could be made; in particular, hypertext applications are not frequent although the techniques and tools (i.e. HyperCard, Guide) are very simple and accessible and could be usefully employed for technical documentation in several domains.

IV SOME NUMBERS

The following figures show some uncorrelated statistics extracted from our interview data base.

A. From Application Questionnaires

1 Problem Type (Fig. 1)

The first problems approached with AI methods (diagnosis and interpretation) are still very popular among petroleum applications. Pure process control applications are starting, although some were indicated as diagnosis/maintenance. The theme of intelligent front-ends was not listed in the questionnaire, but appeared to be a major problem type being addressed by new projects. Even if the technique is not very mature, some plan generation applications with ambitious goals were identified.

2 Status in 89 (Fig. 2)

The project status in 1989 indicates how much progress we need to make before seeing AI accepted as an operational tool. A large majority of projects are still limited to demonstrators, prototypes, β-tests; a few others are completed but not used anymore. There are only a dozen software which may be considered as products, either

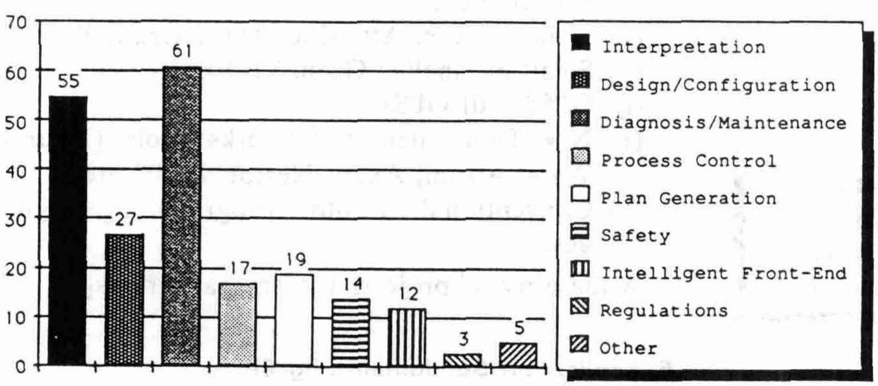


Figure 1
Type of problem.

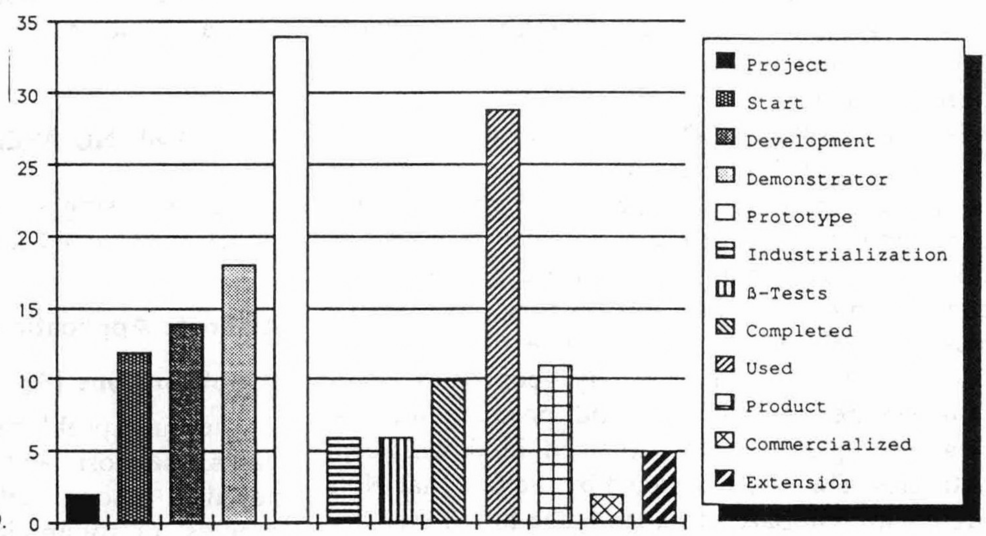


Figure 2
Status in 89.

internally used or commercialized. Only five are now in an extension phase, meaning that the first generation of the software has been accepted and that new features are being implemented.

3 Project Cost (Fig. 3)

A large majority of AI projects are small projects, with budgets well under .6 M$ (FF 3M). Most oil companies tend to like projects with limited goals, on very precise domains, instead of large knowledge bases trying to formalize the expertise in a wide domain. However, there are a few important developments, but they are not purely AI. These projects often use AI as one of the development methodologies among others such as simulation, parallel processing, etc.

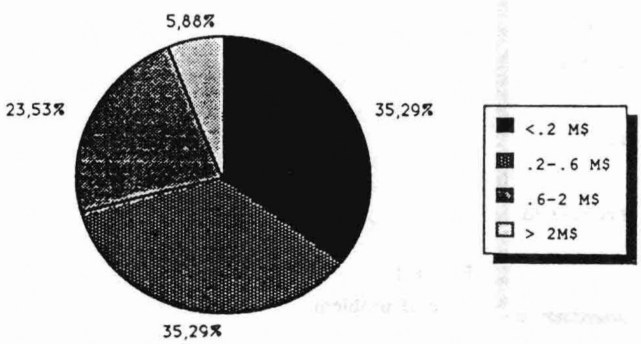


Figure 3
Project cost.

4 Computers and Software (Fig. 4, 5)

In the next figures, the following groups are made:

(a) Dec Vax : all VMS machines including mainframes, VaxStations, MicroVaxes;
(b) Unix workstations : Sun, HP, Apollo etc.;
(c) AI stations : Symbolics, Xerox, Explorer etc.;
(d) Lisp : all Lisps (Common Lisp, InterLisp, LeLisp etc.);
(e) Prolog : all Prologs;
(f) ESE/ADS : AI development software on IBM mainframes;
(g) Hybrid : Kee, Art, Knowledge Craft, Kool;
(h) Small PC shells : Guru, VP-Expert, XI+, etc.;
(i) OPS5 : all OPSs;
(j) NN Tool : neural networks tools (NeuralWare, Ansim, Axon, Nestor, PDP3 etc.);
(k) Conventional : all other programming languages.

A majority of projects use several languages.

5 Application Subdomain (Fig. 6)

This figure shows a predominance of upstream applications in our interview data base. Geology, Production, Reservoir Engineering and Refining are the most frequently mentioned domains.

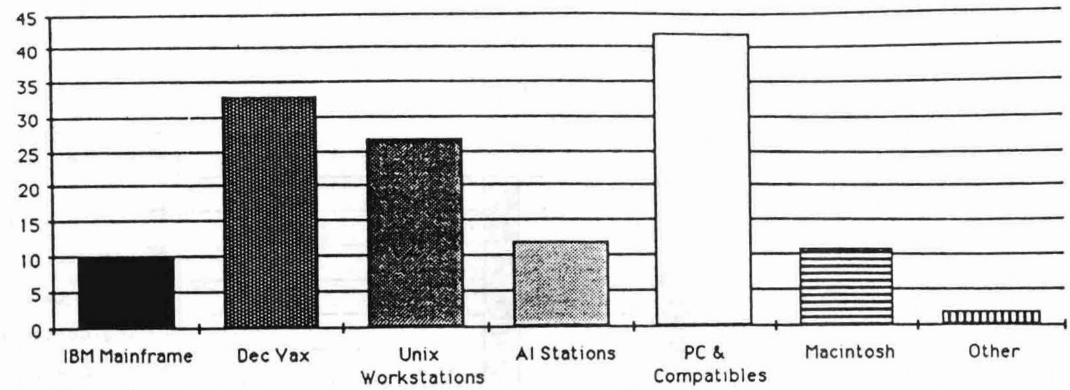


Figure 4
Type of hardware.

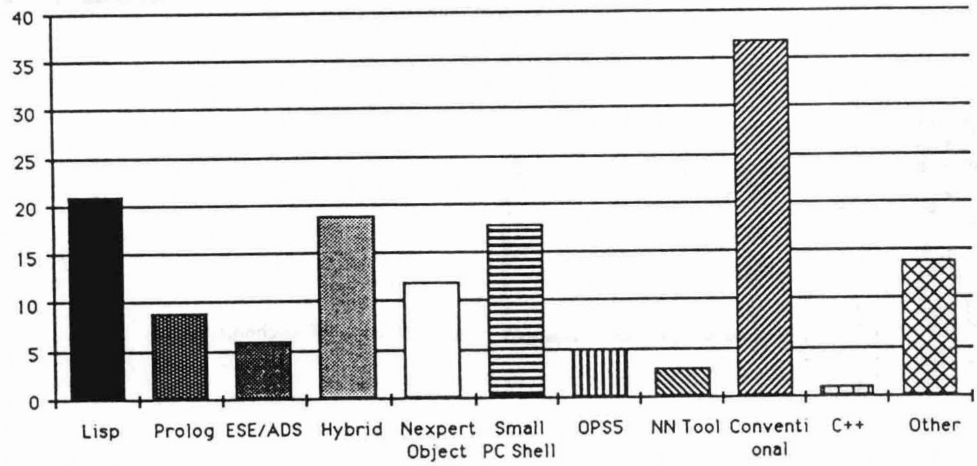


Figure 5
Type of development software.

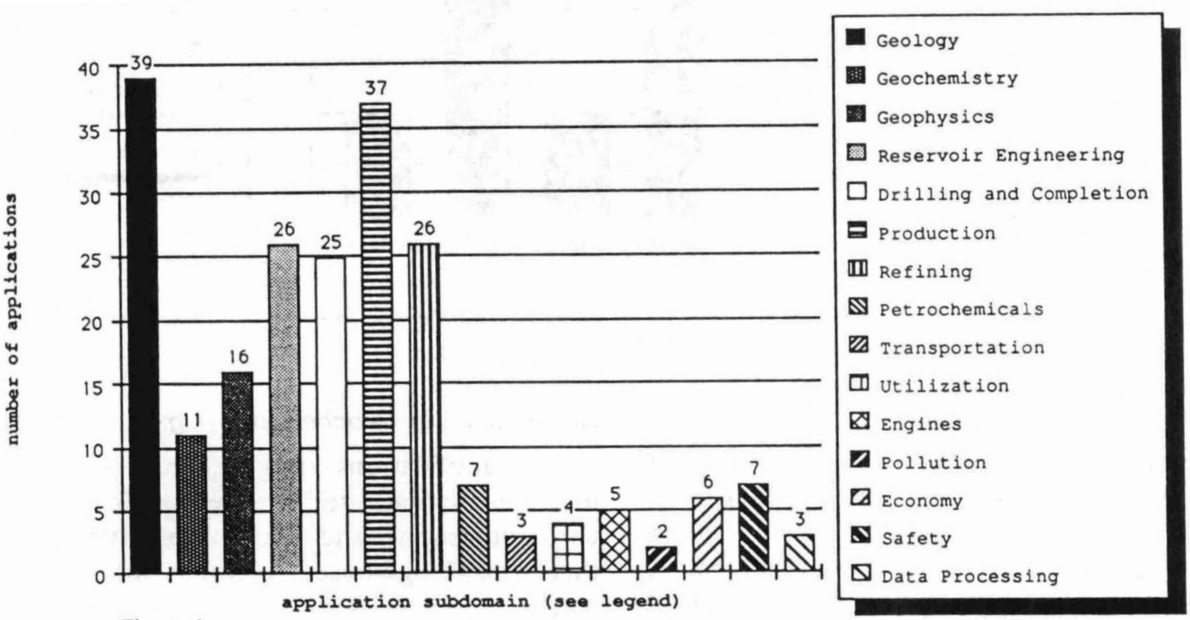


Figure 6
Application subdomains.

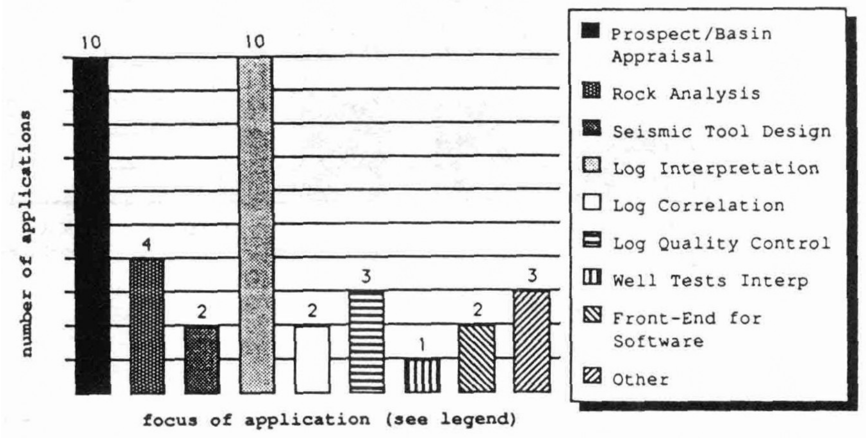


Figure 7
Applications in Geology.

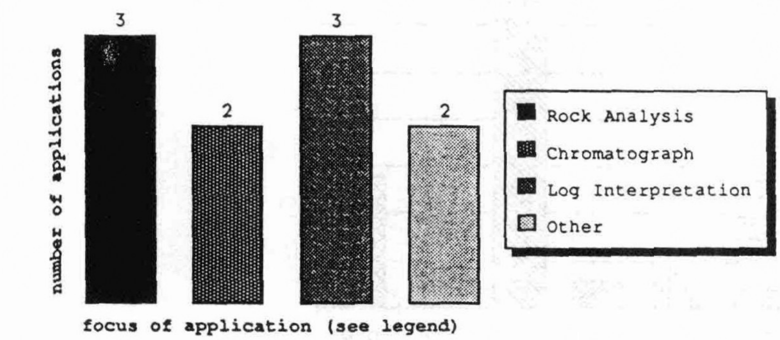


Figure 8
Applications in Geochemistry.

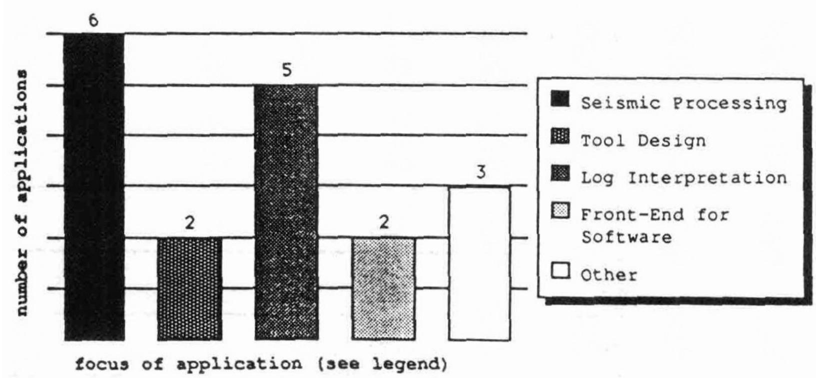


Figure 9
Applications in Geophysics.

Applications in Geology (Fig. 7)

In geology, most applications are made on prospect/basin appraisal and on log interpretation. The first one is an heterogeneous field in which all applications have unique characteristics, whereas log interpretation, correlation and control applications generally have the same ambition, although with different techniques (Expert Systems, Signal Processing, Neural Networks etc.).

Applications in Geochemistry (Fig. 8)

Ten applications in geochemistry have been identified, equally split between rock analysis, gas chromatography and log interpretation, with either knowledge-based methods or neural networks.

Applications in Geophysics (Fig. 9)

What we call "seismic processing" here are all the applications relative to one or several steps of seismic data transformation and interpretation. Two applications were mentioned for the preparation of seismic campaigns, a few others in the field of log interpretation.

Applications in Reservoir Engineering (Fig. 10)

Well pressure test interpretation is a very popular subject, and so are all applications — once again — pertaining to log analysis. As reservoir simulation models are large complex programs, several attempts have been made for developing intelligent front-ends for them.

Applications in Drilling and Completion (Fig. 11)

Process control is the main theme in drilling and completion, for both safety and cost reasons. Drilling tools design/choice and completion design are popular too, most often with knowledge-based systems, with one exception (neural network).

Applications in Production (Fig. 12)

Almost all applications in offshore petroleum production are process control and process design applications. We divided the process control application in subfields : production control, equipment diagnosis, performance monitoring. Production control is oriented towards the global production process, whereas equipment diagnosis generally focuses on the causes of failure of one equipment, and performance monitoring is concerned about keeping one equipment's behaviour close to its nominal values.

Risk analysis and safety procedures are becoming a major field for expert systems.

Applications in Refining and Petrochemistry (Fig. 13)

Surprisingly enough, process control is still not very popular among refiners. Specific AI tools for process control are commercially available but they have not been fielded yet. Equipment diagno-

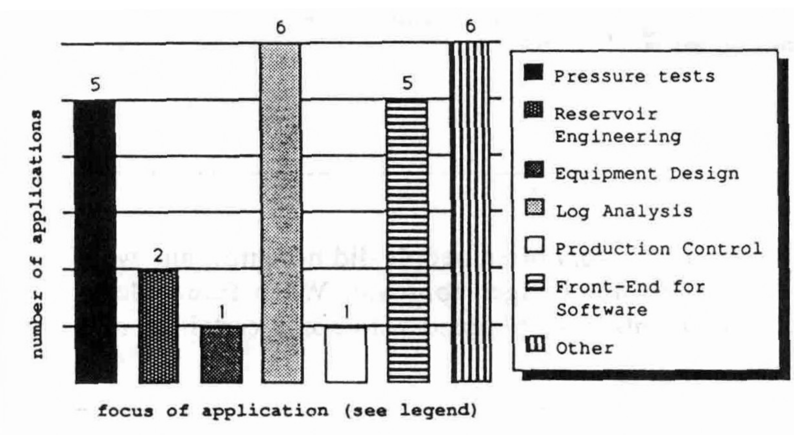


Figure 10
Applications in Reservoir Engineering.

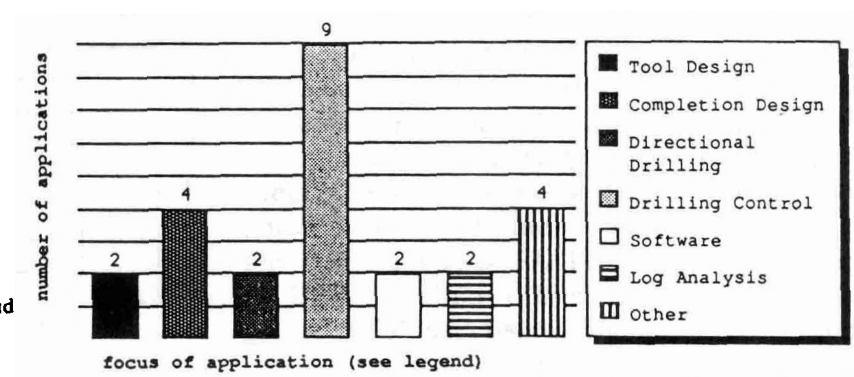
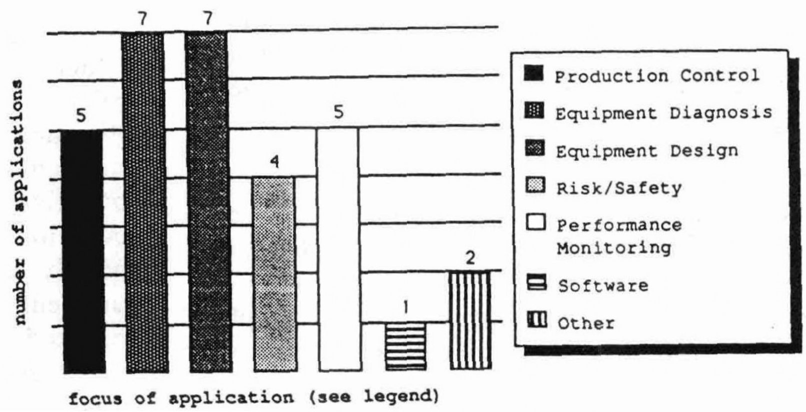


Figure 11
Applications in Drilling and Completion.

Figure 12
Applications in Production.



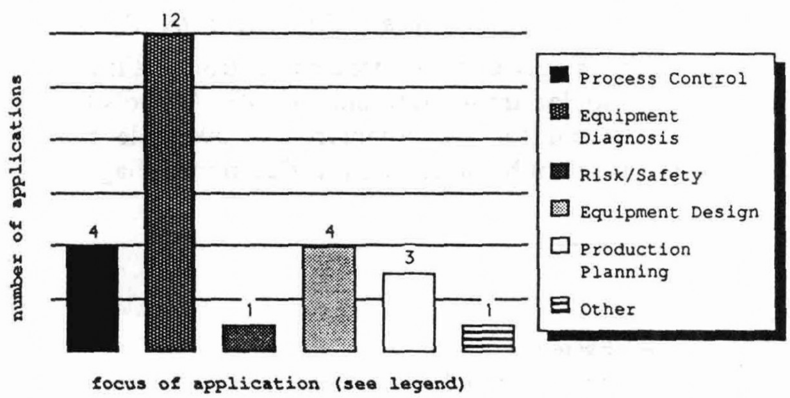


Figure 13
Applications in Refining and Petrochemistry.

sis is the main theme encountered in this application area, and some equipment design and production planning can be found. We did not find any expert system working in closed loop, whereas this already took place in other industries.

6 Satisfaction Index (Fig. 14)

People are moderately satisfied with their applications. The average value is between seven and eight, which we would call "good" or "not bad". Five applications were given a ten, and therefore could be considered as "success-stories". Once again, these indications should be taken with care, because we interviewed AI specialists and not users. Both modesty and proudness acted as opposite forces and prevented people for giving too high or too low satisfaction indexes.

7 Future (Fig. 15)

We asked the question : "what will follow this work ?". Very often people did not know and were waiting for budget approval. When future developments were planned with some certainty, in a

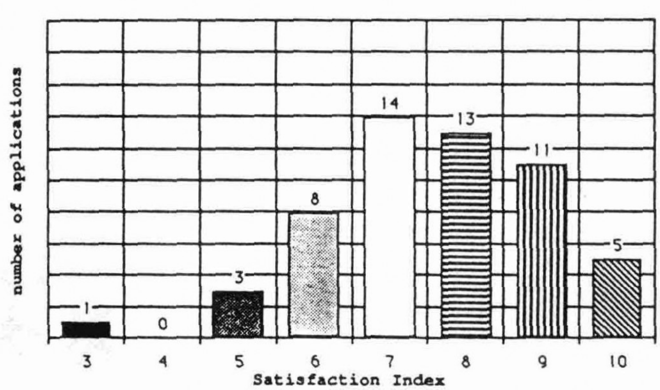


Figure 14
Satisfaction index.

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