EXPERT SYSTEMS IN THE MARINE ENVIRONMENT

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1. INTRODUCTION

This paper describes the work in progress within the world marine industry in the field of expert systems, focusing specifically upon areas of relevance to oil tanker safety and reliability. It does not address the problems of ship safety from a structural point of view, but rather from the control perspective. Although structural aspects remain crucial to overall ship safety, in the long run the prevention of accidents and machinery failures through improved crew support facilities, onboard computer systems and improved crew training are vital for the long-term future of shipping.

2. WHY ARE ADVANCED COMPUTER SYSTEMS NEEDED ?

Computer-based systems are an answer to two fundamental problems in the marine industry, costs and safety. They are not the entire answer, but when properly designed, implemented and supported, they can serve as a major weapon in the shipowner and operator's armoury.

Computer systems have become commonplace in shipping in the last 10 years, ranging from headquarters control of ship movements, finances, maintenance and spares through to onboard loading instruments, engine monitoring equipment (in unattended machinery spaces) and navigation aids (from ARPA through to GPS and ECDIS).

With the increased traffic of the 1970's, the problems of navigation became more complex, whilst the retrenchment of the 1980's and resultant cost-cutting also led to reductions in crewing levels, including moves towards the one-man bridge and integrated ship control. As this trend accelerates, future ship efficiency has become dependent upon the development of advanced technology, to permit bridge staff to monitor and control various ship functions efficiently and effectively. With the paring of manpower towards a minimum, it becomes increasingly essential for safety reasons that all systems are continuously monitored and where appropriate controlled by automatic machinery. Both safety and ship economics depend upon appropriate use of technology, and specifically upon integrated, reliable and intelligent technology.

The marine industry has traditionally been a conservative one, and has placed great emphasis on reliability and safety of equipment, leading until recently to the comparatively slow introduction of advanced technology. However, this has been rapidly changing in the last 5 years, and government and other initiatives have led to the rapid introduction of advanced computer-based systems in a variety of areas, and in-depth research into the possible introduction of expert systems into ship manufacture, management and operation.

3. A BRIEF INTRODUCTION TO EXPERT SYSTEMS

"Artificial Intelligence is the study of how to make computers do things which, at the moment, people do better" (Rich). As such, it is a continually changing discipline, with subjects previously considered as 'pure' AI emerging slowly into the commercial world. As with user interface tools, parallel hardware and pattern recognition, this has now happened to expert systems.

3.1 Expert Systems and Their Applications

Expert systems are computer programs within which the knowledge of human experts in a specific domain is stored and applied to solve problems, in such a way that the knowledge itself is represented explicitly, and separately from the mechanism by which it is applied (known as the inference engine). Some work on expert systems has aimed at actually emulating the cognitive processes of experts (this field is more generally known as cognitive science), but usually the objective is equivalent results to that of an expert, plus comprehensible reasoning.

The origins of expert systems lie in the late 1970's, in the work of the Stanford Heuristic Programming Project on the Mycin series of systems. [BUCHANAN 1984]. They were developed to solve problems not susceptible to an algorithmic solution, due to their complexity, ambiguity or uncertainty. However, the uses of expert systems have broadened during the 1980's, and they are now used also for rapid prototyping for conventional problems, and for a variety of text-based and symbolic reasoning systems (such as the animation of regulations). There have been thousands of applications worldwide since the early 1980s, mainly in engineering, finance and medicine.

Good applications are those where the domain is **technically feasible** i.e.

- the domain is well-bounded
- there is a recognised expert (or experts)
- there is agreement on the knowledge of the domain
- the problem requires several minutes to several days to solve
- conventional approaches will not work (for example because of the cost, or because no algorithmic solution is possible)
- the task requires expertise to solve i.e. qualitative as well as quantitative judgements, and the use of reasoning rather than purely numeric processing
- common sense is not a key component in problem solving.

In addition, the application must be **organisationally and commercially viable**:

- the problem must be recognised
- management must favour a technical solution
- the users must favour the expert systems approach
- there must be a discernible business benefit
- the management and users must be willing to modify normal working practice to utilise the system.

3.2 Knowledge Representation

The most common expert systems representation technique has been to use rules, in the form of 'if...then...' statements, where the 'if' component states a condition which if true will lead to the deduction of the consequent or 'then' part. Such rules are generally applied to the facts about a specific problem in one of two modes. In the **forward chaining** mode, if the condition is true, then the action is applied and new facts created which could lead to new rules applying. In the **backward chaining** mode, the aim is to prove the final conclusion of a rule to be true by determining if its conditions are true. If necessary this may mean finding another rule which might prove one of the conditions and trying to see if this rule applies, thus working backwards from rule to rule until known facts are reached or a test fails. [KATSOULAKOS 1989]

Initially, rules manipulated either text strings or simple variables. However, they were soon combined with object-oriented or frame-based systems, within which the objects over which a system reasons are defined hierarchically, representing the real structure of the domain, and independently of the knowledge which is applied to them. Within these definitions were often included functions (known as **methods** or **demons**) which carried out certain immediate deductions. As a result, the majority of rule-based systems now quantify over objects.

3.3 Development Tools

The tools used to build expert systems have generally been divided into three groups; shells, languages and environments. **Shells** provided one simple knowledge representation technique (generally rules) plus one inferencing technique, along with easy to use interfaces and links to other programs. They were generally low cost and ran on P.C.s. **'AI' Languages** generally ran on graphics workstations, and provided a set of suitable language structures from which it was the developers job to build the required tools. The most common languages used were LISP and Prolog. **Environments** were high-cost systems designed for top of the range hardware (often dedicated LISP machines) providing a variety of facilities, generally built on top of an AI language, to carry out many different forms of representation and inference, plus complex graphics and user interaction facilities.

Since the mid-1980's the distinction between the three groups has narrowed. Shells have expanded their functionality, and have also moved upmarket in price and hardware requirements. Many are now object-oriented and hence require more processing power. They now range from simple examples, such as Crystal, through to high-end shell/environments running on P.C.'s and graphics workstations, such as Nexpert Object and Goldworks. Languages have also changed. Additional tools have been provided to assist in the development and presentation of 'AI' languages, such as windowing tools and graphics debuggers, 'C' has emerged as an expert system development tool for reasons of portability and speed, and object-orientation has been added to many languages, including 'C', Pascal and now Prolog. As a result, the AI development environments such as KEE, ART and Knowledge Craft have been severely squeezed.

The representation and use of uncertainty in reasoning is another feature of expert systems work which has long been emphasised. Ad hoc estimates (generally numerical) are placed upon the likelihood of events, based on expert heuristics, and functions developed to combine and use them (such as Bayes rule). In practice, uncertainty has been used less than might be expected, partly due to the unverifiable nature of the numeric estimates used.

The ability to learn is another feature associated with AI and expert systems. This is still a research area, of enormous long-run importance, but which is not yet in the commercial world, outside the use of induction from examples and neural networks (the newest subject of computing 'hype').

For further information on the background to expert systems, the structure and functioning and the research status, a large number of textbooks now exist, including WATERMAN 1986, CHARNIAK 1985 and RICH 1983.

4. DOCUMENT STRUCTURE AND FOCUS

The information presented here is taken from many sources, including published papers, press releases and research reports. The focus is upon expert systems rather than other forms of 'AI' system, upon civilian rather than military systems, and upon tools of benefit to tanker safety. The overall sample is to some extent biased, since it focuses upon UK and US systems, plus those European and Japanese systems with which LR has contact. Thus all its conclusions can only be provisional, and some of the information presented in unfortunately out of date. However, it is believed that enough of the marine work done so far has been identified for it to constitute a significant (albeit biased) sample.

Section 5 covers the main body of the document, describing firstly three large-scale initiatives, then describing work in progress of importance for tanker safety under five major headings; collision avoidance, regulations compliance, inspection and planned maintenance, condition monitoring and fault diagnosis, and damage control. These are not the only issues of operational importance for tankers, but they are the major issues which have so far been addressed by expert systems work. The section ends with a discussion of other systems of interest in the marine field. A summary of the results, from a variety of perspectives, is provided in section 6. Section 7 describes the services LR are offering in the expert systems field. Section 8 describes other related research work in progress in LR, and the paper ends with some conclusions and predictions for the future.

5. MARINE EXPERT SYSTEMS

This section describes the state of the art in marine expert systems work worldwide, focusing upon work of relevance to the safety and operational security of tankers. The final subsection is a brief review of additional work of general interest. A more detailed review of the systems described here can be found in HORNSBY 1990.

5.1 Integration Projects

There are three marine expert systems projects whose aims transcend those of individual systems.

1. KBSSHIP

The KBSSHIP project is an EEC ESPRIT-funded collaborative project aimed at developing advanced information systems for use on board ship. The partners involved are the Danish Maritime Institute, Lloyd's Register, Soren T. Lyngso, Krupp Atlas Electronic, the East Asiatic Company, the National Technical University of Athens, and the Instituto Superior Technico. The KBSSHIP consists of a set of specialist expert systems, communicating via a central database and system manager. After two years of background work, the full systems began development in 1989.

There are five main systems: the Expert Voyage Pilot (EVP), which aims to emulate the expertise of the master in navigation, the Expert Loading System (ELS), which is an intelligent loading system for tanker cargo distribution, the Expert Maintenance System (EMS), an intelligent planning and scheduling system for maintenance activities, an Expert Diagnosis System (EDS), for fault diagnosis in main and auxiliary engines, and the Statutory regulations and Classification System (SCES), which provides information to deck officers and other KBSSHIP systems on the applicable statutory and classification society constraints on operation at any given time. The systems communicate results through a central blackboard, which is controlled by the System Manager Expert System (SMES).

The systems are at the prototype stage at present. They are being produced on SUN-4 series hardware, under Unix, using Allegro Common Lisp and Portable Common Loops (PCL). KBSSHIP is designed for modular installation, and for use on board a variety of medium-to-large ships. Several subsystems will be installed on a Danish bulk carrier in 1991 [ABBOTT 1988, KATSOULAKOS 1989b]

2. The Intelligent Ship Project

This Japanese national project for high reliability intelligent ships, which ran from 1984 to 1988 was carried out by the Japanese Shipbuilding Research Association, plus seven major shipyards and six Japanese shipping lines. The results included automatic navigation systems, route planning, collision avoidance and automatic pier arrival and departure systems. The long-term aim was unmanned ships with fully-automated control and navigation systems. [OHNUMA 1989] Significant expert systems research and development went on, particularly for manoeuvring control and ship route optimisation. The project includes the production of a Captain Expert which incorporated the knowledge of a master [DUMBLETON 1990] Since 1989, the status of this work in not known.

3. The Fleet Management Technology Programme

Finally, the US Maritime Administration has since 1985 been supporting a variety of expert systems research activities, to explore the potential and pitfalls of AI. The result was not integrated, but it inspired the largest group of separate developments so far produced in this field.[DUMBLETON 1990]

5.2 Collision Avoidance and Piloting Systems

As has been often recognised, the great majority of ship collisions and groundings have been due to human or procedural errors, rather than mechanical failure. Voyage piloting and collision avoidance has therefore been one of the most important applications of expert systems worldwide, with at least ten systems competing to produce related results.

1. COLLISION AVOIDANCE: Liverpool Polytechnic

Liverpool Poly are developing an expert system for collision avoidance, which aims to provide the best course to avoid other vessels, in situations where the collision avoidance rules comes into play. The rule-base is based on the International Regulations for Preventing Collisions at Sea (CollRegs), supplemented by expert knowledge. It is an advisory system only, which monitors other ships from radar, and suggests courses of action to the captain, such as speed reductions and course heading changes. However, it is designed to function in real-time.

The system has a risk analysis component, using a distance and time required for a safe manoeuvre to calculate a risk factor, which is then mapped onto situation descriptions from 'emergency situation' to 'target passed and clear'. The system also has a manoeuvre-generation module which proposes a problem-avoidance route using a generate and test procedure. It is designed to handle tanker-like ships, in open-water, with good visibility and under power, and can deal with multi-ship encounters. It does take account of visibility restrictions, but does not have information on coastlines and water depths, nor does it take account of likely other ship manoeuvres.

The system runs on a Victor 286 machine under MS-DOS, and is written in Prolog and 'C'. The number of rules is apparently quite small, and are used in a forward-chaining fashion. The performance (within a ship simulator) is said to be good. [SMEATON 1988, SUNDAY TIMES 19 JUNE 1989]

2. COLLISION AVOIDANCE: Plymouth Polytechnic

Plymouth Poly have also developed a rule-base collision avoidance system based on CollRegs. The system was developed for a two-ship situation, and has been extensively tested in simulation. It was written in 'C' on a P.C., and is capable of real-time on-board ship operation. It makes use of both static data on ship size and manoeuvrability, and dynamic information on other ships (in off-line simulation). The system is requires to recognise hazard situations, determine the status and rights of each ship, choose a course of action and then monitor the other ships.[BLACKWELL 1988]

3. NAVIGATION SIMULATOR: Ship Research Institute

The Ship Research Institute of the Japanese Ministry of Transport has been involved with Mitsubishi Heavy Industries and Ishikawajima - Harima Heavy Industries in a large program within the Intelligent Ships programme for the development of an automatic navigation system. Expert systems components were designed and embedded within a simulation to encode the expertise of the ship navigator. It contains regulations governing navigation and collision avoidance manoeuvring considering other-ship distances, speeds and type of cargo, for multiple ship situations.

This was a production rule system, written in LISP and the Flavors object system, and runs on a Symbolics 3640. It has been applied to navigation in Tokyo Bay, and apparently performed satisfactorily. [FUWA 1987]

4. COLAV: University of Tokyo

Tokyo University have also been involved in an expert system for collision avoidance, which was intended to behave like an expert master. As with other collision avoidance systems, its goal was to implements CollRegs, amongst other heuristics.

The system was forward-chaining, developed in OPS5. It assumed perfect information, and modelled itself and other ships, to determine the state of target ships and the type of encounter situation. It then predicts the risk of collision and plans avoiding action. Its behaviour was evaluated within a simulator in circa 50 encounter situations, including a four-ship case, and considered to be satisfactory. [KOYAMA 1987] Its current status is unknown.

Work on piloting in congested waterways can shade into the collision avoidance process, and there have been at least three other systems developed for this purpose.

5. PILOTING EXPERT SYSTEM: Rensselaer Polytechnic and Others

Rensselaer produced under the MARAD program a shipboard piloting expert system for the Port of New York. This was a standalone decision aid, which provided decision support to masters, mates on watch and pilots in congested waterways, in navigation, safety and collision avoidance. It contained expertise from local pilots, oriented towards a transit through New York harbour.

The system was developed using Intellicorp's KEE 2.0, on a Symbolics 3600 family LISP processor. The Human-Computer interface was mouse- and menu-based, plus digitised sea-charts to represent current position. The user provided information on visibility, traffic conditions, equipment, status changes and changing conditions. PES uses forward chaining rules and frames. Simulation testing showed improved bridge team performance in communications and compliance with regulations, but no improvement to general track-keeping performance. [GRABOWSKI 1989, DILLINGHAM 1989].

6. SHIPBOARD PILOTING EXPERT SYSTEM: Rensselaer and Others

Work on the Piloting Expert System, which was temporarily shelved after completion, was re-evaluated and a new successor project, the Ship Piloting Expert System, begun soon after the Exxon Valdez disaster. This has the same prime contractor, sponsor (MARAD) and subject but with the involvement of Exxon Shipping Company's Integrated Bridge team. This three-year project began in 1989, and aims to port the work developed for New York to Valdez harbour, and to KEE 3.1 on an 80386 micro and a Sun-3, running the Unix operating system. The system will be installed and tested on board ship. [GRABOWSKI 1989-90, FAIRPLAY 4 JANUARY 1990]

7. MANOEUVRING EXPERT SYSTEM: Instituto Universitario Navale

The Naples ION is involved in a project supported by the National Council of Research (CNR) of Italy, to develop an on-board manoeuvring advisor. Its goal is to use expertise and mathematical knowledge to predict the effects of manoeuvres, for training purposes to reduce the number of manoeuvring errors, especially in congested waterways. The system had not been implemented as of early 1988, and its current status is unknown. [BIANCARDI 1988]

There is another group of systems also under development, which are less concerned with safety and more with efficiency and operational cost. Their goal is the optimisation of voyage plans, taking into account more factors than can be considered by algorithmic solutions calculated at present.

8. THE EVP: KBSSHIP

The Expert Voyage Pilot is a prototype route optimisation system, making use of numerical algorithms for speedkeeping and ship responses, and adding to this heuristic reasoning for route optimisation using predicted and statistical weather information, navigating to minimise total voyage cost and the risk of heavy weather damage. The system has been tested at the algorithmic level. It makes use of on-line sensor data and is integrated within the KBSSHIP framework.

9. EXPERT SEAKEEPING GUIDANCE SYSTEM: Ocean Systems Inc.

This Californian company, with assistance from MARAD and American President Lines, have produced three linked 'expert' systems, which are now being sold in the marine market (see for example FAIRPLAY 4 JANUARY 1990). The first, the ESGS, produces seakeeping and speedkeeping performance characteristics, using on-line sensor data such as acceleration and roll. The Expert Ship Routing System then carries out voyage planning on this basis, whilst the Expert Shipboard Weather Station unpacks SATCOM forecast wave data and creates weather charts for use by ESRS. [CHEN 1989] The evidence indicates these are not strictly 'expert' systems at all. They have all been written in 'C' and Assembler [DUMBLETON 1990, CHEN 1989, FAIRPLAY 4 JANUARY 1990] Since 1987, these systems have been incorporated within the American Bureau Lines C9 and C10 series of ships, within integrated bridge navigation aids. [FAIRPLAY 27 JULY 1989].

10. MARDIS: Liverpool Polytechnic

Liverpool are also involved in a UK DTI-funded project to develop an intelligent voyage planning system, based on commercially available information such as bunker prices, likely weather and port costs and limitations, for use on shore and at sea. The main users are expected to be 'tramp' operators. Research prototypes were developed using rule induction software and the ENVISAGE shell, with the user interface on a P.C., and an interface to the main databases held on a VAX using Poplog. [THOMAS 1988]

5.3 Regulations Compliance Systems

Regulations advice and compliance systems cover both those which ensure that design regulations are complied with, generally by shipbuilders or classification societies, and those concerned with ensuring that operational regulations are applied correctly, and the correct procedures followed. The collision avoidance systems described above are related to this second category, as does the SCES system.

1. PAPERS: Lloyd's Register

One application under development in LR under the first category is that for appraisal of pumping and piping regulations for oil tanker crude oil venting. This has been developed using Prolog and the Flex toolkit, with expertise from senior experts in design appraisal, and runs on IBM PS/2's. Work began in 1989, and it is intended to go into operational use during 1990. It is hoped that as a result the efficiency of design appraisal procedures within the society can be enhanced.

2. SCES: KBSSHIP

Unlike PAPERS, the Statutory regulations and Classification Expert System, also being produced by LR, focuses purely upon providing to deck offers and to other KBSSHIP systems, sets of regulatory constraints upon ship operation. It is not only a text navigation system, but also queries other KBSSHIP systems and the user to decide what rules and constraints are applicable at a given time. The system has a land-based component (the Updater), from which the regulations specific to a given ship are downloaded, for installation on board the SCES Advisor (see figure 1). Versions of the system are being built for a product tanker and a bulk carrier. The regulations being encoded in this form include the operational components of LR's design regulations, SOLAS, MARPOL, Port Entry guides and CollRegs.

3. Other Appraisal and Assessment Systems

Other classification societies have also been involved in this area, as a natural extension of their work, including Germanischer Lloyd, NKK and Bureau Veritas, as have regulatory authorities such as the Canadian Coast Guard. A summary of appraisal systems is contained in Table 1. Most of these systems (save SCES) appear to be quite small, in the 50-100 rule region, and have either been implemented using shells or LISP, upon small P.C.s. They all attempt to animate regulations, some in purely a text form.

4. Non-Marine Applications of Interest

Two other applications are also worth attention. Scicon Energy of Aberdeen have produced XPERMIT, an expert system for oil platforms which combines the knowledge of supervisory staff with safety procedures and regulations, and issues printed work permits, describing instructions for the job, including safety precautions. The knowledge-base interfaces to a database containing details of the specific platform's equipment, maintenance procedures and maintenance work in progress. [OFFSHORE ENGINEER DECEMBER 1988]. In 1989, a subset of the system, known as 'Permit Tracking', which maintains a computerised log-book of permits, was installed on Total Marine Oil's Alwyn North field. [CONDITION MONITOR No.33 SEPTEMBER 1989, MARINE ENGINEERING REVIEW JANUARY 1990]. In addition, British Nuclear Fuels Ltd. have produced TRANAID, which applies the IAEA regulations governing transport of radioactive material. It is written in the Leonardo shell and is a backward chaining rule-based system. The system is in use in four BNFL sites and the product is being marketed. [SOFTWARE WORLD Vol.20 No.4]

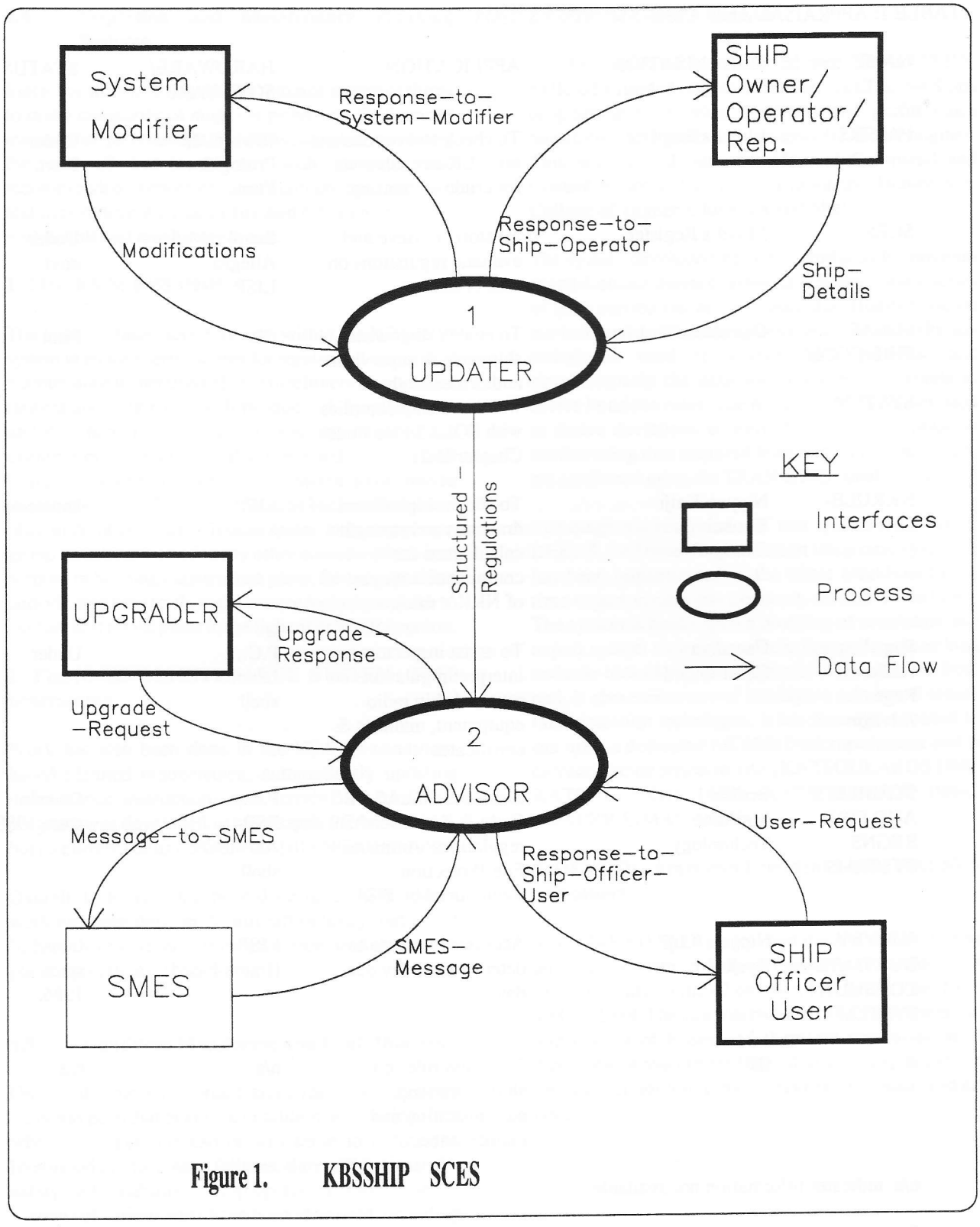

Figure 1. KBSSHIP SCES

TABLE 1: APPRAISAL AND ASSESSMENT SYSTEMS

NAME	ORGANISATION	APPLICATION	HARDWARE/ SOFTWARE	STATUS
PAPERS	Lloyd's Register	To check tankers designs meet LR's regulations for crude oil venting.	IBM PS/2, Prolog & Flex	Under Devt.
SCES	Lloyd's Register	To store, retrieve and evaluate regulations on ship operation.	Sun-4, Allegro LISP	Under devt.
SOLAS FIRE CODE SYSTEM	Germanischer Lloyd	To enable shipowners, shipyards & supervisory authorities to check whether a ship complies with SOLAS Fire Code Chapter II-2.	n/a	Pilot
NKRULE-CHECK	Nippon Kaiji Kyokai	To check shipbuilders drawings and strength calculations for compliance with part of NKK's rules.	LISP	Unknown
Ships' Radio Regns. Advisor	Canadian Coast Guard	To assist inspectors to interpret regulations on required ship radio equipment, manuals & certificates.	P.C., Level V shell	Under Test
STABILITY AND FIRE REGNS. SYSTEMS	British Maritime Technology	Animates SOLAS, IBC Code & other merchant ship regulations. Animates Fire Protection Regulations of 1984.	P.C., ESP-ADVISOR shell	On sale since 1988
SURVEY DUE DATE CONSULTN SYSTEM	Nippon Kaiji Kyokai	Accessed database to determine survey due dates.	LISP (frame-based)	In use since 1986.
AI2	IHI	To access rules on ship operation, administration and maintenance.	n/a	n/a

n/a indicates information not available.

Sources:
Nippon Kaiji Kyokai systems: BABA 1988
Canadian Coast Guard System: DUMBLETON 1990
Ishikawajima-Harima Industries: YOSHIDA 1988.

5.4 Inspection and Maintenance Planning Systems

Since fire in machinery spaces remains a serious threat to many categories of ship, the provision of advanced maintenance procedures and systems can assist in reducing the risk of non-compliance with statutory and recommended inspection and maintenance regimes, and thus reduce the risk of fire and other emergencies within hull and machinery space.

1. THE EMS: KBSSHIP

The Expert Maintenance System within the KBSSHIP system in an intelligent planner for regular and emergency maintenance inspections of ship machinery, for product tankers and bulk carriers. It produces daily plans, and updates them in the light of new information, for example on equipment faults, predicted motions and changes in port arrival times. It is interfaced on-line to the other KBSSHIP systems, feeding back maintenance plans to the other systems. It takes spares, tools, manpower, group maintenance and many other considerations into account in building maintenance plans, for user-specified periods, and uses truth-maintenance techniques both to explore and revise plans in the light of new information.

2. PLANNED MAINTENANCE SYSTEM: FMT programme

Work has also been done in the USA on condition-based planned maintenance, automatically updating maintenance instructions and deriving schedules. A program was developed using a small PC-based shell, but its current status is unknown. [BIANCARDI 1988].

Overall, little work has been done in this field. More work has been done in the aircraft industry, but as yet little of this has filtered through to marine maintenance planning systems.

5.5 Condition Monitoring and Fault Diagnosis

One of the most important areas for expert systems work has been that of engine condition monitoring. If or when these systems can or will serve to reduce the likelihood or machinery failures, they will increase the safety and reliability of ship operation. Twenty-seven systems of various sorts have been identified, including eleven on-line diesel engine diagnosis tools.

1. CPMPS: Lloyd's Register

Lloyd's Register has been involved since 1986 in CPMPS, a UK DTI-funded project under the UK Efficient Ships programme to develop condition and performance monitoring and predictive systems for diesel engines. This was carried out with Marconi Command and Control systems, Newcastle University, Humberside College of Higher Education and Shell.

The system developed has been produced for medium speed 4-stroke diesel engines. It is based upon a series of tests carried out at Newcastle and Humberside on test-bed engines. The data was then analysed and induction techniques used to derive fault patterns, and simultaneously the data was analysed by experts to derive heuristic rules. The reference set of values used to derive deviations is derived from an interpolation routine using data acquired from tests or on-line. Faults are confirmed using the TRANSENG simulation model.

The diagnosis component of this system is known as DEEDS, the Diesel Engine Expert Diagnosis System. It has been implemented in the Muse blackboard real-time expert system environment, on Sun-3 machines. The system is based upon a blending of simulation and expert system techniques, including pattern matching and rule-based heuristic diagnosis. It has a graphic front end. It also makes use of intelligent rule-based sensor fault detection techniques. It has been downloaded to run upon a dedicated MC680x0 microprocessor and is currently being tested on-site. [KATSOULAKOS 1988, KATSOULAKOS 1989b, KATSOULAKOS 1989c, BANISOLEIMAN 1989]

2. DEXTER: American President Lines, MACSEA and others.

This MARAD FMT project had the aim of developing an expert system to help in diagnosis of problems in main propulsion diesel engines. The project ran from 1987 to 1989. The aim was reduced off-design operation and control of losses and therefore minimisation of downtime. Areas covered included the main engine and cylinder condition, turbocharger performance and air coolers.

The system had an on-line real-time interface with an engine monitoring system, plus a combustion analyser. There was also a sensor diagnosis module, based upon consistency of measurements, and a trending module. The fault diagnosis knowledge was based on automating the MAN/B&W diesel engine performance evaluation procedures, which included a classification of operating trends based on key parameters. The diagnosis strategy was based on discrepancies between expected performance, derived from functional models of current performance (service and reference data), and real data. The faults for which the system was developed were overloading, power distribution imbalances, fuel injection timing problems, turbocharger fouling and air filter and cooler fouling. Pattern-matching associated specific fault patterns with maintenance actions. The system was production rule-based.

The system runs on an IBM PS/2 model 70, and is permanently installed on the test ship, the President Harding, in the engine room. The data acquisition and analysis software is written in 'C'. [DEXTER PROGRESS REPORT APRIL 1988, DABBAR 1989, DILLINGHAM 1989, DUMBLETON 1990]

3. KIS: Kawasaki Heavy Industries Ltd.

Kawasaki have been researching into new diagnostic systems for naval propulsion machinery, using their own Kawasaki Inference System, a production system, which made use of certainty factors, and generated possible faults using circa 400 forward chaining rules, selecting from the appropriate fault subset. KIS was written in a database language, but the rules port to LISP. It ran on 6800 and 8086 chips.

4. DYMOS: Ishikawajima-Harima Heavy Industries Ltd

The Japanese shipbuilder IHI has carried out work on a fault diagnosis system for on-line breakdown detection and prevention within main engines. This has gone under various titles, but is now generally known now as DYMOS (Dynamic Monitoring System). It was constructed using induction, specifically a tool known as 'D-SAN RGS'. They use a 3-values logic, with patterns associated in a lookup table for each fault. A system was developed using this tool for at least the lubricating oil system. [YOSHIDA 1988]. The system in some form was installed on board ship in 1986, carrying out on-line monitoring of parameters, compared with reference data, to derive fault information. [DUMBLETON 1990]

5. MARINE DIESEL ENGINE FAULT DIAGNOSIS: Norwegian Institute of Technology

The Norwegian Institute of Technology has also produced a condition monitoring and fault diagnosis for marine diesel engines. It uses various pattern recognition techniques, including fault trees and expert systems. The system has rules for the diagnosis of failures in the cylinders, air and gas path, bearings and other components. certainty factors are also used. No testing was done, and it is not known on what system or software the program was implemented. [WHITE 19??]

6. CAPA/MODIS-Geadit: MAN/B&W

This Danish company developed a system named CAPA as an off-line performance diagnosis, cylinder balance, load sharing and turbocharger performance analysis system. Data entry was then manual, but it did go into operational use in some form. The system was then upgraded and renamed, with on-line data acquisition, links to a planned maintenance system and trending. The system runs on a P.C., but the tools used are unknown. [DUMBLETON 1990]

7. DICARE: Krupp MaK

This West German company built an expert system for fault diagnosis in Krupp diesel engines. It can be used either manually or on-line, and includes some trending. It is a comparatively simple system, which functions only at present for the main engine, but was first installed in 1986, and there are now 34 shipboard installations. [DUMBLETON 1990]

8. DIESEL-PROF: Promaco A/S

This Norwegian system was an extension of work done on the MIP calculator, which uses a PC-compatible to analyse data to determine engine condition, fuel consumption, fuel oil ignition quality and hull/propeller fouling. It makes use of reference condition information. The expertise in the system does not appear to be substantial. [DUMBLTEON 1990]

9. FIKS: Wartsila Diesel

Wartsila in Finland have been involved in expert systems research and development for a number of years. This has resulted in the production and marketing in 1986 of a Fault Indicating Knowledge System (FIKS), which provided advice on alarm causes. [HANSFORD 1986] FIKS was a rule-based diagnosis system, integrated within an on-line condition monitoring and maintenance package. It was P.C.-based, and ran on Wartsila 4-stroke engines. [DUMBLETON 1990] No information is available on the tool used.

10. Expert Diagnosis System: KBSSHIP

The EDS within KBSSHIP is a model-based diagnosis system, based on a concept known as multi-level flow modelling, whereby a system is modelled as a hierarchy of processes, involving mass and energy flows. Once deviations from expected behaviour are identified, candidate hypotheses are generated and then resolved using truth-maintenance techniques. As yet this is only a prototype. It is intended to be built into an existing alarm system.

11. DIEMOS II: The Machinery Health Monitoring Project

In the UK, non-marine companies Ricardo's, Solartron, Westland Helicopters and Cognitive Applications were involved in a project, funded under the Alvey programme, aimed to produce general purpose software to handle the diagnosis of all types of rotating and reciprocal machinery. The DIEMOS II system for diesel engines was one implementation of this.It was designed to function on-line, monitoring sensors and questioning the operator. The engine was modelled in terms of a hierarchy of processes, and the basic analysis strategy was to compare the actual and expected condition in qualitative terms, then reason about the effects of these changes on the rest of the engine. The system was intended to be general and modular, using a blackboard-based approach. It did not recommend remedial actions. It is not clear to what extent these goals were achieved. The current state of this system, after the completion of the project, is uncertain. [RICHARDS 1988]

In addition, there have been several other systems of interest, for steam and gas turbine diagnosis, produced for the US Navy or for electricity generating companies, plus the well-known DELTA system produced by General Electric. They are identified in Table 2.

Finally, there are also a number of systems built (not specifically for marine applications always), for diagnosis of problems in engines through vibration analysis (seven systems identified) or lubrication analysis (four). Work has been done by GEC using expert systems to diagnose vibration problems in large turbine generators. [SIZER 1988], and related work has been done by Computer Systems Inc. and Mechanical technology Inc. in the USA [PETERSEN 1988, CONDITION MONITOR No.16 1987] DLI Engineering Corp tested a Machinery Condition Analysis System, which was rule-based and made use of certainty factors for diagnosis from vibration data, on an aircraft carrier. [DUMBLETON 1990] NVM was developed for the US Navy to for real-time analysis of noise and vibration data from gas turbines.[KLEIN 1986] General Electric were also involved with steam turbine blade rotor crack diagnosis using rules (using the GEN-X shell).[SCHEIBEL 19??] Intelligent Applications in the UK also sell a tool (VIOLET) for vibration analysis [MILNE 1988]

Century Oils in the UK has made some use of expert systems in analysing results from oil samples from engines, as have Wearcheck in South Africa. [SMITH 1988] Exxon also use an expert system within their lubricant analysis service Exxcare, which provides operational advice to ships' engineers. [DUMBLETON 1990] NKK have also been involved in a ferrographic analysis expert system for the diagnosis of faults using wear particles using the COMEX V02 shell. [SUZUKI 1989]

It is interesting that the majority of diesel engine diagnosis systems have eventually developed a very similar approach, starting from quite different directions. In each case, data has been acquired and analysed, resulting in a three-values logic, above expected, below expected and normal, based upon service data or reference information. Subsystem models have been used to narrow down faults, then rules (based on expertise or induction) have generated candidate faults. Some systems have also used trending. LR's CPMPS appears to be the only to use a simulation model. Despite this unanimity, in general, the diesel engine diagnosis systems appear to have been comparatively shallow, and not wholly successful. The land-based systems appear to have been the most successful. They were often rewritten for speed, and appear to have been quite large (DELTA had in 1987 530 rules). The American Systems were all written in LISP. Approaches which have addressed only parts of the problem (e.g. vibration and lubrication analysis) may prove more successful in the short run.

TABLE 2: OTHER ENGINE DIAGNOSIS SYSTEMS

NAME	COMPANY & COUNTRY	APPLICATION	HARDWARE & SOFTWARE	STATUS
IDAX 100	Dundics Enterprises Inc. USA	Steam propulsion monitoring & data acquisition for the US Navy, using trend analysis & on-line diagnosis.	Intel 80186 own OS	Installed on 3 test ships.
PDS	Westinghouse USA	forward-chaining rule based system for turbine condition monitoring	SRL, Franz LISP (rewritten in C) VAX 11/780	In use since 1984
DELTA	General Electric, USA	Diesel engine electric locomotive diagnosis & training	LISP (rewritten in FORTH)	In use.
STEAMER	US Navy	For training officers in operation of steam plants on 1078 type frigates.	Zeta-LISP, Flavors	n/a
STOCHASM	n/a	Gas turbine lubrication fault diagnosis on-line for US navy ships	n/a	n/a

Sources:
IDAX 1000: DUNDICS 1989
PDS (also Diagnostic Expert System): OSBORNE 1986, LAFFEY 1988
DELTA: WATERMAN 1986, BIANCARDI 1988, PERAKIS 1987
STEAMER: WATERMAN 1986
STOCHASM: LAFFEY 1988, MALKOFF 1987

5.6 Damage Control

Damage control is as yet an areas which has received little consideration for commercial vessels. However, incident management for tankers could in the long run be a viable option. We therefore briefly describe four pieces of research and development uncovered.

1. SALADIN: Merlin-Gerin

This French company has developed an expert system for naval surface vessels, which presents a graphic report of shipboard fires, predicting their likelihood of spreading and advising the fire control officer on the most appropriate action to take. It is written in Prolog, with a graphic interface, and contains a ship object model representing structural connectivities and relationships. The system runs on Sun 3/60's, Apollo's and MicroVax under Unix. [FAIRPLAY, 27 JULY 1989, MOTORSHIP NOVEMBER 1989] It is now operational in some form. [DUMBLETON 1990]

2. SHIPBOARD CONTINGENCY PLANNING SYSTEM: ABS

The FMT supported the American Bureau of Shipping to develop a shipboard simulation and advisory tool to aid ship personnel in emergencies, especially flooding and damage to watertight compartments. Part of this has been done using expert systems. It has been written in FORTRAN and developed on VAX and IBM P.C.s. It is an intelligent expansion and extension of loading programs which provide stability advice. The actual level of expertise present is doubtful. [REITER 1989] A follow-up to this work started in 1989, to extend the system and install it on board ship. [DUMBLETON 1990]

3. DAMOCLES: Netherlands Organisation for Applied Scientific Research (TNO)

Netherlands TNO are involved in developing a damage control expert system for use on board ship within the Netherlands navy. It is triggered off by alerts such as fire or running aground, and works in 'near real-time', using strategic metarules to assess damage and execute contingency plans. It is written in Quintus Prolog and ProWindows, and interfaces to an Oracle database. [AI LTD BROCHURE].

4. BALLAST: Pacer Systems

This American company produced an expert system for the US Navy for damage control and ship stability management. It is a development of the ship stability calculation programs, aiming to provide officers in stressful situations with correct calculations of stability and counter-flooding proposals. It is written in BASIC and runs on dedicated Wang machines. It provides some graphics support and can be used for training. In 1987, the US Navy requested a proposal to outfit 51 ships with it. [WARSHIP TECHNOLOGY 1988/9]

Some work was also done at the UK Royal Naval Engineering College at Manadon. Overall the stress is clearly upon advisors for stressful situations, and for counterflooding and ballasting proposals (related to loadmasters such as the Expert Loading System). An interesting omission is the absence (as yet) of any evidence of land-based systems for tanker spill recovery and cleanup.

5.7 Other Systems

We complete this section by reviewing three solutions to a similar problem, that of container stowage planning, which has to a great extent been solved, and has constituted one of the more successful areas of expert systems application.

The three systems being compared are the Ship Planning Expert System, produced by the Singapore Information Technology Institute and Singapore Port Authority [AYLING 1988 and CHEW 1989]; STOW, developed by Arctec Offshore Corporation, Farrell Lines Inc. and JAYCOR [DILLINGHAM 1989], and the Container Positioning System of Sea-Land and others. [DUMBLETON 1990] STOW was concerned with stowage on board ship, whilst the other two were primarily concerned with loading and unloading plans for shipyard or container transit areas, aiming to minimise crane and container movements.

The aim of the Singapore system was to reduce the turnaround time for containers in the Port as a whole, by automating the planning of loading and unloading, both at the crane level, and at the yard level. Sea-Land's system dealt with containers arriving one-by-one, attempting to find an optimal position within a yard for each, to minimise the stack operations needed to obtain the container when required. STOW addressed a very similar problem on the ship side, with the aim of minimising 'overstows', when a container above has to be moved to allow another to be unloaded.

STOW required knowledge of port sequences, plus economic and safety constraints such as strength and stability, and of dangerous cargoes regulations. Sea-land's CPS similarly require knowledge of handling of reefer containers and dangerous goods, plus rules for inbound and outbound cargo. Singapore's planner deals with a variety of constraints, including container arrangements in the yard, actual ship type and stacking, different container priorities, distance between cranes and the tide. It could not solve the problem entirely in all situations (nor could the other two systems) so it also relied upon expert user involvement for exceptional cases, and to choose from options under certain conditions.

The Port of Singapore system appears to be the most developed and most successful. Work began in May 1986 and after a basic systems was tested in the field, a full version was delivered in 1989, which is now apparently in operational use.[CHEW 1989] Sea-Land's system has bene tested in Hong Kong [DUMBLETON 1990], whilst STOW was only developed to a prototype stage. It was tested using data from Farrell lines, to generate real stowage plans. This had apparently only limited success.

The Singapore system was built using two Texas Instruments Explorer workstations, and was written in Lisp and Flavors. Stow in contrast was written for a P.C. compatible, and for speed of operation was implemented directly in Turbo-Prolog, with explicit representation of certainty factors, whilst CPS was written in PASCAL, also for the P.C.. The CPS has about 50 rules, STOW 26, whilst the Singapore system's size is not known, but is believed to be significantly larger.

Thus different but closely related problems were addressed at different levels of complexity, using different tools and with apparently different levels of success.

We complete our review with a tabular description of a variety of other systems in the marine field (see Table 3).

TABLE 3: OTHER MARINE EXPERT SYSTEMS

SYSTEM	ORGANISATION & COUNTRY	APPLICATION	HARDWARE & SOFTWARE	STATUS
ELS	NTUA, Greece	Loading planning for Product carriers (KBSSHIP)	SUN-4, C & Allegro Common LISP	Under Devt.
SARA	TNO, Netherlands	To help with search operations at sea, making & modifying search and rescue plans.	Geminix, LISP & planning shell	Prototype
Not known	Mitre Corp. USA	Nautical Chart Production for Adding wrecks	P.C., Prolog	Demo
ERIK	US Coast Guard, USA	Interpreting merchant ship reports in real time as part of AMVER system	VAX 11/785 Common LISP	Unknown
MEMEX	Ship Analytics Ltd & University of Connecticut, USA	Energy management for medium speed diesel engines, predicting wear effects on performance	VAX, Franz LISP	Demo
SURVEY FEE CALCULATING SYSTEM	Nippon Kaiji Kyokai, Japan	Calulates survey fees and service charges	P.C., LISP (frame-based)	Prototype
SEAFUEL	Shell Seatex, UK	Identification of problems in bunkered residual fuel oils	IBM P.C. ESP-ADVISOR + Prolog	In use on board own ships
ROCOCO	BMT & others, ESPRIT	Improved monitoring and control during building of ships and oil platforms.	n/a	Under Devt.
VESSELL	NTUA, Greece	Second-hand ship purchase and repair costing, using databases	Compaq, Xi Plus & Dbase IV	Under Devt.
SEALOAD	Sea-Land US Corp.	Optimal loading of a single container	P.C., n/a	In use

n/a indicates information not available.

Sources:
SARA: DUMBLETON 1990,
MEMEX: DILLINGHAM 1989,
SEAFUEL: IVES 1988
VESSELL: KRYTATOS 1989,
Mitre Corp System : DUMBLETON 1990,
SURVEY FEE CALCULATING SYSTEM: BABA 1988,
ROCOCO: CONDITION MONITOR No.31,
SEA-LOAD: DUMBLETON 1990

6. OVERALL CONCLUSIONS

6.1 Application Areas Addressed

As described throughout this document, the major strands of expert systems research and development within the marine industry of relevance to tankers have been collision avoidance and voyage planning, diesel engine diagnosis, regulations compliance, maintenance planning, and damage control. In addition, container loading and unloading has proved a fruitful area of application, as has military target recognition (not discussed here).

Research was done in 1987 in the USA on potential application areas by commercial cost-benefit, feasibility, marketability and suitability of the problem. 19 potential applications were identified.[PERAKIS 1987] When compared with our results, it indicates a significant similarity in application areas, with a lack of marine research and development in engine efficiency advice and maintenance procedures being particularly clear, amongst the areas identified by the analysis as being suitable.

The choice of application areas appears to have been a function of the technical feasibility of the application from an expert systems perspective and the needs of the organisation in the long term, but also the interests of researchers and their funding bodies.

6.2 Languages, Tools and Techniques Used

Examining the tools used by these applications, we can see a great variety, but a natural grouping into three areas:

1. Simple Shell-based systems

These shells, such as Level V, Xi Plus, ESP-Advisor and Crystal, are generally rule-based, running on P.C.'s, comparatively simple and easy to use. Example systems are Seafuel, the MARDIS system, and the BMT regulations advisors. They have not been as widely adopted as might have been expected, and constitute less than 20% of the work done.

2. AI Language-Based Systems

The main AI languages used are Lisp and Prolog. It was estimated that in 1987 in the US, 90-95% of all AI programming was done in LISP [PERAKIS 1987]. The results collected here bear this out, especially in the USA (and to some extent in Japan), indicating that circa 40% of the relevant research work has been done in LISP. Many different dialects have been used, from Common Lisp to ZetaLisp and Franz Lisp. Examples of applications using LISP include KBSSHIP, several of the NKK systems, ERIK, MEMEX, DELTA and Steamer. The UK and the rest of Europe appear to use Prolog more often (and circa 20% of the systems reviewed here have been developed in this language). Examples include PAPERS, the Japanese Navigation Simulator, Saladin and STOW. This conforms with the general impression of the expert systems market.

3. Conventional Languages

About 15% of 'expert' systems have apparently been implemented in FORTRAN, 'C', PASCAL or even BASIC. These include a Collision Avoidance system, NVM, Ballast, and SCPS. It is noticeable that several systems have been developed in LISP and then reimplemented in C or another procedural language.

Very few systems have made use of large development environments, the exceptions being the SPES system implemented under KEE, and CPMPS which uses Muse.

It is noticeable that real-time on-line diagnosis and control systems are almost entirely unused. These systems combine a 'conventional' procedural component for sensor data filtering and calibration, graphical interface tools and a knowledge-based component of varying complexity. They are now widely used in chemical plants and other process control applications. Examples include G2 from Gensym Corp, Genesia from EDF, LINKMan, ESCORT and Muse.

The hardware platforms for expert systems work are almost entirely the I.B.M. P.C (and compatibles) and the D.E.C. Vax, in various forms. In addition, Suns, Symbolics and Explorers have been used in research projects.

The operating systems used are primarily MS-DOS and Unix.

Most systems were built using conventional knowledge acquisition techniques, with a few occurrences of induction based reasoning, with doubtful success. Many of the systems built with some publicity using induction have failed to survive (at least in the public eye). The reasons for this are not clear. However, the closed world assumption of the induction process (whereby induction discriminates between faults rather than characterises them) does mean that it can consistently misclassify examples of faults which have never before been available. Purely rule-based systems have proved very suitable for some simple applications, but deeper modelling appears to be necessary to handle more complex problems relating for example to fault diagnosis.

Both forward and backward chaining system have been used, and the majority of real-world applications have made use of object or frame-based reasoning.

In terms of AI-problem classifications, such as that proposed in KATSOULAKOS 1989, marine systems have concentrated upon diagnosis, interpretation, control and instruction. Little work has been done on design problems (e.g. ship superstructure or oil platform design) and planning has received less attention than expected (integrated and centralised marine fleet management and planning systems would appear a valuable opportunity being missed).

6.3 The State of the Nations

There have been a large number of developed-state national programmes oriented towards improving the competitiveness of their marine industries, generally by crew reductions and the introduction of high technology. The majority have not involved direct expert systems work. The main leaders in expert systems work to date have been the US Fleet Management Technology program and the Japanese projects, with the result that the USA and Japan have led the field in terms of marine expert systems work, as this survey shows once again. The UK and West Germany have strong expert systems roles, but the majority of the practical work has been non-maritime, whilst much of the marine work in Europe has been comparatively small scale.

6.4 Sectoral Involvement

Expert systems have been produced by almost every type of organisation in the marine industry, from governments and military through research institutes and universities to classification societies, shipbuilders and equipment manufacturers. It appears that the leading role to date has been taken by the government, in association with classification societies and ship builders. Commercial companies have produced a number of small systems, but few have gone into practical use yet. Engine manufacturers have focused especially on fault diagnosis of their own equipment. Shipowners and operators have mainly been involved through making vessels available to projects for testing purposes. Classification societies, especially LR, have been in the vanguard of the marine expert systems field.

It is also noticeable that a number of companies with strong interests in the maritime market, including Krupp Atlas Electronic, Plessey, Siemens and Ferranti have significant AI and expert systems involvement, in large EEC and other research and development programs, such as Archon (ESPRIT) and TEX-I (West German research programme). As yet, these have not fed back fully into the marine field, but eventually commercial pressure will eventually force such a move.

7. LLOYD'S REGISTER'S SERVICES IN MARINE EXPERT SYSTEMS

The field of expert systems is still, from the commercial point of view, comparatively new, and LR is in the process of setting up a set of services in this area, which will be available during 1990. For several years LR have been involved in software development, on behalf of clients or for certification purposes (including the LR.PASS systems). They are now extending this interest into the expert systems field.

As described above, LR's Performance Technology Department is involved in a series of applications designed to demonstrate the benefits of expert system technology both to the marine industry and to the Society's own activities. Beyond that, LR is aiming both to develop consultancy expertise for clients and to provide assessment services. The services LR aims to offer are the following:

a. Feasibility services, examining potential client applications and reporting on their feasibility and the appropriate tools and technologies which should be used.

b. Consultancy on building expert systems, including appropriate development methodologies and user-centred design philosophies. LR is involved in the largest European methodology project for knowledge acquisition, the KADS-II project, and has a large and dedicated team of expert system research and development staff, involved currently in projects both internal and external (such as KBSSHIP).

c. Bespoke developments for clients and the development of products for commercial sales. The company has expertise in most major AI programming languages, including Prolog, LISP, Pop-11 and C, with shells (including Crystal and Leonardo) and with the major development and delivery environments (Sun workstations and IBM P.S./2's). The company is following a strict software development quality assurance programme.

c. Appraisal of expert systems for safety, reliability and maintainability. As expert systems are installed on ships wishing to be classed with LR, the company must be able to assess their reliability and safety. Certain systems may even be considered for type approval. LR will also provide third-party assessment of development work carried out by other organisations, and hope to become deeply involved in the assessment of land-based expert systems in general.

8. SOFTWARE VALIDATION IN LR

LR's Performance Technology department is also involved in another area of direct relevance to tanker safety, that of the verification and validation of software (which has already been introduced under expert systems).

It has become increasingly clear over the last few years that all complex engineering systems will in future contain embedded microprocessors, controlled by software. Traditionally, LR and the other classification societies have not assessed the software itself, but have rather focused on hardware environment tests, specifications of minimum functionality and quality control procedures for the programs' construction. However, it is now impossible to assess the safety or reliability of systems without some consideration of the safety and reliability of the software. An examination of the vast mass of computer-based products for shipping today, many of which have type approval or will require it in the future, indicates the great need for independent testing and verification of software systems themselves. Seaborne software-based products include automatic navigation and trackkeeping systems, loading instruments, engine controllers, voyage planning systems, financial packages and maintenance and spare parts systems. Ship central office functions are also being automated, in finance, loading, voyage estimation, crewing, maintenance and supply. The same problems apply to software used for design and design appraisal. In each case, there is a growing need for independent assessment of software, and specifically for examination of the source code itself, for bugs, non-standard constructs and dangerous or incorrect code ad deviations from specification (formal or informal).

This view has been reinforced by recent changes to product liability in the UK and elsewhere, and the emphasis upon analysis techniques and the use of formal methods in recent defence standards.

As a consequence, LR has made the decision to become involved in the software validation field for marine systems. It is already involved in a European research and development project (known as REDO) under which it has had the opportunity to gain expertise in the validation field, and to build up a team of experienced staff, who have now begun consultancy work for clients in this field.

During 1990, LR will be offering services in the fields of dependability assessment of software-based products, static analysis of programs for integrity, consistency and coherency, assessment of program conformance to standards, formal validation of systems against specifications (in languages such as Z, VDM and OBJ) and advice on the management of testing and other validation techniques. This is expected to include assessment of software submitted to LR for type approval within other engineering systems (to which end LR's type approval procedures were adjusted in 1989).

9. CONCLUSIONS AND FUTURE PROSPECTS

In general, expert systems in the marine industry are still at the prototype stage. Very few if any are in genuine commercial operation. The reasons for this include the cost of development, their complexity of construction, safety concerns, reliability problems for marine hardware of sufficient power, general conservatism and to some extent misplaced enthusiasm. Research and development work has inevitably focused upon more complex problems, often on-line and safety critical. These are intrinsically less likely to reach practical use in the short term, due to their safety and reliability problems. They are more interesting from an AI perspective, and are easier to find funding for, but perhaps do not provide the immediate short term paybacks which would assist the industry into regular day-to-day adoption of such technologies. More obvious and less critical areas such as regulations animation, administration, loading and stock control have been relatively neglected.

Over the next decade, onboard computer systems will become even more common and more complex than today. The lessons of large-scale land-based process plant operations is that once economies of scale make expert systems operation efficient, they will inevitably emerge. The research work being done in Japan, the USA and Europe particularly will undoubtedly lead to pressure to place truly 'intelligent' computer systems on board ships. In some restricted cases this has already happened. Commercial advantage will dictate that engineering equipment will be integratable, and self-diagnosing. It is thus believed that the next five years will see a significant growth in the commercial field. Some of the most obvious areas have been described in this paper, including collision avoidance, fault diagnosis, container stowage, maintenance planning and regulations advice. LR will be ready, both to assess and contribute to these developments.

As mentioned above, some of the main reasons these systems have not already reaches the marine industry in bulk are those of systems reliability, liability (such as problems in classification design appraisal using a program) and perceived safety (the risks of errors). The classifications societies, led by LR will be addressing these problems, in LR's case, linked with their general contributions in the field of software validation.

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