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Advanced ship performance information systems

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SYNOPSIS

This paper reviews current technical progress in information technology (IT) and analyses different integration options for this technology in shipping. A number of advanced ship performance information systems are identified and their architecture and techniques used for their development are described. The special issues raised by the requirement of independent assessment of IT systems are defined and certain recommendations are made.

INTRODUCTION

Information technology, communications and automation are three key elements in modern industrial technology. A sustained drive towards integration of these technologies has been supported by extensive research and development programmes in the USA, Japan and Europe. The integration of IT into application systems such as process control, computer integrated manufacturing and others, is the ultimate goal of many industrial sectors and this could be equally important in the marine industry.

The application of advanced technology through the adoption of integrated ship control is already producing significant improvements in the running costs of new ships. The natural evolution of current technology trends is the integration of information processing, communications and automation systems.

The integration process could follow many different routes, some of which will be analysed in this paper. An obvious choice is to increase integration with autonomous intelligent systems on board the ship. Alternatively, vessels will be regarded as an extension of the head office from which they can be managed through satellite and other advanced communication systems. The increased quantity and quality of information which can be generated on board the ship could be utilised not only by the head office for fleet management, but also by other organisations such as shipyards and classification societies. Fleet management based on the analysis of information transmitted from ships could become increasingly dependent on the use of large data banks containing trading information or technical data.

The first part of this paper considers the question of how shipping is going to be affected by IT. Certain aspects of the research programme at Lloyd's Register are then outlined as a means of defining the scope of current developments. A number of expert systems are then described for a wide range of tasks such as voyage planning and ship maintenance. Some initial views on the subject of independent assessment of intelligent integrated systems conclude this paper.

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INTEGRATION OF INFORMATION TECHNOLOGY IN SHIP APPLICATIONS

Recent technology changes

During the past decade the highest growth areas, both economically and technologically, have been related to IT and telecommunications. This is affecting the competitive structure of the majority of industries.

IT developments can be divided into four application areas:[1]

1. Software technology.
2. Advanced information processing.
3. Advanced microelectronics.
4. Computer integrated manufacturing.

In software the main thrust appears to be towards creating integrated project support environments (IPSEs) and other computer aided software engineering (CASE) tools, which can provide effective support for the software development process. The introduction and use of formal notations and more rigorous methodologies for software design, validation and maintenance is the second major development area. Another major research drive is towards more 'open' computer systems, in which hardware and software from different computer manufacturers can be simply integrated and applications can be more easily ported.

Advanced information processing is required in most application areas. The main goals in this area have been to apply knowledge based systems (KBS) in order to solve practical problems and, more generally, to integrate AI techniques into sophisticated software systems such as alarm handling in chemical process control and nuclear power generation.

In the hardware field, research on parallel systems is now reaching fruition, with multiple-processor systems (particularly transputer-based) now achieving significant improvements in processing power. Research in the area of massive low-level parallelism using 'neutral networks' is receiving renewed interest, both via software simulations and hardware realisation of the networks.

The interfacing of IT with the users' activities through advanced microelectronic products largely determines the direction of innovation in all industrial sectors. Developments in microelectronics have focused on the design and production of semiconductor components, especially integrated circuits with increasing attention to issues of flexibility and on-chip integration. Computer integrated manufacturing is concentrating on tools for real time manufacturing control and robot controllers.

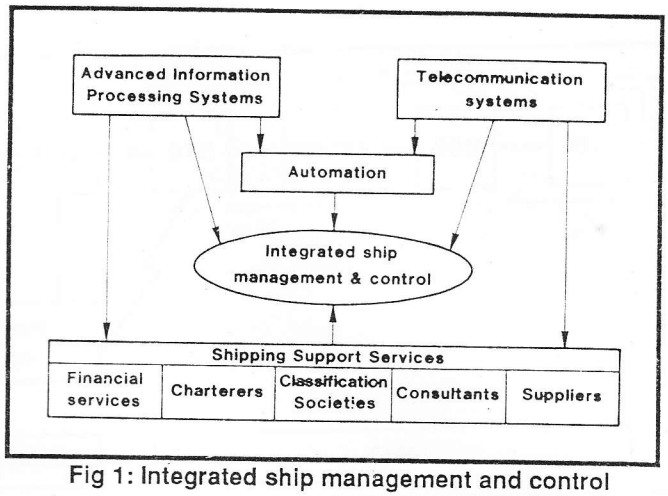

Fig 1: Integrated ship management and control

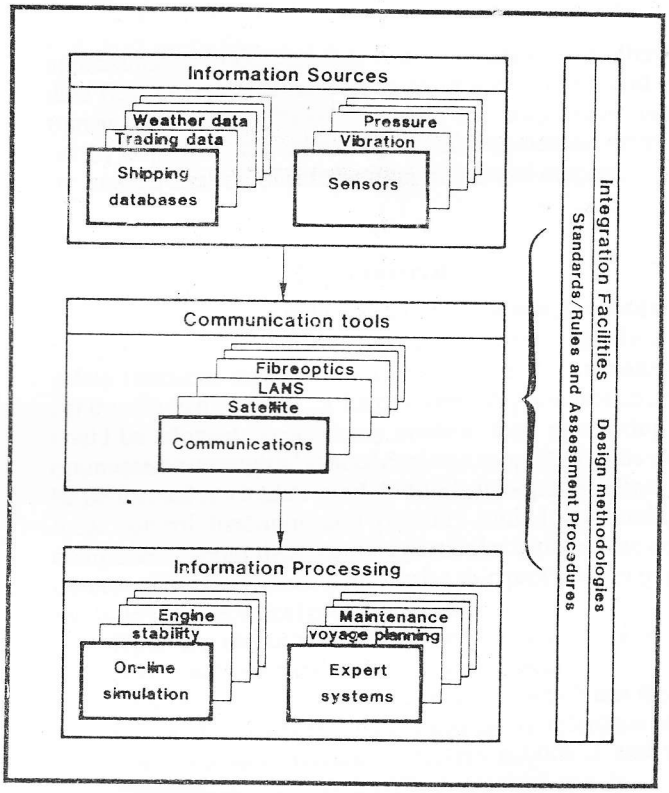

Fig 2: Main IT subdivisions

Integration possibilities of information technology systems in shipping

In shipping, the introduction of computers has been slower than in many other industries. There has been significant on board automation, but until recently there has been little progress towards 'intelligent' data processing.[2] The introduction of reliable microcomputers is now changing this situation. In the past five years the adoption of computers has become common for most newbuildings, and a variety of programs have been made available to execute shipboard functions. Ship management information tools are also becoming widely accepted, including data-links to provide commercial information and satellite navigation and facsimile machines for transmission of weather data. Electronic information interchange is having a profound impact on the way in which shipping companies communicate with their ships, agents, terminal operators, port authorities, national traffic control organisations, suppliers, weather and routing services, classification societies and other marine support organisations. The field of documentation (paperless trade and transport) is already producing significant economic savings. For this purpose, ocean carriers are increasingly using public or private network organisations. Further advancement will be dependent on integration (Fig 1) and the rate of development in each of the main IT subdivisions (Fig 2).

Future integrated ship management systems aimed at increasing ship productivity are likely to be developed in two distinct directions:

1. Autonomous shipboard systems.
2. Shore based ship management.

Both approaches have been briefly analysed.[1] It is likely that individual companies will develop systems which emphasise features of the two approaches at different levels. How-

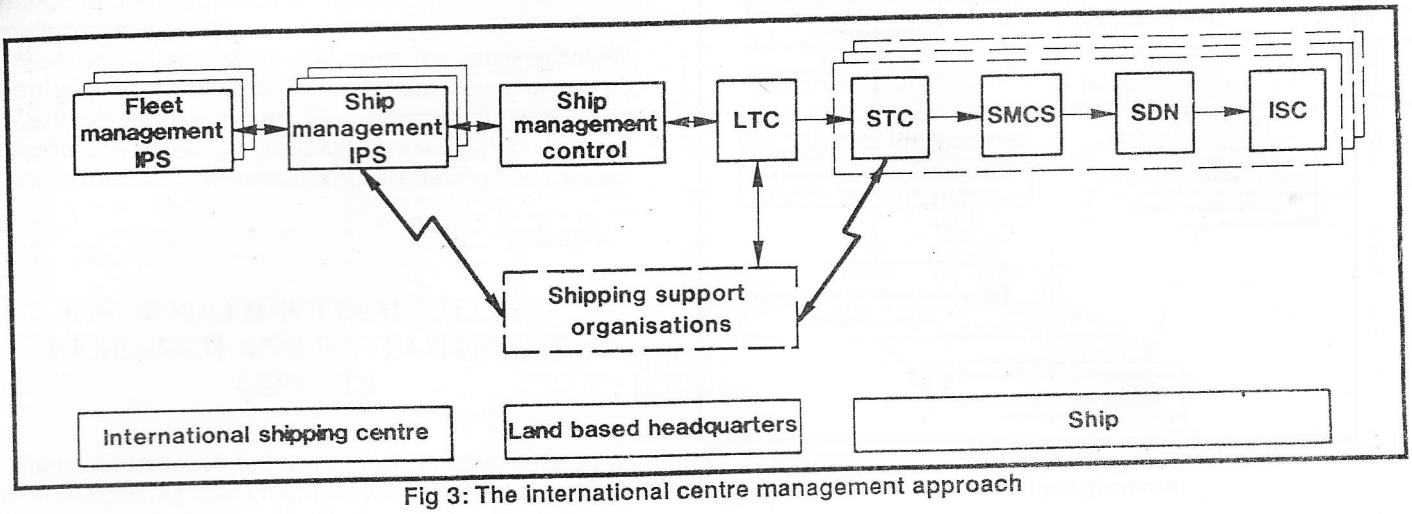

Fig 3: The international centre management approach

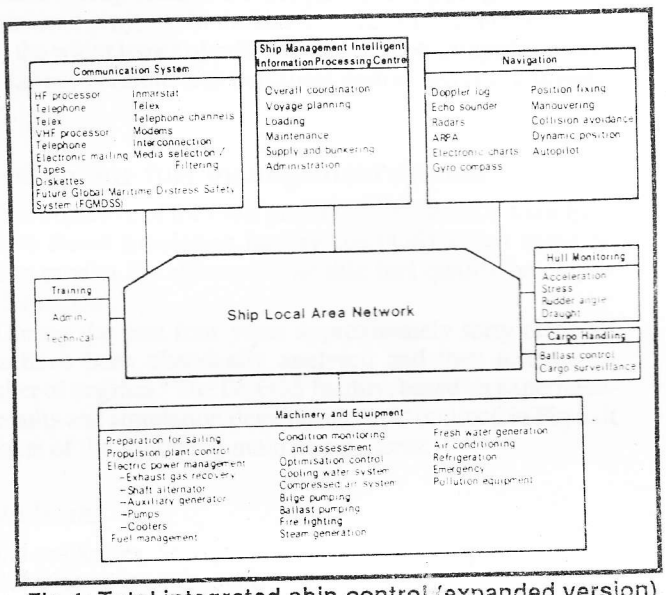

Fig 4: Total integrated ship control (expanded version)

ever, a certain amount of information analysis and decision making will need to take place on board the ship for the following reasons:

1. Input of observations from the crew are required in diagnosis and prediction.
2. Communication cost will decrease by minimising the amount and frequency of data transfer.

A third option, shown in Fig 3, indicates that information processing for many shipowners can be undertaken by an independent international centre. A ship today is part of an integrated transportation system. Centralisation of the information processing tools required to support the overall transportation system into an international centre would improve the efficient use of information technology facilities. A large number of users of such a centre would ensure enhanced quantity and quality of data and consequently a better basis for trend analysis and reliability assessment. Furthermore, combining the resources available in the industry for this purpose will improve the possibility of producing an advanced IT capability.

The key parameter in the move towards integrated transportation is the communications advancement. When INMARSAT began operation in February 1982 there were 1000 ships equipped for satellite communications. Now there are approximately 7000. Satellite communications can offer high data flow everywhere as well as short access times and good transmission safety. Current research activities would contribute by improving the efficiency of transmission networks and the standardisation of information inputs and outputs.

Total integrated ship control

In order to realise reductions in crew levels, the entire ship navigation, manoeuvering, propulsion, cargo handling and safety functions must be controlled from a ship management centre. To achieve this, a hierarchical ship control structure could be adopted. Supervisory control, fault monitoring and optimisation through advanced decision support systems would be performed at a higher level. Individual loop controllers with local control functions and possibly with local intelligent components could then regulate particular actions. The development of such a system to maximise ship profitability implies the following technical requirements:

1. Optimum physical and functional integration of navigation, machinery and safety control systems.
2. Availability of an adaptive controller which can identify deviation from performance and safety reference conditions and can institute corrective actions if and when required.
3. Rigorous standardisation of equipment, procedures and interfaces.

The diagrammic arrangement of Fig 4, using local area networks (LANs) provides a possible configuration for the integration of all the ship operation functional sub-systems. The processing units are divided into seven local area networks:

1. Ship management LAN.
2. Machinery and equipment LAN.
3. Communications LAN.
4. Navigation LAN.
5. Hull monitoring LAN.
6. Cargo handling.
7. Training LAN.

Apart from management and training, each other network interfaces with instrumentation and performs control regulation tasks. Fibre optic media provide many advantages (frequency division multiplexing, several services on a single conductor, priority scales) for transmission of data over long runs such as the two interconnected networks. The carrier sensor multiple access with collision detection (CSMA/CD) is the most common protocol used. Developments in open systems are impor-

nt here for the integration of equipment built by different manufacturers.

Most of the technology and tools for communication, control and even individual expert systems is certain to be available in the near future. The technical difficulty is to achieve total integrated ship management with a high degree of reliability, flexibility and intelligent and efficient user interfacing.

INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT ASPECTS

The current research and development programme in information engineering coordinated by the performance technology department is diagramatically described in Fig 5. It consists of three EEC funded collaborative projects, the condition monitoring project under the UK efficient ship programme and two internal projects. In the internal project, 'AI in LR operation', the wider issues of information technology application in the marine, offshore and industrial sectors are being investigated.

Diesel engine fuel management system

The objective of the fuels project was to develop a comprehensive diesel simulation facility (DEFOS) which could be used to predict the effects of variable fuel quality on engine 'performance'.[3]

During the past four years approximately forty different fuels have been chemically analysed and then tested in a number of engines.[4] The DEFOS facility, based on experimental results and simulation developments, is outlined in Fig 6. It consists of the following main components:

Data bases

- Fuel properties.
- Fuel treatment equipment.
- Engine design details.

Models

- Fuel treatment.
- Heat release.
- Cycle simulation.

Expert systems

- Fuel matching.
- Engine matching.
- Fuel characterisation for combustion.
- Fuel characterisation for maintenance.
- Optimiser.

Depending on the information available on fuel properties, engine and fuel treatment equipment, DEFOS could be used to provide either qualitative advice or detailed quantitative predictions. The difficulties in developing DEFOS have centred around the fuel knowledge analysis. In particular, although extensive experimental tests have been carried out, direct use of the results in expert systems (through induction, for example),[5] is virtually impossible. Engineering interpretation of results is now being combined with qualitative reasoning models in order to refine and extend the system.

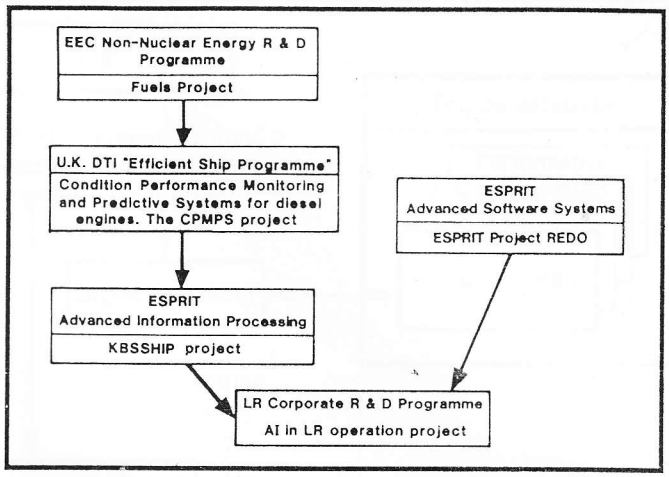

Fig 5: Information engineering research and development programme

The diesel engine condition monitoring project

The aim of the condition monitoring project (CPMPS) is to establish the principles of a diesel engine management system required to improve availability, optimise maintenance, provide facilities for integration into a ship control system, make better utilisation of engineers and optimise performance.[6]

The CPMPS system design has been described previously.[7, 8] A set of data obtained for the engine is processed through logical reasoning, planning procedures and simulation modules in order to generate advice, as shown in Fig 7. The main flow of processing compares engine data with precalculated reference levels from a 'reference generator', detecting any significant deviations. The deviations are then passed on to the diagnosis expert system DEEDS,[8] which attempts to assess the engine state and to detect any fault conditions. In parallel, fuel effect parameters are calculated by a fuel characterisation expert system. Fuel and fault information is then used in the prediction sub-system in order to suggest optimum engine settings and to project future maintenance requirements.

The development of the CPMPS system has been based on knowledge obtained from two sources. First, experimental data from engine tests under fault conditions which have been used to create fault patterns. Second, an engineering interpretation of the engine response under different operating conditions. The concept of using on-line engine simulation to validate decisions generated by the expert system was first introduced in the CPMPS system.

The ESPRIT KBSSHIP project

Within the European strategic programme of research in IT (ESPRIT), KBSSHIP is aimed at developing design concepts and prototypes for the implementation and utilisation of advance IT systems on board ships.[9] KBSSHIP is an overall knowledge based system for the on-line optimisation of ship performance. Its goal is to reduce running costs and the frequency and severity of events which could endanger the safety of the crew, ship or cargo. It is involved in planning, implementing and evaluating ship operations. KBSSHIP, by providing support for the problem solving and decision making process, is an advisory system. It cannot take executive action, hence it cannot overrule any decision or action taken by a crew member. KBSSHIP is not limited to one type of marine vessel. Individual sub-systems are expected to be applicable to ships of many sizes and functions.

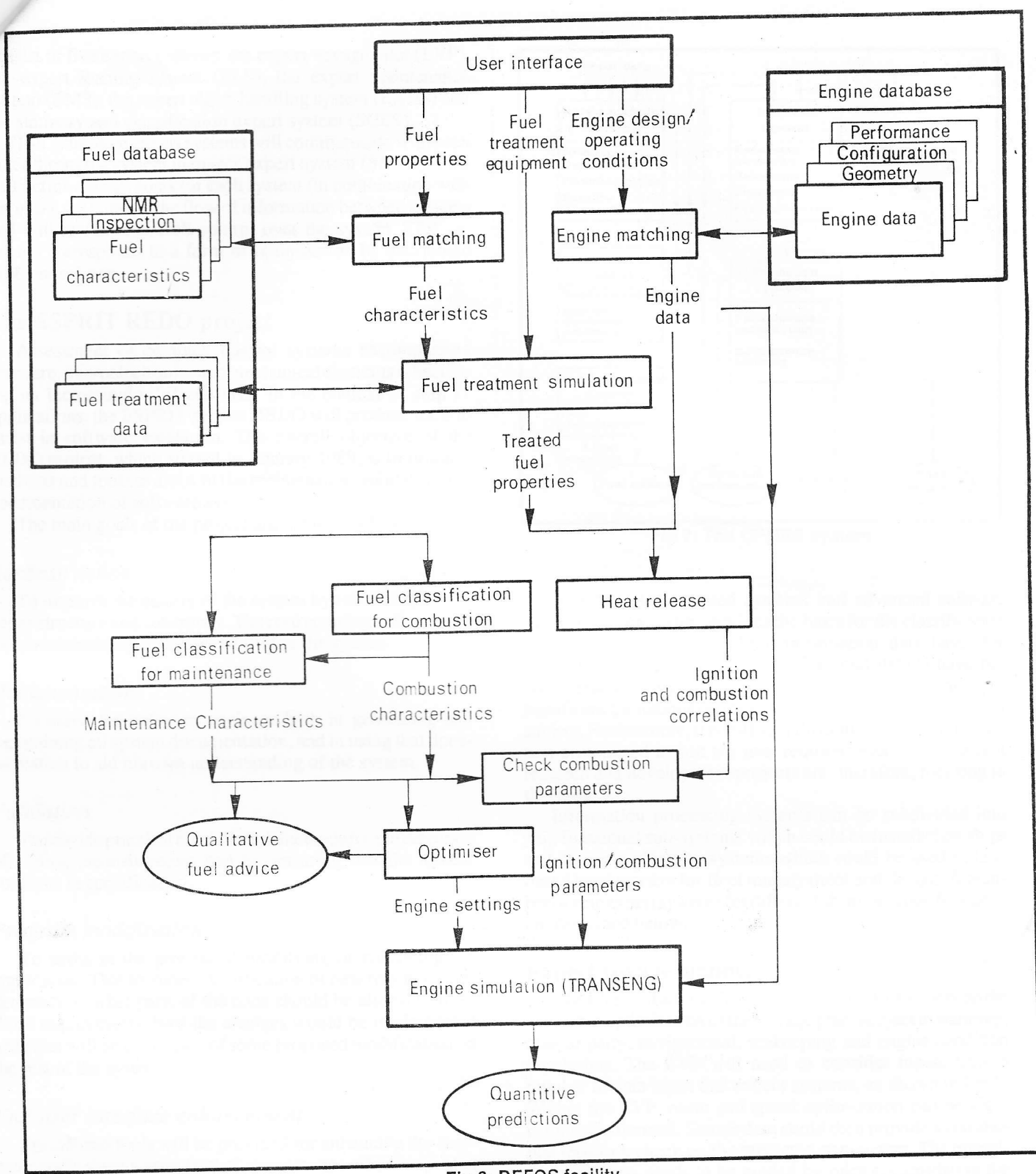

Fig 6: DEFOS facility

The application of knowledge based techniques in ship operation encompasses many challenging problems, involving assessment of multiple influences, both external and internal to the ship, and integrating diverse and multi-disciplinary tasks. External factors include environmental conditions, such as winds and sea states, operation constraints, such as chartering schedules and fuel quality, and the broad economic and social issues. The internal factors involve hydrodynamics, machinery, structures, stability, control, maintenance, electronics and management. Perhaps the major contribution of the KBSSHIP project to date has been the partia integration of these different engineering and economic disci plines through the use of the knowledge based techniques. In th next three years a full implementation of the KBSSHIP shoul demonstrate the benefits of KBS techniques in ship manage ment.

The KBSSHIP architecture has been designed to encompas most of the major application areas involved in ship manage ment and performance organisation, with the flexibility t respond to multiple problems. The full KBSSHIP system wi

consist of five expert systems: the expert voyage pilot (EVP), the expert loading system (ELS), the expert maintenance system (EMS), the expert alarm handling system (EAHS) and the statutory and classification expert system (SCES).

The individual expert systems will communicate with each other through a system manager expert system (SMES). This will define overall goals for each system (in combination with the user), will control the flow of information between systems and will maintain overall control over the system. This approach corresponds to a form of optimisation by distributed problem solving.

The ESPRIT REDO project

Assessment of complex control systems encompassing software, microelectronics and mechanical elements is becoming an increasingly difficult task. In the context of ship IT applications, the ESPRIT project REDO will produce tools to assist in software validation. The overall objective of the REDO project, which started in January 1989, is to produce methods and tools to assist in the maintenance, validation and documentation of software systems.

The main goals of the project are detailed below.

Reconstruction

To improve the quality of the system by rebuilding it with better structure and coherency. The restructuring will increase the maintainability and assessability of the system.

Documentation

To assist the software engineer both in generating and maintaining all system documentation, and in using that documentation to aid his own understanding of the system.

Validation

To provide practical but thorough methods for the detection of coding inconsistencies and for ensuring that the system confirms to specification.

Program modification

To assist in the process of modifying or enhancing the application. This includes identification of new requirements, determining what parts of the code should be altered to meet those requirements, how the changes would be implemented and what will be the impact of some proposed modification on the rest of the system.

End-user interface enhancement

Specialised tools will be provided for enhancing the computer code, since a great deal of maintenance effort is spent in this task.

A common approach will be taken in the development of the above facilities conceived as an integrated tool kit and accessed through a single uniform interface for the software engineer.

ADVANCED SHIP PERFORMANCE INFORMATION SYSTEMS (ASPIS)

ASPIS categorisation

ASPIS systems emphasise either the data bank type of activity information sources or the information processing task

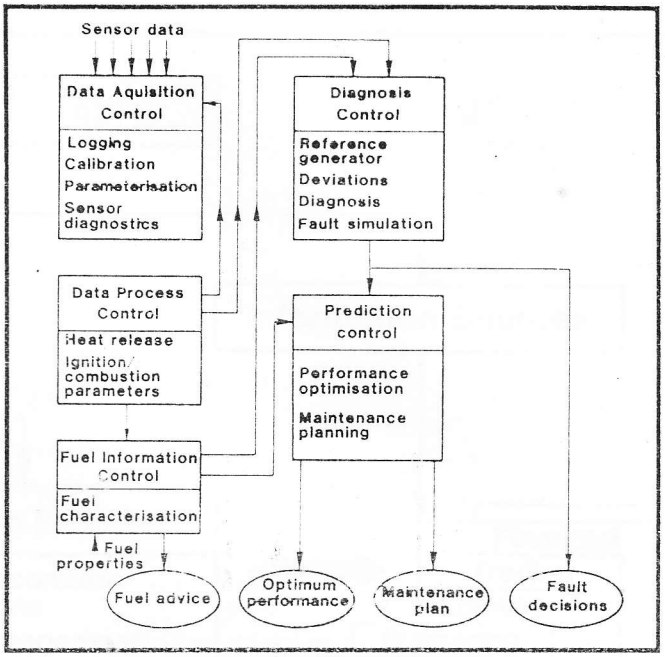

Fig 7: The CPMPS system

utilising knowledge based systems and advanced software support facilities. This provides the basis for the classification scheme shown in Fig 8. Ship information data bases for weather, bunkering, supplies and financial details have become established in recent years. However, there are still significant limitations on the extent and quality of data in each subject. Furthermore, it is still very difficult to extract information customised to suit the user requirements. Many current research and development projects are, therefore, focusing in this area.

Information processing systems can be subdivided into ship functional sub-systems which could be installed on ships and shipping planning systems which could be used in land based headquarters for fleet management and design. A number of ship expert systems for different ship operation functions are described below.

Expert voyage planner

The EVP will advise the ship's master or deck officer on the economic optimisation of the voyage plan, subject to statutory, charter party, navigational, seakeeping and engine condition constraints. The EVP will need to consider inputs from a number of data bases and expect systems, as shown in Fig 9. Within the EVP, route and speed optimisation can be algorithmically derived. Sensor data could then provide a continuous feedback check on the predicted parameters. The optimisation process needs to be guided by rules encapsulating the experience of ship's masters in resolving conflicts or making decisions in the absence of complete information. The key element in the development of voyage planners, as in many other engineering systems, is in the knowledge aquisition analysis and representation.

The expert loading system

The ELS will provide advice to the chief officer on the optimal loading of the ship (cargo and ballast distribution, trim and draught). A diagramatic representation of the ELS is shown in Fig 10. The optimum loading plan can be achieved by the generation of alternative loading plans and by then testing these plans against legislative, charter party and environmental

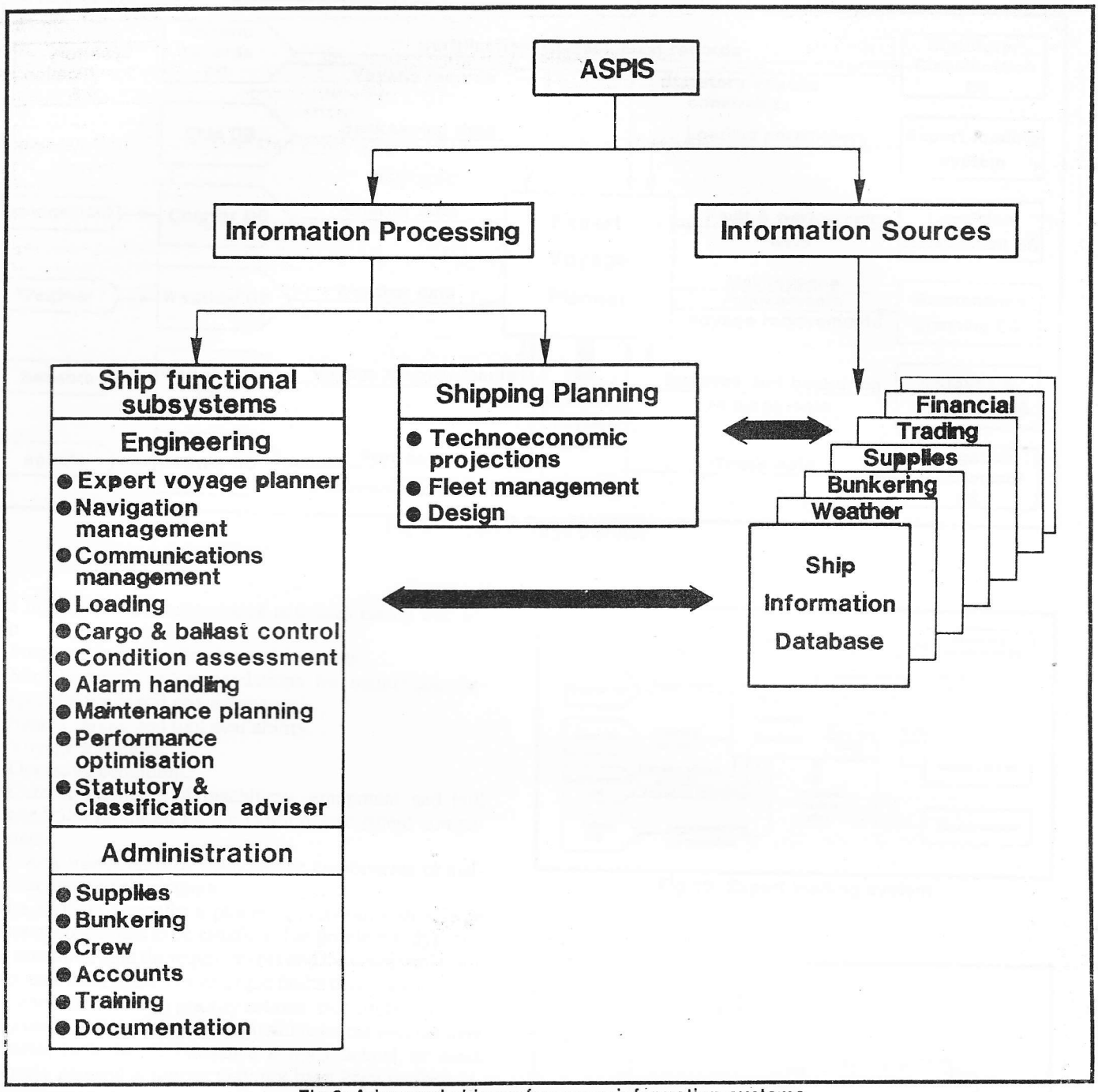

Fig 8: Advanced ship performance information systems

conditions. A particularly suitable approach is the 'generate and test' methodology. The knowledge of the master is contained within the 'generation' program which provides an initial cargo distribution plan satisfying the basic minimum criteria. This solution is evaluated both technically and economically by the 'testing' program. Modifications are then performed by the 'optimiser' using knowledge of how to refine a proposed solution on the basis of its performance. Again, another important aspect for loading systems is the information provided by direct measurements. Direct input of bending stress and draught can be used for two purposes:

1. Refining the intended loading plan.
2. An absolute check on safety criteria.

Slamming indicators for both frequency and intensity can also provide the data for trim optimisation in ships with light forward draught.

Expert maintenance system

The functional requirement for the (EMS) is to optimally identify and schedule maintenance activities in order to maximise engine availability and minimise maintenance costs.

The system will achieve these goals by:

1. Reducing downtime resulting from breakdowns and from maintenance performed at sea which require the engine to be stopped.
2. Minimising unnecessary and premature maintenance.
3. Complying with statutory and classification requirements.
4. Optimising productivity of labour and resources.
5. Minimising the inspection required to ascertain maintenance needs.

In order to achieve this, the EMS will optimise and plan

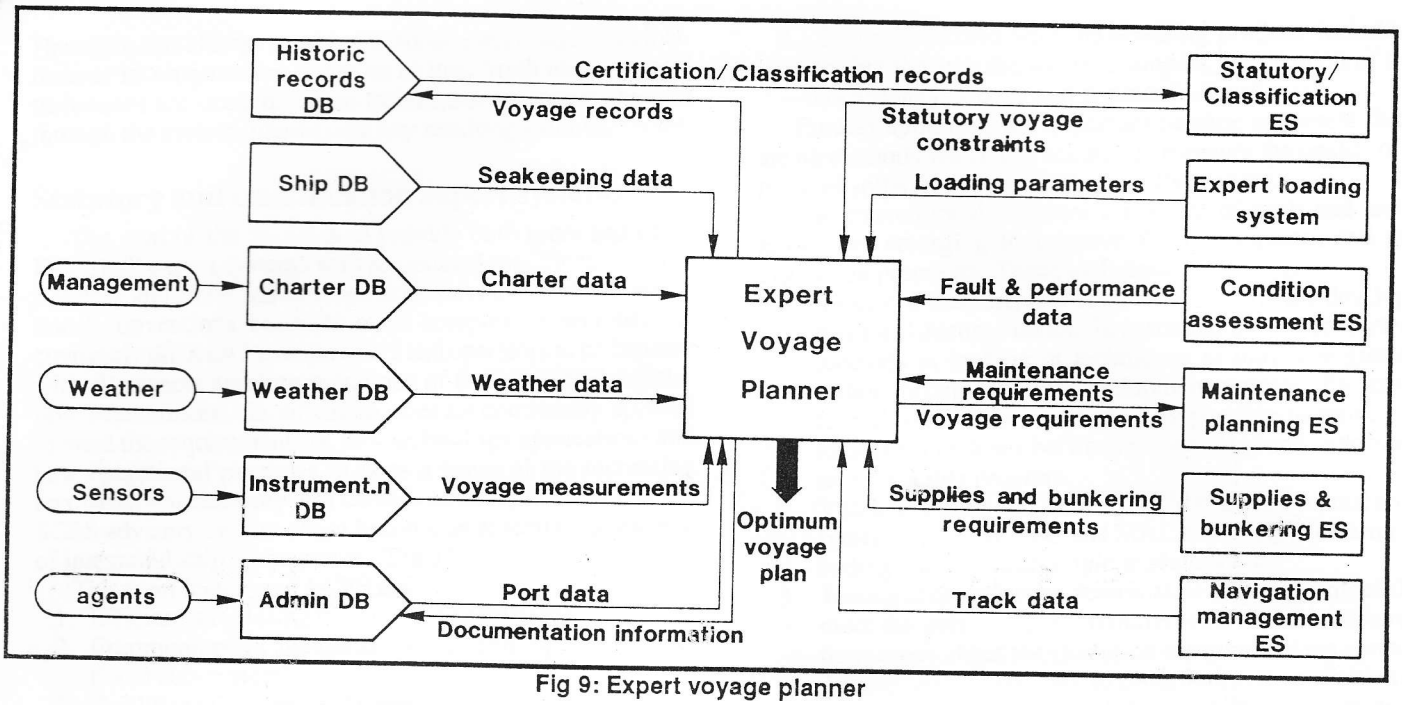

Fig 9: Expert voyage planner

future inspection and maintenance activities taking into account:

1. Statutory and classification requirements.
2. Manufacturer's recommendations for maintenance/inspection times and procedures.
3. Spares, labour and tool availability.
4. Voyage schedules.
5. Operating conditions.
6. Current estimates of machinery, equipment and hull condition produced by a condition assessment component.
7. Likely interactions of worn engine components or malfunctioning sub-systems.

The EMS is basically a planning problem with a large number of constraints to be satisfied. The problem is dynamic in the sense that both the requirements and the constraints may change on a daily basis. For example faults may arise necessitating immediate or high priority actions, the number of engineers available may change through sickness, the weather may deteriorate such that maintenance is not practical, or some previously planned activities may not have been performed. The maintenance plan produced by the EMS, therefore, has to be operated in response to changes in requirements or constraints. To achieve this the system produces a long term schedule and this is refined into a detailed short term plan.

The output from the EMS is a daily maintenance plan that gives details of the tasks to be performed and the resource allocation. The system requires information about completed tasks, available resources and access to sensor data from equipment like the main engines and electrical systems. The sensor data is needed to allow predictions to be made about when equipment needs maintaining. The other information is to allow the plans to be updated.

The EMS makes use of diagnostic information about faults (provided by the condition assessment expert system) to allow corrective measures to be planned, and to make predictions about the 'knock-on' effects of faults (which will effect maintenance requirements). The interpretation of 'condition' information can be carried out by combining heuristic rules with the qualitative reasoning models.

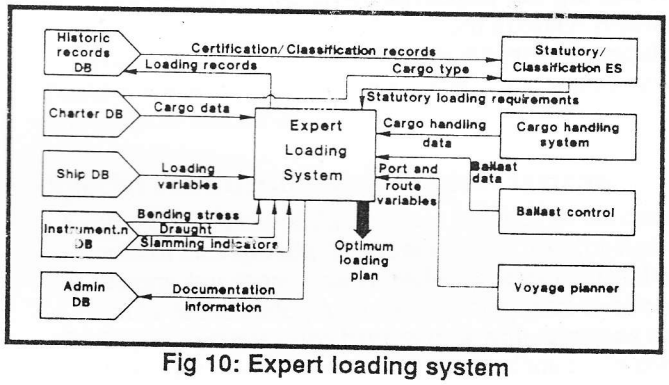

Fig 10: Expert loading system

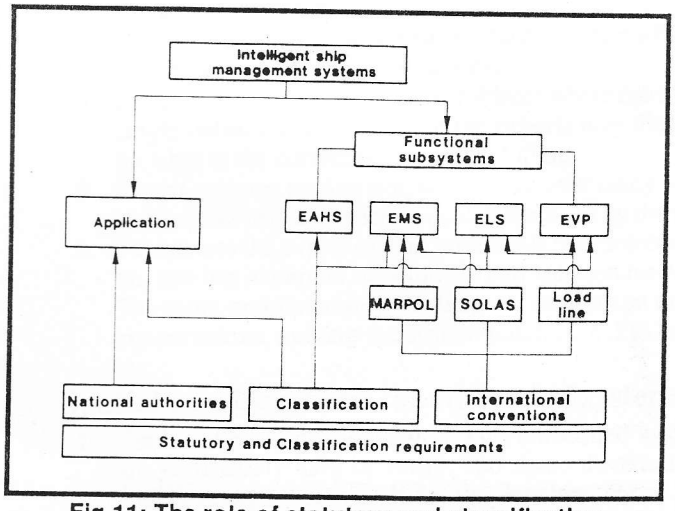

Fig 11: The role of statutory and classification requirements

When a constraint is changed, a fault arises, or sensor data indicates that some unexpected maintenance action is required. The impact of this 'change' must be assessed to see whether it can be accommodated with small changes to existing plans.

However, this change must not introduce any constraint violations or inconsistencies. To achieve this, 'truth maintenance' techniques are needed. These techniques propogate changes through the system, identifying any resulting inconsistencies.

Statutory and classification expert systems

The goal of the SCES is to provide both users and other KBSSHIP expert systems with an updated specification of the statutory and classification regulations. As the field of international conventions becomes more complex, it becomes increasingly difficult for shipowners and operators to be familiar with all aspects and interpretations of the associated legislation. Furthermore, classification rules are continually updated to meet the requirements of new technology applications and new operational practices. It is as a result of the increasing complexity of statutory and classification regulations that the SCES advisory system could become an essential component of integrated ship management (Fig 11).

The main features of SCES are:

1. Efficient structuring of rules and regulations.
2. Communication standards with all ship operation functional sub-systems.
3. Facilities to customise the system for type, gt, dwt, length and intended trade.
4. Communication links with classification shore based systems.

ASSESSMENT OF ADVANCED SHIP INFORMATION TECHNOLOGY SYSTEMS

A major factor in the adoption of IT systems to assist in ship management will be the ability to assess the quality of those systems in terms of safety, reliability, conformance to user requirements, maintainability and modifiability, speed and efficiency. Software evaluation is still a key area of research, particularly in the fields of expert systems and embedded software systems. There are currently no methods which can guarantee the correctness of a software system, although a number of techniques and appraisal guidelines do exist to give improved levels of confidence in the system. These will need to be adapted, further developed and combined with any existing ship certification criteria in an overall policy for quality assessment or classification of ship operation support tools.

Three main areas for assessment are normally considered:

1. System design appraisal: programmable electronics and communications (LANs).
2. Hardware appraisal.
3. Software appraisal.

Rules and guidelines are already well established for the first two areas.[10]

In the following section the special requirements for software appraisal are analysed. The need to assess the overall system (consisting of mechanical, electrical, hardware and software) as as integrated entirety is emphasised.

Software appraisal

Methods for evaluation of software naturally divide into two main groups:

1. Those concerned with the development process itself, including evaluation of the techniques used for system analysis, specification, design, documentation, implementation, verification and testing.
2. Those concerned with the resulting product, including testing through the use of examples, verification of the consistency of code and appraisals in use.

Process appraisals are important because at present there are no methods which can accurately measure the quality of a piece of software just by analysis of the system.

For conventional software a number of tools and techniques are emerging to improve the development and the evaluation processes. These include:

1. Improved methods and standards for software development and documentation. In particular the field of formal methods is looking at techniques to introduce greater rigour throughout the development process. By using formal verification methods it is possible to prove the logical equivalence between a (formal) specification and an executable program.
2. Validation tools and techniques. Static and dynamic analysers (such as SPADE and MALPAS) help to determine coding anomalies and style inadequacies.
3. Testing is necessary to demonstrate that program results meet the user's original requirements and that assumptions made about the execution environment are correct. Testing tools can be used to assist both in the definition of appropriate test cases and their use in the assessment process.

However, all of the above techniques are still limited in their use and have not yet been extended to expert systems or embedded software. The following highlights the special difficulties encountered with these systems and introduces the principles of assessment models.

Special considerations for expert systems

1. The correctness of the software depends on the correctness of the expertise. This is not always based on rigorous theory, but more usually includes rules of thumb and tricks of the trade which are extremely hard to assess.
2. Expert systems often have to deal with reasoning about time, uncertain or incomplete data and uncertain knowledge. The schemes for representing and reasoning with such knowledge do not have well defined semantics and cannot be validated.
3. There are few widely accepted standards or criteria for the expert system development process.
4. Expert systems often deal with problems where there is no single definitive answer. Even the experts may disagree on what is the correct or optimal solution.
5. Expert systems tend to simplify or take over many of the user's tasks and so reduce critical assessment by the user.
6. Sometimes the expert system problem is non-deterministic, and has a number of solutions and solution methods. The same problem may give different answers on different occasions, making the system much harder to test.

Special considerations for embedded systems

1. Timing constraints associated with embedded systems are particularly hard to verify, and again there are few widely accepted standards for the development of such systems.
2. The software is usually tested in a simulated environment and so performance cannot be guaranteed in situ.

Assessment model

Because of the described difficulties, appraisal methods have been and could continue to concentrate on the develop-

ment process, where the common good practices for developing conventional systems still apply. However, any assessment process would be improved if it is based on a predefined assessment model. The assessment model should consist of two subdivisions:

1. The definition of target objectives or requirements.
2. The set of measurements (metrics) which can be used to evaluate the requirements.

Metrics can be specified for software quality (complexity, maintainability, reliability and portability, for example), hardware and mechanical components. This enables a systems approach to be adopted in the evaluation of the target objectives.

CONCLUSIONS

Information technology and advanced communications provide new opportunities for improved fleet management. Increasing use of 'intelligent' information processing either on board the ship or at a shore centre will provide the means to define and refine strategic policies and to optimise ship profitability.

Communications, expert systems, data bases and computer hardware do not pose difficult technical requirements. However, the development of practical and realistic appraisal tests is still a key issue. Further research and development is required to improve the standardisation, adaptability and reliability of IT systems, to develop further sensory systems and adaptive controllers and to increase the efficiency of user interfaces.

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