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The Impact of Information Technology and Advanced Information Systems in Future Fleet Management

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ABSTRACT

The paper examines current technical progress in Information Technology, communications and automation and introduces a framework within which these technologies can be applied to ship operation. It presents aspects of Lloyd's Register's research activities in this field, such as the development of expert systems for condition monitoring and ship maintenance. Safety, reliability and independent assessment issues for the emerging integrated fleet management systems are analysed.

INTRODUCTION

Information Technology (IT), communications and automation are the three key elements in modern industrial technology, affecting the day-to-day lives of most of the developed world. There is a growing convergence between technologies and systems, as information technology is extended and supplemented by work in the fields of telecommunications and application electronics. A sustained drive towards technology integration has been supported by extensive research and development programmes in the U.S.A., Japan and Europe. The efficient integration of IT into application systems is the ultimate economic goal of these programmes.

It is inevitable that general technological progress will lead to the application of IT and advanced communication and automation systems in shipping. Moves towards enhanced operational flexibility and computerized ship management require increasing use of electronics, computers, instrumentation, data processing and communication. The application of advanced technology through the adoption of integrated ship control has already led to the recent order of three ships in Denmark, for which manning levels of seven have been approved.

Future fleet management systems will need to combine advanced information processing, communication and automation systems (see figure 1). In particular, knowledge-based or expert systems will provide a means to optimise ship operation by providing a coherent picture of the ship environment, taking into account uncertain and changing conditions, such as weather and sea states, economic factors and ship performance data. Vessels will increasingly be regarded as an extension of head office from which they can be managed. To achieve this, computer-based communication modules able to integrate data from many sources, including satellite, VHF and HF transmissions will also be needed. The increased quantity and quality of information which can be generated on-board the ship will be required not only by head office for fleet management, but also by other shipping support organizations such as Classification Societies.

LLOYD'S REGISTER'S RESEARCH PROGRAMME

Within Lloyd's Register the impact of IT in the marine industry is being closely monitored. Practical experience has been gained of expert systems through the development of applications in several marine technology areas (1). Most of these developments have been carried out by the Performance Technology Department in collaboration with many industrial and research organizations, under three research programmes. The first is the Fuels Project, funded by the Energy Programme of the Commission of the European Communities (EEC) and the U.K. Marine Technology Directorate (MTD). The project is producing a fuel characterisation expert system, with the active participation of 30 members, from oil companies, engine manufacturers and research establishments. This project, which is nearly completed, is closely linked to a second, the Condition Monitoring Project, which is funded by the U.K.

Department of Trade and Industry (DTI) and the MTD. A new generation of condition monitoring systems for diesel engines is being developed, incorporating fault diagnosis and maintenance expert systems. The third project is the ESPRIT Project 'Shipboard Installation of Knowledge-Based Systems' (KBSSHIP). ESPRIT is the European Community Strategic Programme of Research in Information Technology. KBSSHIP is aimed at the development of an integrated expert system to support the master and officers in optimizing the safe and economic operation of merchant vessels. A new ESPRIT project led by Lloyd's Register has also been recently approved, aimed at developing a tool kit which will assist in the maintenance and verification of existing software. This major research project (named REDO) is expected to have a significant impact on the independent assessment of future ship-related computer programs and integrated control systems.

TECHNOLOGY CHANGE IN THE 1980'S AND 1990'S

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 not only of the information intensive industries, such as banking and publishing, but of all industries and services. At the same time the IT industry itself is changing at an accelerated rate as substantial research and development activities are being supported by the industry itself and by government-funded programmes in the U.S.A., Japan and Europe. Following the research and development programme agreed by the Commission of the European Communities (including ESPRIT, RACE and COMETT) and equivalent programmes in the U.S.A. and Japan, a picture of the possible pattern of technological change can be drawn.

Telecommunications

In the telecommunications area the main expected milestones are the advent of the Integrated Services Digital Network (ISDN) followed over the next decade by an Integrated Broadband Communication Network. Direct Broadcasting by Satellite (DBS) and High Definition Television (HDT) are the other important developments.

Information Technology

IT developments can be divided into four areas:

- Software Technology
- Advanced Information Processing
- Advanced Microelectronics
- Computer Integrated Manufacturing

Software Technology

In software the main thrust appears to be towards creating Integrated Project Support Environments (IPSE's) and other Computer-Aided Software Engineering (CASE) tools, which can provide effective support for the software development process. In ESPRIT the Portable Common Tool Environment (PCTE) has been designed to satisfy these aims and is being extended to support new tools from the areas of knowledge engineering and formal methods. The introduction and use of formal notations and more rigorous methodologies for software design, validation and maintenance is the second major development area. Within this area automatic code generation is becoming increasingly important.

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 more easily ported. There is strong support for Unix as the emerging standard, with groups such as the Open Software Foundation and X/Open defining and refining standards. More generally, the European-wide ISO Open Systems Interconnection and similar CCITT standards are establishing inter-protocols to increase inter-connectibility in tele-communications and networking. IBM's contribution to this trend has been to develop its own Systems Applications Architecture and Systems Network Architecture (which encourage networking and portability across IBM equipment).

Information Processing

Advanced information processing is required by most application problems. The main goals in this area have been to apply knowledge-based systems in order to solve practical problems, and, more generally, to integrate artificial intelligence techniques into sophisticated software systems. Slow but steady progress is being made in most of the traditional expert system research areas such as knowledge acquisition and representation, and the development of application-independent support tools. Evaluation and assessment methods for expert systems are becoming an important research and development area. In the wider field, image processing, natural language understanding and speech recognition are artificial intelligence techniques now achieving commercial acceptance.

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 "neural networks" is the newest research direction, encompassing with hardware and software simulations.

Microelectronics and Computer Integrated Manufacturing

The interfacing of IT with the user's activities in finance, production and other fields 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. Optical circuits functioning near the speed of light are a long-term research goal.

Computer Integrated Manufacturing is concentrating on tools for real-time manufacturing control and upon robot controllers. At the same time efforts are directed at the creation of architectures and interfaces which will make possible the integration of systems from different vendors.

ADVANCE TECHNOLOGY IN SHIPPING

Computers in Ship Operations

In the maritime industry the introduction of computers has been slower than in many other industries. There has been significant onboard automation, but until recently there has been little progress towards "intelligent" data processing. The introduction of reliable microcomputers is now changing this situation. In the past five years the adoption of computers has become common for most new builds, 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 receivers for transmission of weather data.

Further advancement will relate to the presence or absence of the following factors:

- Access to Information Sources
  * Externally, to advanced databases on trading data, weather, supplies, and others.
  * Internally, to more and better sensor data.
- Access to Communication Tools
  * External: Satellite-data transmission.
  * Internal: Fiber-optic cabling.
- Information Processing Systems
  * Algorithmic Computer Programs (Stability, Strength, Simulation).
  * Expert Systems.

- Integration Facilities

    * For design methodologies.
    * Common interfaces.
    * Improved standards.

The rate at which new technology will be adapted and adopted in shipping is an unknown variable. Future integrated ship management systems aimed at increasing ship productivity are likely however to be developed in two distinct directions:

- Autonomous Shipboard Support Systems (The AS approach).

- Shorebased Ship Management (The SM approach).

Implementations of both approaches are likely to appear in the medium term, providing increased level of automation and ship-to-shore communication. Both approaches will share two common features:

- Total integrated ship control
- Use of advanced communications

Ship Management Information Processing Systems

Intelligent information processing to optimize overall ship management can take place either on-board or in the shore based head quarters. In the AS approach, it will tend to take place on board, whilst SM approaches will focus on land-based processing, with management information and decisions communicated to the vessel (see figure 2). The appropriate actions could then be administered through a local 'ship management control system' as shown in Figure 2b. The ship-to-shore communication arrangements will also be different. It is likely that individual companies will develop systems which emphasise features of the two approaches at different levels, however, a certain amount of information analysis and decision making will need to take place on-board the ship for the following reasons:

- Input of observations from the crew are required in diagnosis and prediction.

- Evaluation of the quality of information generated through ship sensors can be performed more efficiently locally.

- Communication cost will decrease by optimising the amount and frequency of data transfer.

Such a system can thus be viewed as a Distributed Artificial Intelligence system.

Knowledge-based techniques and tools can be applied to several aspects of ship operations initially to provide advisory functions, and in the future to extend automation by interacting with ship controllers.

Knowledge-based systems are required in the following areas:

- Voyage planning
- Cargo loading planning
- Cargo and ballast control
- Condition assessment
- Statutory and classification advice
- Alarm handling
- Maintenance scheduling
- Communication management
- Training
- Ship supply and bunkering
- Administration management.

The interdependency between the above tasks requires an overall strategy for system integration which will optimize ship 'Performance'. Performance criteria such as economy and safety change during a voyage, thus creating a requirement for flexible communication and co-operation for different tasks. Co-operation between different subsystems could be supervised and partly controlled by an 'Overall Co-ordination Expert System'.

Automation of Certification

An important aspect of ship management is compliance with certification and classification requirements. Public administration files transferred to National Departments of Transport and Classification Societies for the purpose of certification must contain reliable data. New techniques to validate such data will need to be developed.

Marine Communications

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 processing and exchange (paperless trade and transport) is already producing significant economic savings. For this purpose, ocean carriers are increasingly use public or private network organisations, Value Added Networks, and Value Added Services. A ship is therefore becoming part of an integrated transportation system. Satellite communications are used not only for data transfer between ship and shore but for actual monitoring and management of the vessel itself.

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.

The areas of future work are:

- Efficiency of available transmission networks.
- Standardisation of information structures.
- Legal issues.

<u>Total Integrated Ship Control</u>

In order to realise reductions in crew levels, the entire ship navigation, maneuvering, propulsion, cargo handling, and safety functions must be controlled from a ship management centre. 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:

- Optimum physical and functional integration of navigation, machinery and safety control systems.

- Availability of adaptive controllers which can identify deviation from performance and safety reference conditions and can institute corrective actions if and when required.

- Rigorous standardisation of equipment, procedures and interfaces.

The diagrammatic arrangement of Figure 3 using Local Area Networks (LANs) provides a possible configuration for the integration of all the ship operation functional subsystems. The processing units are divided into six Local Area Networks:

- Ship Management LAN
- Machinery and equipment LAN
- Communications LAN
- Navigation LAN
- Cargo handling and hull monitoring LAN
- Training LAN

Apart from management and training each other network interfaces with instrumentation and performs control and regulation tasks. Fibreoptic 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 CSMA/CD (Carrier Sense Multiple Access with Collision Detection) is the common protocol used. Developments in open systems are important here for the integration of equipment built by different manufacturers.

Most of the technology and tools for communications, 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 adaptability
- Intelligent and efficient user interfacing
- Integration.

ENGINE RESEARCH PROGRAMS

<u>Diesel Engine Fuel Management System</u>

The objective of the Lloyd's Register consortium fuels project, funded by the Commission of European Communities

Non-Nuclear Energy Research and Development programme was to develop a comprehensive diesel simulator to be utilized for the design of a Fuel Management System. Such a system can be used to increase engine tolerance on variable quality fuels and could become part of an overall engine control arrangement.

In spite of the recent reductions in the price of fuel oil, this is still one of the areas where the greatest economies can be made. The wide variation in fuel quality gives rise to a corresponding wide variation in combustion performance. Experimental results have indicated that fuel savings of the order of 3% to 12%, depending on engine size and type, can be realized. The function of the Fuel Management System is to advise engineers on optimum engine settings having identified the fuel effects on combustion and maintenance through a fuel characterisation expert system (2). In developing this expert system two data sources are used: engine tests and fuel chemical analysis. Fuels which share a common ignition or combustion performance criterion are grouped together. A prototype rule based system is then produced which classifies a given fuel with respect to ignition, combustion and maintenance effects. For example, ignition effects can be described by fixed percentage ranges of change in the ignition delay period from a reference (i.e. engine operation with gas oil or equivalent). A second sensitivity parameter is also introduced to account for the larger deviations encountered at low loads, with certain fuel types. One of the findings from the work carried out to date is that at least three fuel properties are necessary to discriminate completely all the fuels tested into groups of common ignition and combustion performance.

The Condition Monitoring Project

In 1986 Lloyd's Register formed a consortium with Marconi Command and Control Systems Ltd, the University of Newcastle Upon Tyne, Humberside College of Higher Education and Shell (representing a shipowners advisory group) to undertake a research and development programme into 'Condition/Performance Monitoring and Predictive Systems for Diesel Engines'.

The aim of the CPMPS project is to establish the principles of a system required to:

- Improve availability
- Optimise maintenance
- Provide facilities for integration into a ship control system
- Make better utilisation of engineers
- Optimise performance

for diesel engines.

To achieve this goal it is required to develop an advanced engine monitoring and management system with five main functions:

- Condition Monitoring
- Diagnosis of Engine Faults
- Performance Monitoring
- Performance Optimisation
- Prediction of Maintenance.

The CPMPS system design has been described in references 3 and 4. A set of data obtained from the engine is processed through logical reasoning, planning procedures and simulation modules in order to generate advice. There are five main functional subsystems in CPMPS described below:-

- Data acquisition and data processing
- On-line engine condition assessment
- On-line fuel characterisation
- On-line prediction of optimum engine settings
- Planning maintenance.

The sequence of operation commences with the acquisition of a "batch" of engine data. This is processed to smooth out transients and to detect any sensor faults. It is then conditioned and parameterised. The main flow of processing compares the engine data with precalculated reference levels from a 'reference generator' mathematical simulator, detecting any deviations and filtering out those which are regarded as unimportant. The deviations are then passed on to the diagnosis system which attempts to assess the engine state and to detect any fault conditions. In parallel, fuel effect parameters are calculated by the fuel characterisation expert system. Fuel and fault information is then used to suggest optimum engine running conditions and to project future maintenance activities on the engine. Reports are generated for the user at the appropriate times.

System adaptability to different engine types is accomplished through on line System Calibration during the initial system set up. The system will prompts the operator for engine design details from which it will calculate what operating conditions should be set up. In each such condition the system will scan the data in, and use it to repopulate the 'reference generator' model. Deviation detection and diagnosis will, in the meantime, be suspended. Recalibration will take place after completion of engine overhaul and change of engine part or sensor.

Details of the sequence of processes during normal, steady-state processing and diagnosis are shown in the state transition diagram of Figure 4. All the components of CPMPS have been implemented in an object-oriented system which has provided an efficient means to represent the structure and function of engine components. Combining pattern recognition techniques with causal models has been found to be effective in both the diagnostic and maintenance planning expert systems developed.

THE ESPRIT KBSSHIP PROJECT

Introduction

In recent years the European Community has combined its scientific and industrial strength in a concerted approach to information technology. Within such a framework, KBSSHIP is aimed at developing design concepts for the implementation and utilization of advanced IT systems on board ships (5).

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 and cargo, by providing support for the problem-solving and decision-making processes involved in planning, implementing and evaluating ship operations. This is to be achieved through the development of a framework for the integration of on-board information to provide decision support in order to allow a small crew to run a ship efficiently.

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, operational constraints such as chartering schedules and fuel quality, and broad economic and social issues. The internal factors involved include hydrodynamics, machinery, structures, stability, control, maintenance, electronics and management. Perhaps the major contribution of the KBSSHIP project to date has been the partial integration of these different engineering and economic disciplines through the use of knowledge-based techniques.

The KBSSHIP Architecture

The KBSSHIP architecture has been designed to encompass all the major application areas involved in ship management and performance optimisation, with the flexibility to respond to multiple problems. It must also deal with a variety of tasks, covering most of the major problem-areas within A.I. The full KBSSHIP system will consist of a number of expert systems, each of which is dedicated to solving one important problem in ship operations. Five such systems have so far been identified: the Expert Voyage Pilot (EVP), the Expert Loading System (ELS), the Expert Maintenance System (EMS), the Expert Alarm Handling and Diagnosis System (EAHS) and the Statutory and Classification Expert System (SCES), (see figure 5).

KBSSHIP is an advice system. It can make no decision about the operation of the ship, so that, in particular, it cannot overrule any decision or action of any crew member. Most importantly, it does not control the operation of the ship. 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. However, some other applications will only function with significant modifications to the digitised charts, weather maps, and from the algorithm base, ship response functions and cost functions, great-circle calculations and route-optimising controllers.

ELS: The Expert Loading System will provide advice to the chief officer on the optimal loading of the ship (cargo and ballast distribution, trim and draught). This is to be achieved by the generation of alternative loading plans and by then testing these plans against legislative, charter party and environmental conditions. The overall AI approach adopted is a '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.

EAHS: The goal of the Expert Alarm Handling and Diagnostic System is to respond rapidly to alarm signals by providing information and advice for dual-trained personnel on the bridge. This will provide a knowledge-based system for intelligent supervision of ship machinery, navigation and safety equipment.

The EAHS has two components. An alarm handling program should provide immediate advice on the possible causes of an alarm and advice on severity and investigations to be carried out. It should also initiate the fault diagnostic and condition monitoring system to identify the cause. State or causal models and temporal logics are the important AI issues in this area.

EMS: The functional requirement for the expert maintenance system is to optimally identify and schedule maintenance activities in order to maximise engine onboard electronic systems, or on new-builds.

The users of the system will primarily be the shipboard officers in charge of navigation, machinery, cargo operations and administration, particularly the master or Deck Officer (D.O.). In addition, secondary users will include shore-based commercial and technical operations. Sea users will access KBSSHIP via one or more computer terminals, sited in the bridge and possibly the engine control centre. The system will be designed to run on one or more separate processors, with an interface which permits several applications to be monitored or run simultaneously. Some of the systems will be aimed primarily at engine room staff, whilst others will be focused on the master and the bridge.

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 Individual Expert Systems

EVP: The Expert Voyage Pilot will advise the ship's master or D.O. on the economic optimisation of the voyage plan subject to legislative, charter party, navigational and sea keeping constraints and engine condition.

The high-level knowledge within this application will relate to charter constraints originating from standard shipping procedures and company policies; to external constraints upon the vessel's track, such as the availability of navigable waterways; and constraints imposed by the vessel and its immediate environment, such as engine power reduction or other damage. The numerical elements within the EVP will include information from sensors and surveillance systems such as hull integrity readings; from the radio link information such as the land geometry and harbour approaches, available from availability and minimise maintenance costs.

The system will achieve these goals by:

- reducing down-time resulting from breakdowns, and from maintenance performed at sea which requires the engine to be stopped
- minimising unnecessary and premature maintenance
- automating the satisfaction of statutory and classification requirements
- optimising productivity of labour and resources
- minimising the inspection required to ascertain maintenance needs.

In order to achieve this, it will optimise and plan future inspection and maintenance activities taking into account:

- statutory and classification requirements
- manufacturer's recommendations for maintenance/inspection times and procedures
- spares, labour and tool availability
- voyage schedules
- operating conditions
- current estimates of machinery, equipment and hull condition produced by a condition assessment component
- likely interactions of worn engine components or malfunctioning subsystems (see figure 6).

Several components of the system had been identified, primarily

i the Maintenance Interpreter, which identifies the alterations to component rates of deterioration caused by faults (from the EAHS), the external environment (from the EVP), and the fuel used,

ii The Planner, which determines for each day the work to be carried out during the next month, replans when the situation changes, optimizes the plan and handles inconsistencies between goals,

iii The state estimator, which monitors the actual deterioration of components, and delays their maintenance if they are deteriorating more slowly that their practical wear rates would suggest (or vice versa).

SCES: The goal of the Statutory and Classification Expert System 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. Further more, 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 KBSSHIP (see figure 7).

The main features of SCES are:

- Structuring of the applicable regulations,
- Communication standards with the EVP, ELS, EMS and EAHS,
- Facilities to customize system for Type, Gross tonnage, Deadweight, Length and Intended trade.
- Communication links with classification shore base system.

EVALUATION OF SHIP CONTROL 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, Functionality, Conformance to user requirements, Maintainability and Modifiability and 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

Communications - Local Area Networks

i) The network topology should be such that the single fault philosophy is maintained. In the event of a failure between nodes, the network should continue to operate, and data transmission should be maintained.

ii) The protocols used must ensure the integrity of data flowing on the network. Limit checking on data values should be incorporated into the systems sharing the network.

iii) The network should handle the maximum data transfer rate without incurring an unacceptable data latency or collision rate.

iv) The network should remain in operation in the event of a network controller failure.

v) The connection or disconnection of nodes should be such that the network continues to operate with minimum disruption.

vi) The usage of the network should be monitored with facilities for indicating faults and other parameters for assessing its performance.

vii) The network installation should be protected against mechanical damage and electromagnetic interference.

2. Hardware Appraisal

It is usually possible to give an accurate prediction of hardware reliability. The key issue for ship board systems is the ability of the hardware to perform to specification under all marine environment conditions including High temperatures, Humidity, Vibration, Power supply variations, Audio and radio electromagnetic interference and Transients in the power lines. Hardware evaluation should be based on extensive tests under real or simulated marine conditions.

3. Software Appraisal

Methods for evaluation of software 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 discussed below:

1. System Design Appraisal

System reliability may be improved if the design incorporates means to recovery, or "fail-safe" techniques in the event of faults or failures. Appraisal of the system design should address the following issues concerning programmable electronics and communications.

Programmable electronics:

i) A common certification requirement is the 'single fault philosophy'. Here the design ensures that the system will continue to function as long as there is no more than one fault in any area or subsystem. This may be achieved by segregation of function (particularly between control, alarm and safety systems) or by adequate redundancy.

ii) Self monitoring facilities: any fault causing a failure of the system to carry out its intended functions should be indicated.

iii) The location of hardware faults should be indicated to a level compatible with a defined repair/replacement policy.

iv) Programs and data held in the system will require protection from corruption caused by power-loss.

v) Means to re-enter a program will be required when any part of the program is stored in volatile memory.

vi) Effective security arrangements will be required for access to program and data.

divide naturally into two main groups:

(i) those concerned with the development process itself, including evaluation of the techniques used for system analysis, specification, design, documentation, implementation, verification and testing.

(ii) 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:

- 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.

- Verification tools and techniques. Static and dynamic analysers (such as SPADE and MALPAS) help to determine coding anomalies and style inadequacies.

- Testing tools can determine which paths through the system are still to be tested.

However, all these 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 with these systems.

Special Considerations For Expert Systems

- 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.

- 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 a well-defined semantics, and cannot be validated.

- There are few widely accepted standards or criteria for the expert systems development process.

- Expert systems often deal with problems where there is no single definitive answer. Even the experts may disagree on the what is the correct or optimal solution.

- Expert systems tend to simplify or take over many of the user's tasks and so reduce critical assessment by the user.

- 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

- 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.

- The software is usually tested in a simulated environment, and so performance cannot be guaranteed in situ.

Because of these difficulties, appraisal methods should concentrate on the development process, where the common good practices for developing conventional systems still apply. Hopefully future research will identify more rigorous assessment techniques.

CONCLUSIONS

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

Communications, expert systems, databases and computer hardware do not pose difficult technical requirements. However the development of practical and realistic appraisal tests is still a key issue. This, together with adoptive technology for control, information processing, and training will probably determine the rate of overall progress. Other key factors include standardisation and reliability of equipment, and sensor applications.

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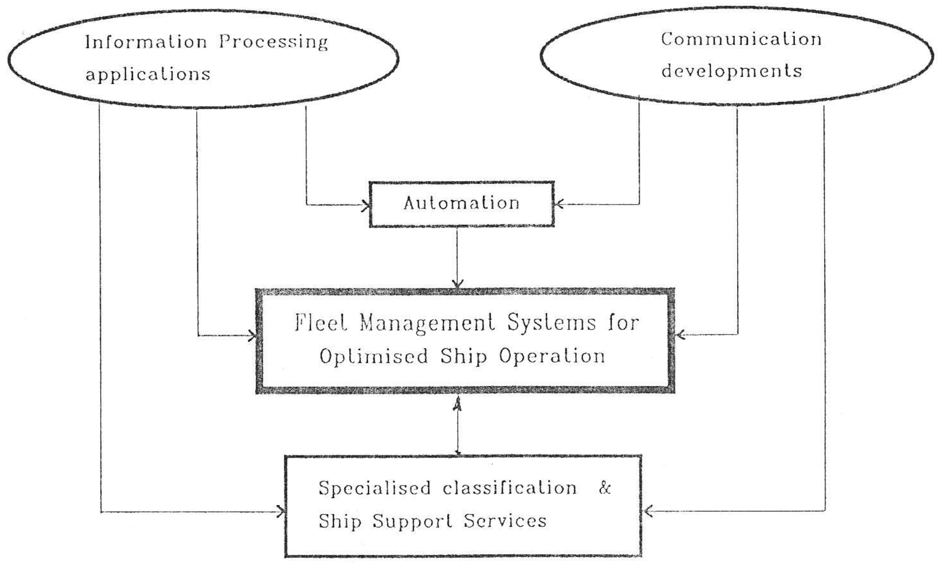

FIG 1. Future Ship Management

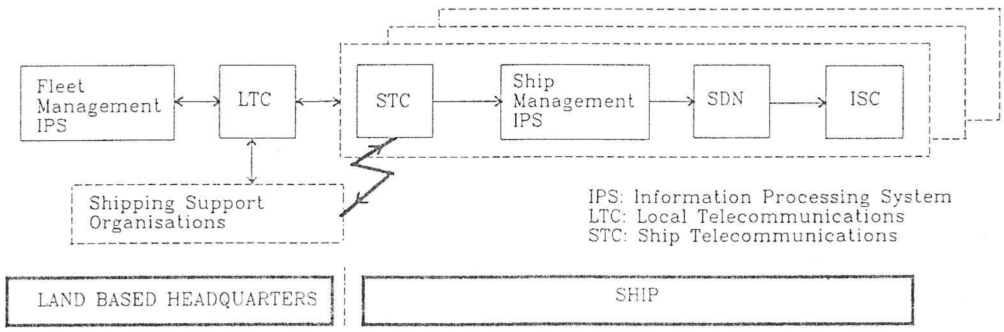

FIG 2a. THE AUTONOMOUS SHIPBOARD SUPPORT SYSTEMS APPROACH

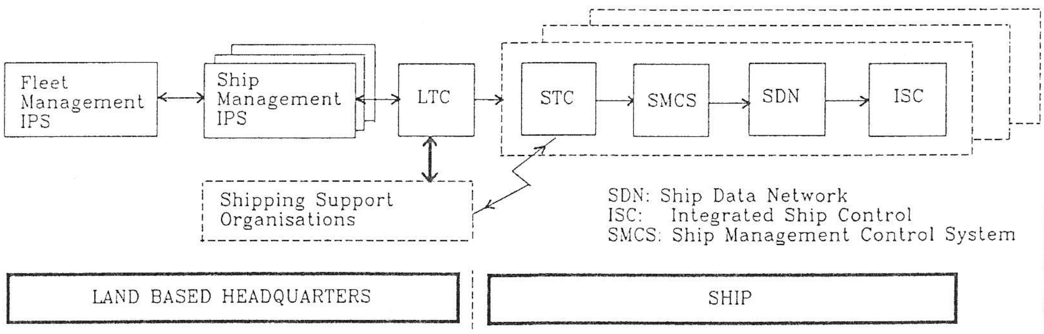

FIG 2b. THE SHORE-BASED SHIP MANAGEMENT APPROACH

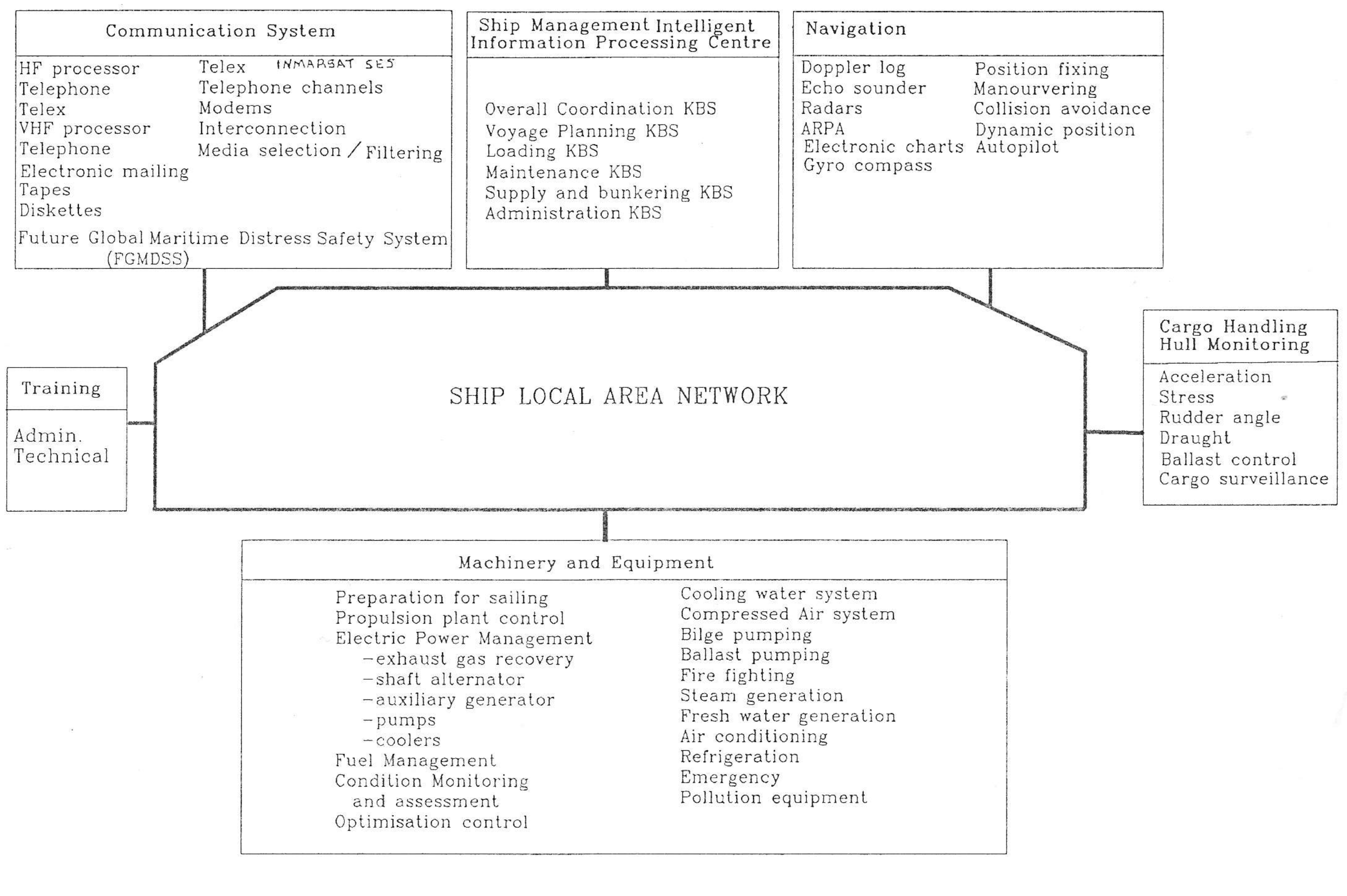

FIG 3. Total Integrated Ship Control

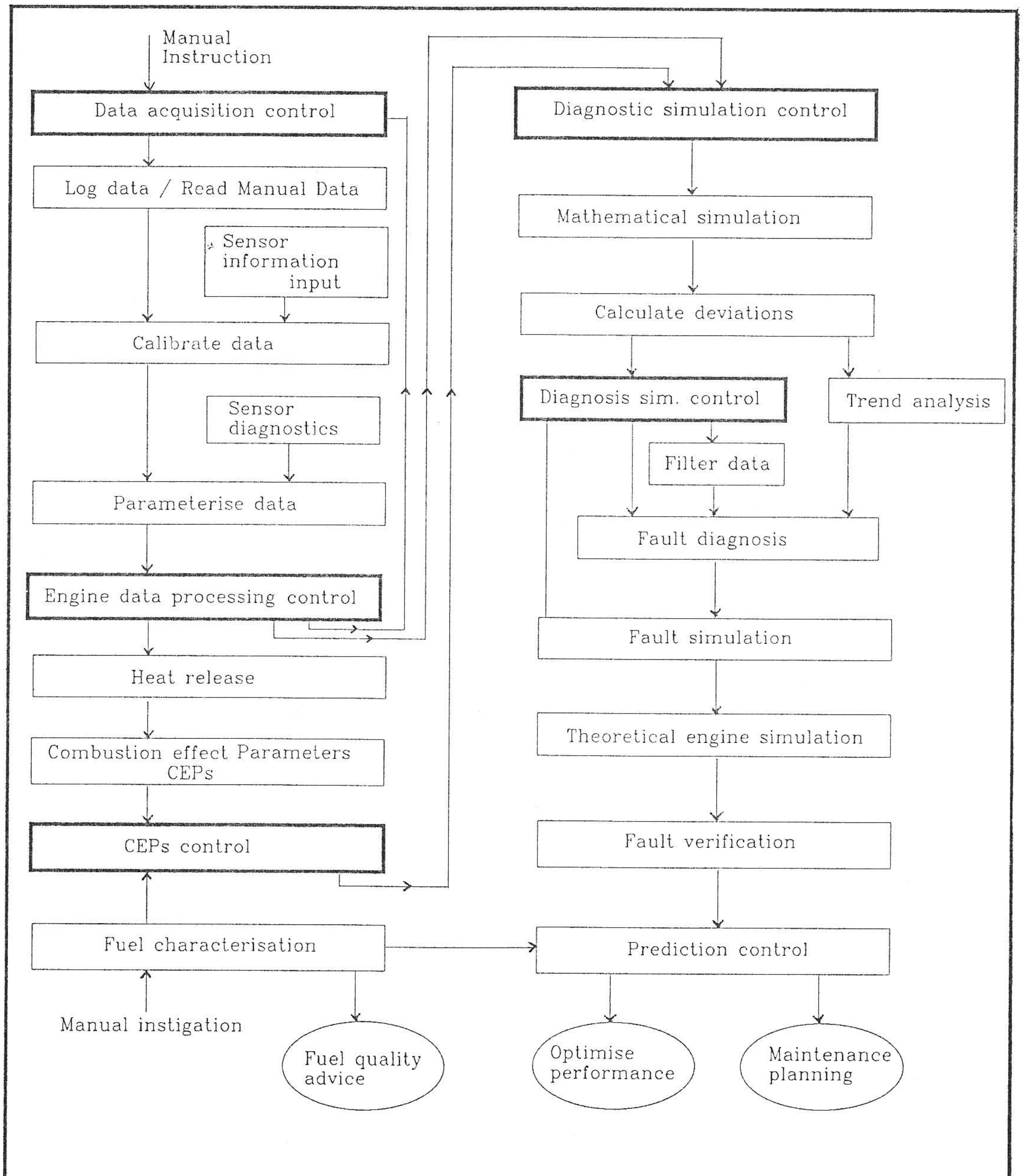

FIG 4. CPMPS CONTROL FLOW DIAGRAM

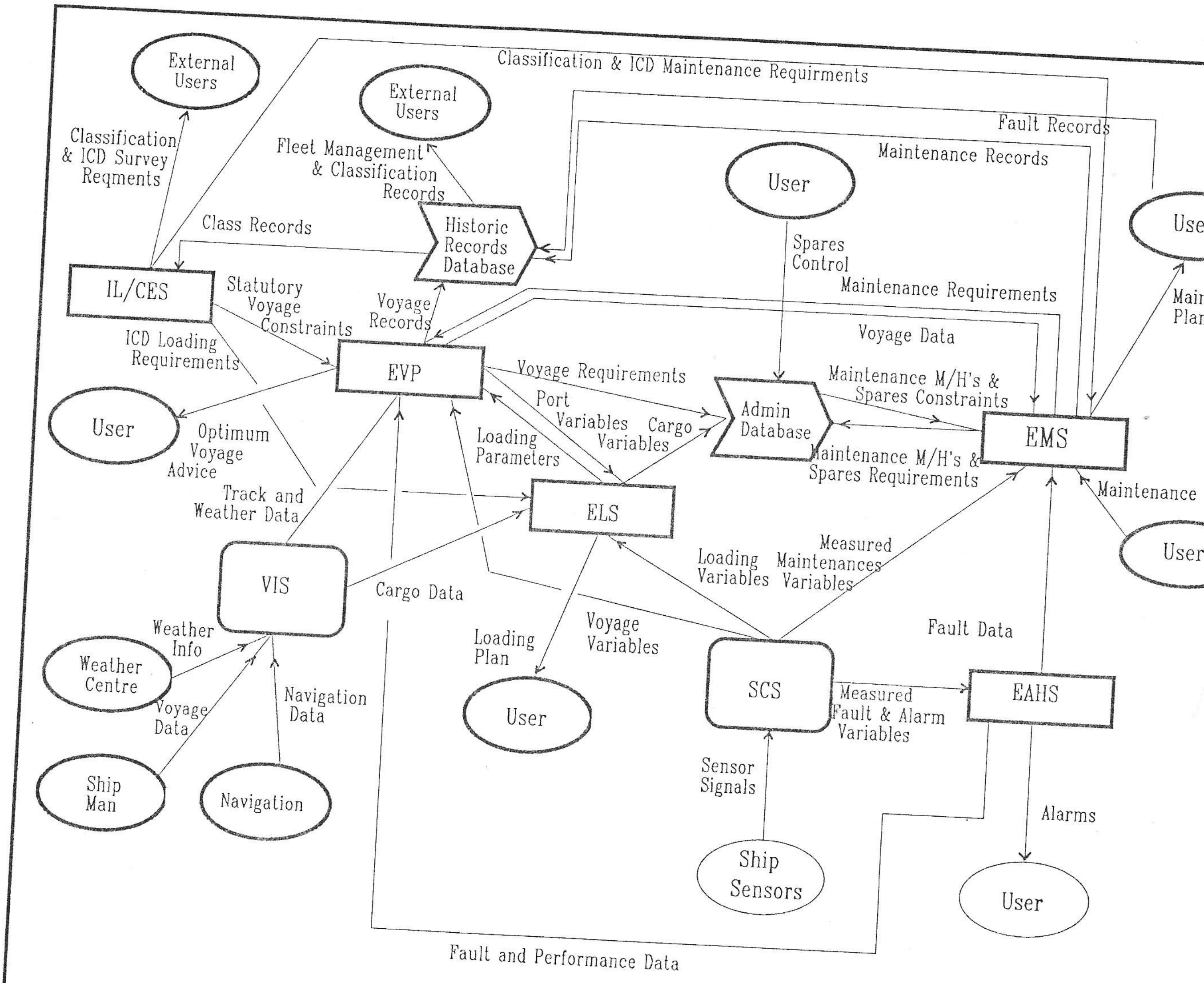

FIG 5. KBSSHIP DATA FLOW DIAGRAM

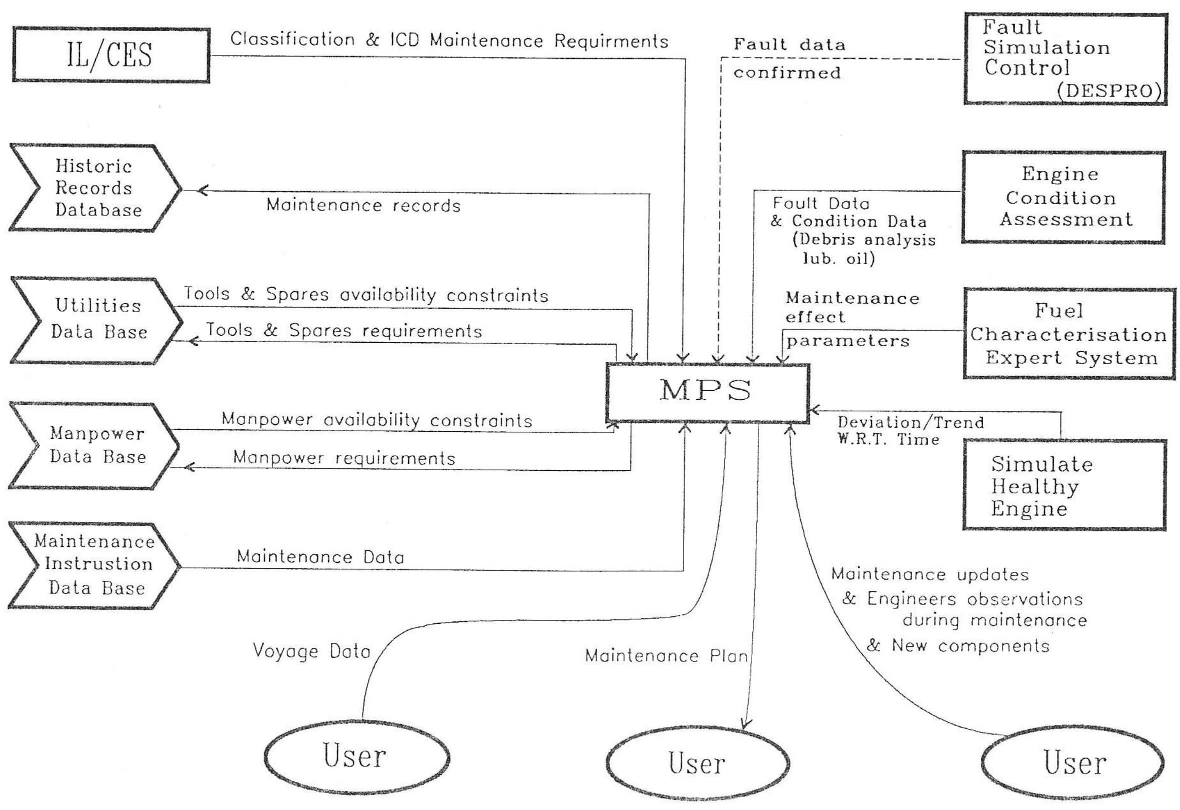

FIG 6. ENGINE MAINTENANCE PLANNING SYSTEM INFORMATION

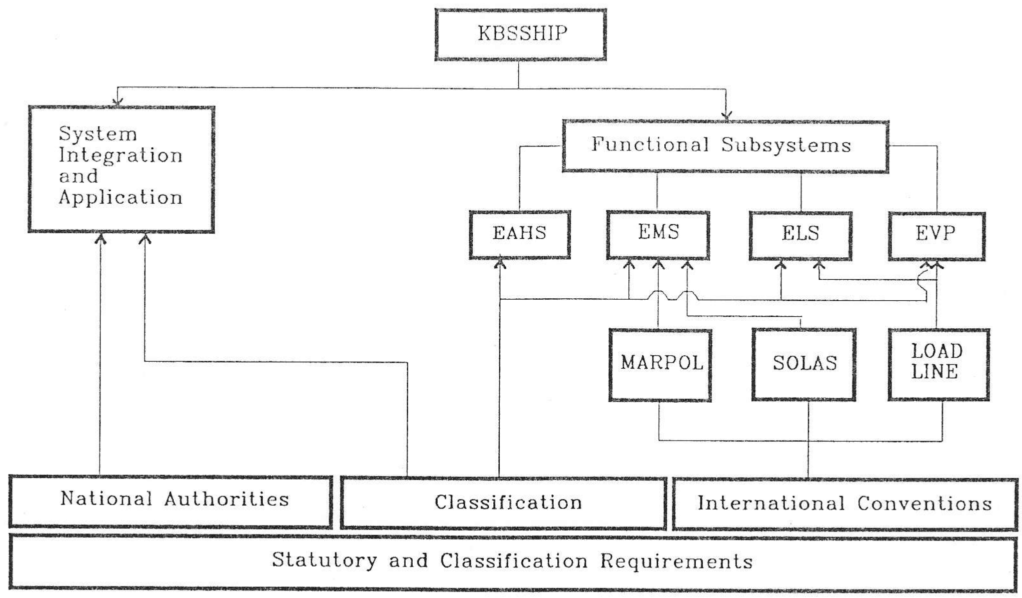

FIG 7. The role of Statutory and Classification requirements in KBSSHIP