THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 Pavonia Avenue, Suite 400, Jersey City, New Jersey 07306 USA
Paper presented at the Marine Structural Inspection, Maintenance, and Monitoring Symposium
Sheraton National Hotel, Arlington, Virginia, March 18-19, 1991

A Survey of Some Important Research Areas Related to Marine Maintenance

C. Aage and **N.G. Fog,** Technical University of Denmark, Lyngby, Denmark

ABSTRACT

The need for effective marine maintenance is very obvious and also recognized by all involved parties, shipowners, classification societies, authorities, etc. Maintenance is a key factor in the economic life cycle of ships and offshore installations, as well as in the safety and risk levels of their performance.

A scientifically based theory of marine maintenance has not yet been established, although many elements of such an approach do exist. This paper presents a survey of some important research areas related to marine maintenance, which together may form the basis of a scientific maintenance method.

1. INTRODUCTION

Marine structures - ships and offshore platforms - represent very large capital investments, and the demands for scheduled operation and planned earnings are consequently high. Public demands on safety for people and environment underline the requirements for fail-safe operation.

The demands on marine structures are in principle not very different from those imposed on other technical systems, such as chemical plants, factories, buildings, bridges, trains, aeroplanes and automobiles. However, certain features are unique to marine structures:

- o Ships and offshore platforms are usually one-off designs, which means that statistical information from large series of identical vessels does not exist (unlike aeroplanes and automobiles).
- o The environmental actions, especially wave loads and sea water corrosion, are very severe on marine structures, and unfortunately only predictable with a high degree of uncertainty.
- o Maintenance work on marine structures is difficult due to the harsh environment and due to low manning rates. Extra manpower cannot easily be brought in for repair and maintenance. Ships may be far from suitable repair dockyards, and fixed offshore platforms have to be repaired and maintained at sea, often by the use of divers and other very expensive specialists.
- o The downtime cost is extremely high. A typical ship costs about $20,000 per day, and the biggest North Sea platforms about $20,000,000 per day of lost production.

Systematic maintenance is a key concept in the endeavour for optimum availability and safety of technical systems in general. Very large amounts of money are spent on maintenance, typically in the order of five per cent of the new-building cost per year. But it is characteristic that the maintenance function is usually governed by the experience and judgment of single persons, instead of a scientifically based analysis.

In contrast to the classical engineering disciplines of design, production and economic management, where scientific methods have been introduced long ago, a systematic research effort and a scientific method in the field of maintenance seem to be lacking. "Maintenance is the last frontier of scientific management!" (Hawcroft, 1988).

There may be several reasons for the neglect of maintenance as a scientific discipline in its own right. First of all, maintenance is so multi-disciplinary that it is not covered by any of the traditional categories of engineers. And secondly, all engineering education and tradition is concerned with the design and construction of new items, not the preservation of old ones. However, most naval architects and marine engineers will be dealing with maintenance problems during their career, and there is a growing understanding of the need for a systematic research effort in the field of marine maintenance.

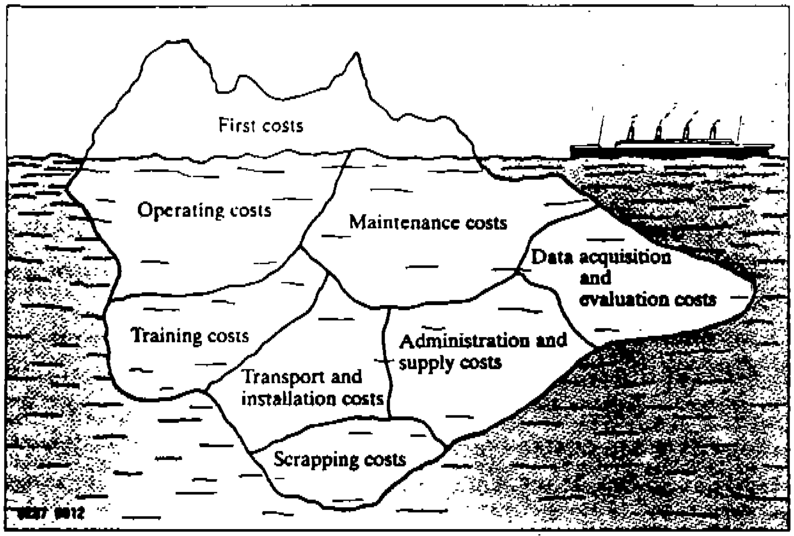

Fig. 1.
The lifetime costs of a technical installation. (Sulzer, 1987).

2. RESEARCH PERSPECTIVES AND NEEDS

Many elements of a scientifically based maintenance method do already exist, such as:

- o Statistical reliability theory
- o Risk analysis methods
- o Fatigue theory
- o Crack growth theory
- o Corrosion theory
- o Methods of accelerated testing of machine components
- o Metods of non-destructive testing and inspection
- o Instruments for automatic measurement and surveillance
- o Computers and database systems for aquisition, storage and analysis of very large amounts of data.

But a synthesis of these different technical disciplines into one universal maintenance theory has never been formulated. However, the idea as such has been described quite precisely under the name of **terotechnology** (from Greek "tereo": to look after, to take care of):

> "Terotechnology is a combination of management, financial, engineering, and other practices applied to physical assets in pursuit of economic life cycle cost. Its practice is concerned with specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification, and replacement, and with feed-back of information on design, performance, and costs." (Hewgill and Parkes, 1979).

In contrast to the traditional maintenance concept, it is emphasized that maintenance is taken into consideration already at the design stage where important system properties such as reliability and maintainability are determined. Furthermore, it is important to realize that terotechnology is not only a technical matter. Organisation and management of human resources are equally important for an optimal solution of these complex problems. In other words, maintenance must be considered in relation to the system's life cycle, and the marine structure - ship or offshore platform - must be seen as part of a greater system in which human resources play an important part.

Even if a coherent universal maintenance theory may not be possible in the near future, if ever, it is realistic to aim for a computerized terotechnology method where all the disciplines necessary for marine maintenance are integrated at a superior systems level as a tool which is easy and fail-safe to use for the operator.

In the following sections some of the more important research areas related to marine maintenance will be discussed.

3. THE LIFE CYCLE CONCEPT

By introducing the life cycle concept the operational cost is replaced by the much more relevant cost of ownership, which comprises all costs during the lifetime of the ship or platform: design, construction, running-in, operation, inspection, maintenance, repair, insurance, demolition, and last but not least the losses due to unavailability of the production capacity.

Unavailability will often be caused by ineffective maintenance. In this connection it should be emphasized that minimum maintenance cost and maximum availability cannot be obtained simultaneously, unless a life cycle concept is adopted.

An economic life cycle optimization may very well end up in designs that are different from the results of sub-optimization of each single phase of the life cycle. Two examples will illustrate this:

1) A few millimetres increase in steel dimensions of an offshore platform may significantly reduce the number of very expensive diver inspections. This possibility will not arise if the construction cost alone is minimized.

2) The demolition costs of offshore platforms are normally not taken into account at the design stage. If the design is based on a life cycle model, a concrete platform which has been found optimal from a construction cost point-of-view may be changed to a steel platform, because the demolition costs are lower for this type of platform.

References: 2, 6, 7, 8, 9, 11, 12, 13, 29, 30, 37.

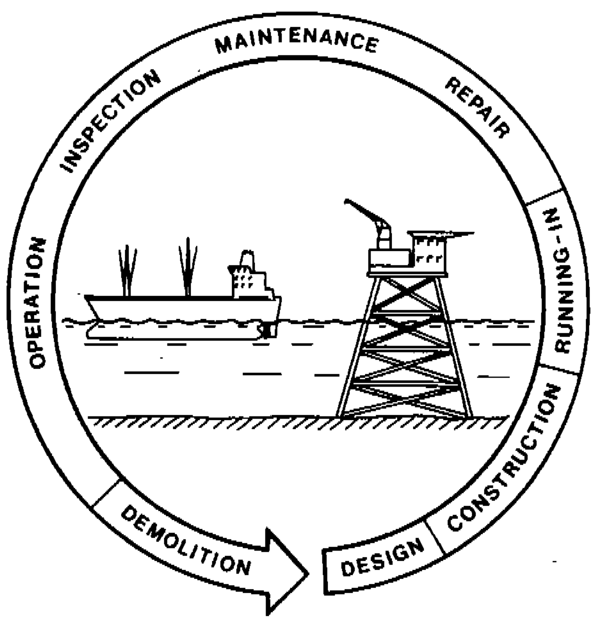

Fig. 2. The life cycle for a ship and an offshore platform.

4. THE HUMAN FACTOR

The human factor is a key element in maintenance management as in all management of large complex systems. All experience shows that human beings make mistakes. Apparently without explicable reason even the most experienced and responsible operators can make disastrous mistakes. Most accidents with ships, airplanes, trains and automobiles are due to human and not technical errors.

On the other hand, human improvisation and intelligence may sometimes save unpredicted situations, which the control system has not been prepared for, from developing into disasters. That, however, seems to be the exception rather than the rule.

Systematic maintenance must, especially due to the safety aspects involved, take the human factor into account. Three examples will illustrate the problem:

1) In a paper factory, the lubrication of all roller bearings in a new production line was put in the hands of one trusted worker. Unfortunately, the man consistently ignored one particular bearing for two years, which resulted in a very costly repair and production stop. The factory, as a result, has introduced automatic lubrication on all bearings in the production line, even if this from a pure maintenance point of view is far more expensive than manual lubrication.

2) On a passenger airplane, loss of lubrication oil pressure was observed in flight on all three engines nearly simultaneously, which almost led to a disaster. The reason was that all three engines had been serviced at the same time by one mechanic, who had changed the magnetic plugs for collection of wear particles, and failed to install the necessary rubber seals on all plugs.

3) The Piper Alpha disaster in July 1988 was allegedly caused by a stream of condensate being sent through a line where a safety valve had been removed for repair and scheduled maintenance, so that the line was open to the air. This resulted in a release of gas which led to the initial explosion that started a chain reaction ending in complete loss of the platform and 167 lives. The production operations team was obviously unaware of the missing valve, and no alarms seem to have warned the operators when they tried to send the condensate through the inoperational line.

In all three cases the human factor is the direct cause that well-designed systems fail, and in all cases it is the systematic maintenance itself that paradoxically leads to the failure. This is probably more than a coincidence. Maintenance provokes untypical situations where normal procedures become useless or directly dangerous.

Several lessons can be learned from the three examples. One single person should not maintain or inspect the same installation over a long period. Back-up systems should be effectively independent, also in terms of maintenance, and should therefore not be serviced and inspected at the same time and by the same person. The human factor requires systematic maintenance to be deliberately unsystematic. And the need for system state information is even greater during maintenance than in the normal production mode.

The human factor problem is related to the problem of keeping the necessary overview in space and time. Overview in space is difficult because large technical systems, such as ships and offshore platforms, are in fact too complex to be grasped as a whole, while at the same time having the operational knowledge about all system components. The solution is to divide the system into smaller subsystems, paying the price of lost overview, especially if the subsystems are put in the hands of different persons.

Overview in time is difficult when the time scales are outside the range of normal human actions, like walking or running. Very fast actions, such as manoeuvring a modern jet fighter, require computer assistance because they are too quick for the normal human brain. But also the very slow time scales give problems. Keeping the overview of the maintenance work on a large technical system over a period of 20 years is nearly impossible for any person, not to mention that the persons in charge will probably change several times over such a span of years.

Here again, computers are the natural tools to provide the necessary overview of the system in the short term as well as the long term. When the inspection and maintenance tasks are deliberately spread out to a large number of persons and over a long period of time, the computer must keep the general overview. And all system functions should be easily and unambiguously understood by many different persons.

The man-machine communication takes place by visual means, except in very few cases, where e.g. sound alarms are used. And usually a computer screen is the man-machine interface. For the purpose of creating an overview of complex systems and large amounts of data, graphical displays seem to be much better suited than text messages or numbers.

Keywords in the human factors research areas are:

- Comprehension of complex systems
- Visual communication
- Diversification
- Man-machine relations
- Human reliability
- Psychology of operational reliability.

References: 5, 14, 16, 20, 39, 42.

5. INSPECTION AND DATA MONITORING

Visual inspection is still the most important method to obtain information of the condition of marine structures with respect to cracks and corrosion. Underwater inspections may be carried out by divers, but very often a remotely operated vehicle (ROV) carrying a TV-camera can do the job more efficiently.

Different non-destructive testing (NDT) methods are used to detect the less visible defects, the most important being magnetoflux and sound emission methods.

Usually, an inspection programme indicating inspection intervals for different parts of the structure is laid down by rules of the class or other authorities. Theories leading to more flexible and efficient inspection programmes, while maintaining a specified safety level, have been developed for offshore steel platforms by Madsen et al. (1989). Instead of fixed inspection schedules, the results of each inspection are used to determine the time until a new inspection will be necessary.

Here again the human factor problem plays an important part. Even the most experienced surveyor or diver will overlook serious cracks once in a while. So there is an unknown risk that structures with these damages continue in service for the next approved period, which is maybe quite long because the serious cracks were not found. This problem, however, is in principle not very different from the problem of structural design. Just as loads and structural strength of marine structures are considered as stochastic variables, we can also consider the inspection quality as a stochastic variable in the safety evaluation of the structure.

Important research areas related to inspection and data monitoring are the following:

- Visual inspection quality
- Fatigue crack detection, visual, magnetoflux, sound emission
- Underwater inspection, divers, remotely operated vehicles
- Pipeline inspection, outside (ROVs), inside (pigs)
- Automatic monitoring systems.

References: 2, 3, 11, 17, 18, 23, 24, 27, 29.

6. BASIC RESEARCH AT COMPONENT LEVEL

Reliability assessment and systematic maintenance planning both require a good knowledge of the reliability of each component of the system. Methods for reliability assessment at the component level have been developed during the last fifty years, especially within the electronics and aerospace industries.

Two main principles are used: statistical information from components in service, and laboratory testing of large numbers of components. In the laboratory, accelerated testing is usually applied, meaning that the testing time is compressed and the stress level in general terms is raised relatively to normal service. The latter method has the obvious advantage of making reliability assessment possible also of newly designed components. However, its use is restricted to relatively cheap mass production items or small standard details. The reliability of large and expensive components in marine systems can be assessed by the use of statistical data bases which have been established in recent years. Some of these databases have been published, but some have only restricted circulation.

Condition monitoring of important single components is applied to facilitate repair or replacement at convenient times. Rotating machinery can be monitored by means of vibration measurements or by continuous analysis of wear particles in the lubrication oil. Research into automation of these methods is going on (Folkeson, 1988).

The following keywords summarize the research areas related to reliability and maintenance at the component level:

- o Materials
- o Tribology
- o Accelerated testing
- o Failure data information
- o Statistics of component reliability
- o Condition monitoring.

References: 3, 6, 9, 15, 29, 30.

7. CALCULATION BASED METHODS APPLICABLE AT SYSTEMS LEVEL

A number of calculation based methods have been developed for the control, administration, and maintenance of large complex systems. These methods have mainly been developed within the aerospace, nuclear and defence industries, but several of them are applicable to ships and offshore structures. Until now very limited use has been made of the more advanced methods in marine maintenance management.

The following keywords give a list of relevant calculation based systems level methods:

- o Operations research
- o Simulation
- o Stochastic modelling
- o Reliability analysis
- o Failure identification
- o Failure tree analysis (FTA)
- o Failure mode analysis (FMA)
- o Failure mode effect analysis (FMCA)
- o Spare parts exchange strategies
- o Inspection and repair optimization
- o Sensitivity and trend analysis.

References: 1, 3, 6, 9, 10, 19, 22, 23, 25, 26, 28, 30, 31, 32, 33, 34, 35, 36, 38, 41, 42.

8. COMPUTERS APPLIED IN MAINTENANCE AND OPERATION

Several systems for computerized maintenance and operation are now commercially available. These systems in general perform administrative functions like job planning, handling of spare parts, budgetting, accounting of wages and material expenses, registration of equipment and its history, data searching and report writing. More sophisticated methods for optimizing the maintenance activities have not yet been utilized in commercially available computer programs.

The role of the computer in systematic maintenance of ships and offshore platforms must be viewed in the context of all the other tasks that are or will be carried out by the on board computer. The computer has already taken over a long list of important jobs on board. A central computer will therefore also collect most of the data necessary for the systematic maintenance, which must be seen as an integrated part of the overall ship or platform operation.

The following keywords give an impression of the multitude of tasks which the on board computers already are or will be carrying out in the future. Each of these computer systems will also have a link to the maintenance management system.

- o Administration
- o Job planning
- o Scheduling
- o Communication systems
- o Navigation systems
- o Integrated ship manoeuvring control
- o Machinery control systems
- o Propulsion control systems
- o Engine control from bridge
- o Process control
- o Safety shutdown systems
- o Gas and fire detection
- o Alarm systems
- o Condition monitoring

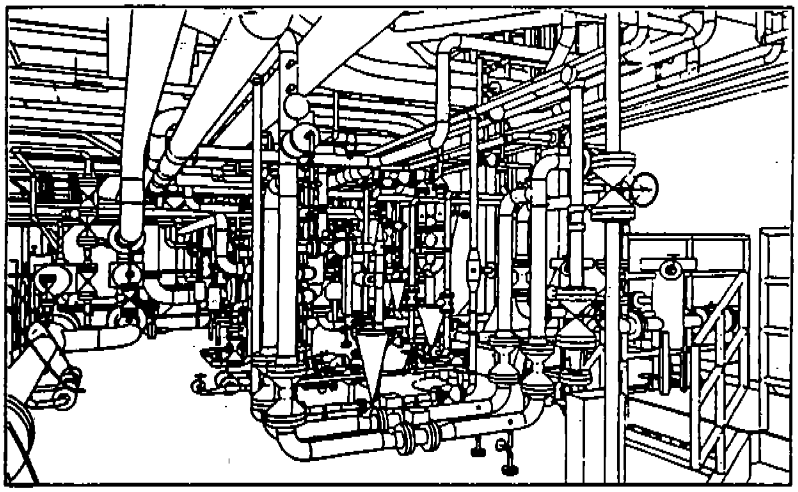

Fig. 3.
A traditional CAD visualization of a complex industrial plant: very realistic, but also very data demanding, and not well suited to create a good overview.

- o Diagnostic support systems
- o Subsea control systems
- o Wellhead safety systems
- o ROV tracking systems
- o Spare parts control
- o Plant history
- o Data base management
- o Report writing.

References: 1, 3, 4, 7, 9, 17, 18, 21, 25, 27, 28, 31, 35, 38.

9. SYSTEMS DESCRIPTION AND MODELLING

An effective computerized maintenance management system must be able to meet the demands mentioned in the preceding sections. A more detailed description of the principles for such a system is given in Fog and Aage (1990, a and b). The following main features will describe the general ideas, especially regarding the man-machine interface.

A maintenance and operation system should first of all provide the necessary overview for many different operators over long spans of time. It should contain all the necessary technical information, the maintenance strategies in a concrete form, and the accumulated experience gathered during construction and operation of the plant. This experience will be observations made by the operators, as well as automatically registered measurements.

The system should be based on a type of computer imaging which gives simple yet physically realistic pictures of the ship or platform. Traditional CAD models usually give very realistic pictures of the object, but they require very large amounts of input data, and the overview produced is not necessarily optimal (Fig. 3). A visual system dedicated to maintenance and operation should render sufficiently realistic but still simple 2D/3D images, it should be simple to use, and require a minimum amount of input data (Fig. 4).

Such a visual system should be interactive, so that the operator can zoom and pan within the model (Fig. 5). A hierarchical system with absolute and relative definition modes of the system figures makes system modelling flexible and facilitates continuous modification and opdating of the system.

Also computer messages to the operator should be made in a visual language that promotes fail-safe operation: pictures and diagrams instead of text and tables.

Keywords for systems description and modelling are:

- o Technical documentation
- o Drawings
- o CAD models
- o Functional 2D/3D visual models
- o Manuals
- o Files, card indexes, data bases
- o Accumulated experience
- o Plant register
- o Man-machine interaction.

References: 7, 8, 16, 20, 38, 39, 40, 41, 42.

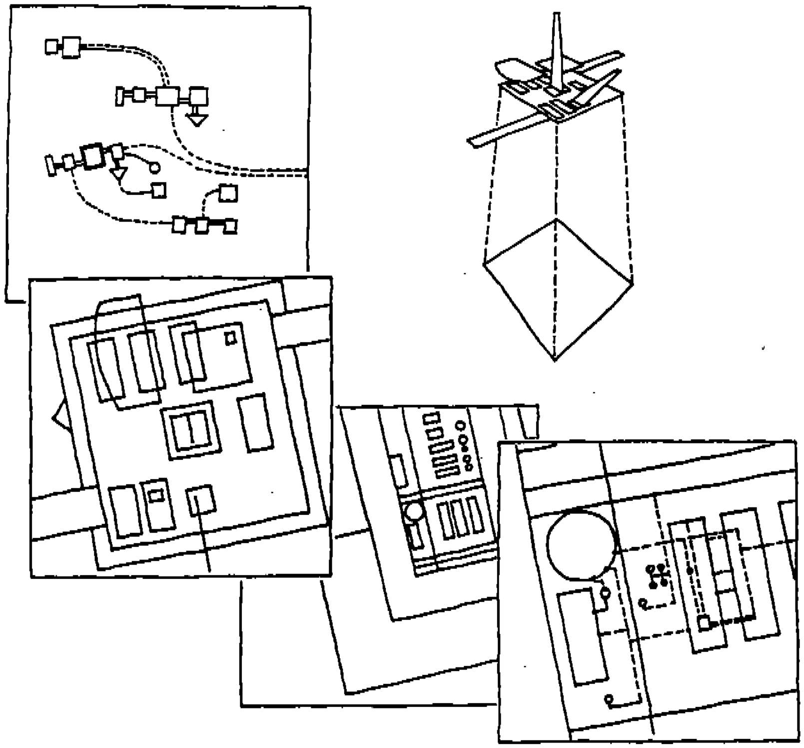

Fig. 4.
Visualization to be used for operation and maintenance of marine structures: adequately realistic, not very data demanding, well suited to create an overview.

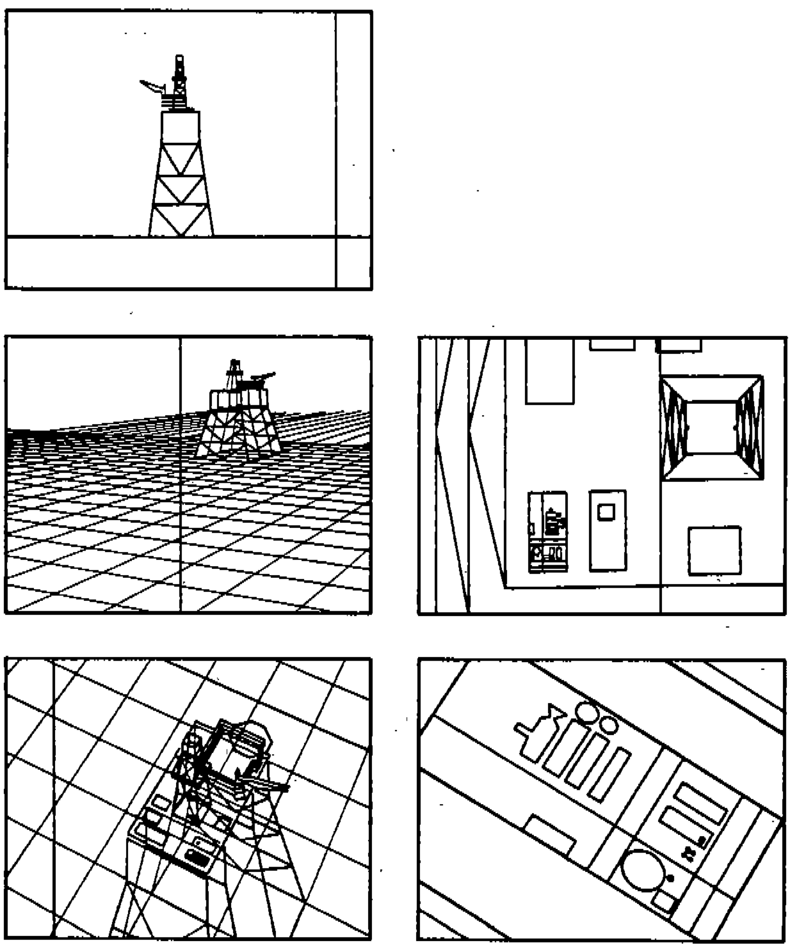

Fig. 5.
Modelling of an offshore platform in a visual system where the operator can zoom and pan within the model.

CONCLUSIONS

Some of the important research areas and principles related to marine maintenance have been discussed, and the needs for further research or implementation of existing results have been pointed out.

The capacity of modern computers to store, process and display large amounts of complex information makes an integrated maintenance management system possible. Such a system can utilize visual modelling by modern computer graphics techniques, whereby some of the human factors problems can be solved.

Prioritizing the different research needs is difficult. The needs will be different for each company, and indeed for each ship or offshore installation. It is important to ensure that the maintenance systems are balanced technically and economically, so that the resources are spent in accordance with the needs.

ACKNOWLEDGEMENT

The presented work has been carried out as part of a Nordic Research Program on Terotechnology, sponsored by the Nordic Industrial Fund and the Danish Technical Research Council.

REFERENCES

1. AMOS-D (1988): Maintenance Systems, Spectec Consult A.S., Oslo, Norway.

2. Bayliss, M., Short, D., and Bax, M. (1988): "Underwater Inspection", E. & F.N. Spon Ltd., London, England, 229 pp.

3. Blatchley, C., Connors, J., and Vecino, A. (1989): "An Integrated Approach to Shipboard System and Equipment Testing for Improved Maintenance Management", Marine Technology, Vol. 26, No. 2, April 1989, pp. 105-119.

4. Blanke, M. and Tvedt, E.I. (1989): "Tomorrow's Ship Automation Systems", Schiff & Hafen, Vol. 41, Heft 8, 1989, pp. 42-45.

5. Evans, E.C. (1990): "Human Factors Underlying the Effective Implementation of the IMO Conventions", Schiff & Hafen, Heft 4/1990, pp. 49-51.

6. Durant, W.S., Lux, C.R., and Galloway, W.D. (1988): "Data Bank for Probabilistic Risk-Assessment of Nuclear-Fuel Reprocessing Plants", IEEE Transactions on Reliability, Vol. 37, No. 2, June 1988, pp. 138-143.

7. Fog, N.G. and Aage, C. (1990 a): "A Concept for Computerized Modelling of Complex Systems as a Tool for Marine Maintenance", Proceedings of the Ninth International Conference on Offshore Mechanics and Arctic Engineering, OMAE'90, Houston, U.S.A., Vol. IB, pp. 525-532.

8. Fog, N.G. and Aage, C. (1990 b): "Marine Maintenance - The Development of a Computer Graphics Program for Modelling and Operation of Complex Systems", Proceedings of Scandinavian Society of Reliability Engineers Symposium, SRE 1990, Studsvik, Sweden, 12 pp.

9. Folkeson, A. (1988): "Terotechnology - Operational Reliability and Systematic Maintenance. Plan for a Nordic Research Program", Proceedings of Euromaintenance-88, Helsinki, Finland, Vol. II, pp. 341-346.

10. Frankel, E.G. (1988): "Systems Reliability and Risk Analysis", 2nd edition, Kluwer Academic Publishers, Dordrecht, Holland, 446 pp.

11. Gaushell, D.J. and Darlington, H.T. (1987): "Supervisory Control and Data Acquisition", Proceedings of the IEEE, Vol. 75, No. 12, December 1987, pp. 1645-1658.

12. Hawcroft, C. (1988): Presentation of paper "Maintenance, Money, Management, and Computers", Proceedings of Euromaintenance-88, Helsinki, Finland, Vol. I, pp. 46-57.

13. Hewgill, J.C. and Parkes, D. (1979): "Terotechnology - Philosophy and Concepts", Terotechnica, Vol. 1, No. 1, pp. 3-8.

14. Hopson, C. (1988): "Industry lessons from Piper Alpha", The Oilman/Offshore, November 1988, p. 3.

15. ILS (1988): "Design Data Detailed", The Motor Ship, Vol. 68, No. 811, February 1988, pp. 44-45.

16. Inagaki, T. and Ikebe Y. (1988): "A Mathematical Analysis of Human-Machine Interface Configurations for a Safety Monitoring System", IEEE Transactions on Reliability, Vol. 37, No. 1, April 1988, pp. 35-40.

17. IPMS (1988): "Integrated Pipeline Management System for Marine Pipelines and Risers", DHI/R&H Pipedata, Virum, Denmark.

18. ISMIS (1988): "Integrated Ship Management Information System", Data-Ship Ltd., London, England.

19. Köhler, P.E. and Valsgård, S. (1988): "Advanced Ship Structural Design and Maintenance", Proceedings of the 13th STAR Symposium and the 3rd IMSDC, Spring Meeting, SNAME, New Jersey, U.S.A., pp. 135-151.

20. Lee, K.W., Tillman, F.A., and Higgins, J.J. (1988): "A Literature Survey of the Human Reliability Component in a Man-Machine System", IEEE Transactions on Reliability, Vol. 37, No. 1, April 1988, pp. 24-34.

21. Lyytikäinen, A., Viitasaari, O., Päivinen, R., and Ristikankare, T. (1988): "Improved Management of Electric Switching Stations

by using a Computerized RAM-data System Module", Proceedings of EuReData Symposium, September 1988, Stockholm, Sweden, 11 pp.

22. Madsen, H.O., Krenk, Ṡ., and Lind, N.C. (1986): "Methods of Structural Safety", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, U.S.A., 403 pp.

23. Madsen, H.O., Sørensen, J.D., and Olesen, R. (1989): "Optimal Planning for Fatigue Damage of Offshore Structures", Proceedings of ICOSSAR'89, 5th International Conference on Structural Safety and Reliability, San Francisco, California, U.S.A., ASCE, New York, pp. 2099-2106.

24. McCord, R.S. (1983): "Influence of Ship Design and Fabrication on Underwater Maintenance and Repair", Marine Technology, Vol. 20, No. 2, April 1983, pp. 177-183.

25. McDermott (1990): "The McDermott International Offshore Automation Package", McDermott Offshore Automation, Houston, Texas, U.S.A.

26. McKelvey, T.C. (1988): "How to Improve the Effectiveness of Hazard & Operability Analysis", IEEE Transactions on Reliability, Vol. 37, No. 2, June 1988, pp. 167-170.

27. MOSES (1988): "Efficient Workshop Scheduling. A Computer Bar Chart for Better Workshop Control", National Engineering Laboratory, East Kilbride, Glasgow, U.K.

28. MPMS (1988): "Maintenance Engineering Systems", Microsystems Technology Ltd., Knutsford, Cheshire, England.

29. OREDA (1984): "Offshore Reliability Data Handbook", 1st edition, Veritec and PennWell Publishing Company, Høvik, Norway, 386 pp.

30. Pomeroy, R.V. (1987): "The Generation and use of Reliability Data for Marine Engineering Systems", Proceedings of ICMES'87, Fourth International Symposium on Marine Engineering Systems, September 1987, Malmö, Sweden, pp. 48-66.

31. PRINS (1988): "Document Information System", EB Industry and Offshore, Fyllingsdalen, Norway.

32. PROBAN (1987): "Examples Manual for PROBAN: PRObabilistic ANanalysis Program", A.S. Veritas Research Report No.: 86-2038, July 1987, Høvik, Norway, 71 pp.

33. Reinholds, E. (1987): "Fault Tree Analysis as a tool of Safety Analysis of Submarine Systems", Proceedings of ICMES'87, Fourth International Symposium on Marine Engineering Systems, Malmö, Sweden, pp. 88-104.

34. Rumble, E.T. and Chu, B.B. (1987): "An Approach for Integrating Plant Operations and Maintenance Information with System Reliability Analysis", Nuclear Technology, Vol. 79, Oct. 1987, pp. 7-19.

35. SCREENWARE (1988): "Controls for Industry", Starkstrom, Strathclyde, England.

36. Solberg, D.M. and Solem, R.R. (1987): "Safety and Reliability - A Methodological and Systematical Approach", Proceedings of ICMES'87, Fourth International Symposium on Marine Engineering Systems, Malmö, Sweden, pp. 67-75.

37. Sulzer (1987): "Economical Operation of Installations and Buildings", Sulzer Technical Review 3/1987, pp. 27-29.

38. Svensson, T., Larsen, L.C., Hinstrup, P.I., and Nielsen, J.A. (1988): "Development of an Integrated Pipeline Management System (IPMS)", Proceedings of Third Hydrocarbon Symposium, Luxembourg, 16 pp.

39. Sylla, C., Drury, C.G., and Babu, A.J.G. (1988): "A Human Factors Design Investigation of a Computerized Layout System of Text-Graphic Technical Materials", Human Factors, Vol. 30, No. 3, pp. 347-358.

40. Tamassia, R., Di Battista, G., and Batini, C. (1988): "Automatic Graph Drawing and Readability of Diagrams", IEEE Transactions on Systems, Man, and Cybernetics, Vol. 18, No. 1, January/February 1988, pp. 61-79.

41. Ulerich, N.H. and Powers, G.J. (1988): "On-Line Hazard Aversion and Fault Diagnosis in Chemical Processes: The Diagraph + Fault-Tree Method", IEEE Transactions on Reliability, Vol. 37, No. 2, June 1988, pp. 171-177.

42. Yoon, W.C. and Hammer, J.M. (1988): "Aiding the Operator During Novel Fault Diagnosis", IEEE Transactions on Systems, Man, and Cybernetics, Vol. 18, No. 1, January/February 1988, pp. 142-147.

Harold Ramsden

Quite a few years back I was manager of maintenance for Global Marine and we had some problems with some of the managers and some of the rig crews cutting boards and cutting openings in watertight bulkheads. We didn't know quite how to cure the problem. I wrote a memo to all the managers saying that if they did that we were going to lose our insurance coverage. Well, that got a letter from the president saying that all managers would confer with the maintenance department before they did anything to the ships. The point is that I read recently about the Oil Pollution Act which is pretty devastating if you look at it in the responsibility of the oil carriers and people that own the oil, people that own the ships and people that charter the vessels. I think if you haven't really read into that, you need to look at it carefully and pay attention to your maintenance to assure safe operation and product handling.