Reliability, Maintenance and Risk Assessment in Naval Architecture and Marine Engineering Education in the US

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SUMMARY *Advances in information technology provide new tools and resources to optimize total life cycle of ships in terms of reliability, safety and the control of operating costs. Regulatory agencies and classification societies are moving towards risk-based/reliability-centered rule-making in the shipping industry. However, reliability, maintenance and risk assessment were not considered to be a part of the traditional Naval Architecture and Marine Engineering curriculum in the US. In this paper, the current status of existing curricula, accreditation requirements and new developments are presented. Finally, emerging needs of the maritime industry are discussed.*

1. Introduction

In the maritime industry, engineering is mostly carried out by naval architects and marine and ocean engineers. A naval architect is usually responsible for the design of marine vehicles as total systems, specifically designing the internal layout, structure and hull form. A marine engineer focuses on the ship's mechanical systems, such us the propulsion, fuel oil and lubricating oil systems. An ocean engineer designs underwater vehicles, offshore platforms, acoustic systems and shoreline facilities [1]. The ship design spiral has traditionally included evaluation of reliability and maintainability. However, this evaluation is usually made qualitatively for merchant ships.

The US Navy recognized the value of reliability, availability and maintainability (RAM) theory a long time ago. The bureau of ships of the US Navy and its successor, Naval Sea Systems Command, have practised formal reliability and maintainability requirements for electronic systems and equipment acquisitions since 1960 [2, 3]. On the other hand, the commercial marine industry has been reluctant to adopt these techniques. Most marine propulsion systems are designed very conservatively, since space/weight restrictions are not as severe as in the aircraft industry. Replacement and inspection times used to be very conservative. Hence, marine propulsion systems are generally reliable. However, fierce competition in the international shipping industry is forcing ship owner/operators to use their scarce resources very carefully. Hence, there is a major effort to optimize reliability, safety and cost effectiveness systematically.

Other industries have enjoyed great benefits by implementing reliability-centered maintenance, concurrent engineering, risk-based approaches for design, regulation and operation, systems engineering and life cycle engineering. The time has come for the commercial maritime industry to enjoy the same benefits by applying these proven

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reliability and risk methodologies. Hence, Naval Architecture and Engineering Programs need to educate their students in these areas.

In this paper, we first discuss accreditation requirements of engineering programs in the US. Then we summarize reliability and risk education history. Subsequently, we discuss reliability and risk-related developments in the maritime industry. Finally, we summarize our recommendations.

2. Reliability and Risk Education in Engineering Programmes

2.1 Accreditation

Reliability, maintenance and risk assessment are interdisciplinary areas that are usually excluded from required traditional engineering curricula in the US. Most engineering schools in the US try to acquire and maintain accreditation by The Accreditation Board for Engineering and Technology (ABET). This accreditation is usually seen as evidence of high education quality. ABET is recognized by the US Department of Education as the sole agency responsible for accreditation of educational programs leading to degrees in engineering. In addition, ABET accreditation is a requirement for engineering licenses in most states.

General basic-level ABET accreditation criteria for curricular objective include the development of "an understanding of the engineer's responsibility to protect both occupational and public health and safety". Curricular content criteria for mathematics and basic sciences require inclusion of differential and integral calculus and differential equations, but only "encourages" additional work in "one or more of the subjects of probability and statistics, linear algebra, numerical analysis, and advanced calculus". Hence, it is possible to get an engineering degree from an ABET-accredited institution without knowing the basics of probability and statistics, the prerequisites for reliability and risk assessment. In the mean time, according to ABET criteria, "it is essential to include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact" in engineering design [4].

The importance of the following topics is not mentioned in ABET criteria: maintenance optimization, concurrent engineering, risk assessment and systems engineering. In fact, the list of engineering programs does not include reliability engineering, life cycle engineering, maintenance engineering, concurrent engineering and systems engineering. These programs can be considered for accreditation under 'non-traditional programs'.

In the US, there are 16 institutions that offer ABET-accredited programs in Naval Architecture, Marine Engineering and Ocean Engineering, as shown in Table I.

An examination of the required courses in these institutions reveals that coverage of maintenance, reliability, risk analysis and safety is minimal. Some of these institutions offer elective courses in these areas. For example, University of New Orleans (UNO) offers a senior-level undergraduate elective in Reliability Engineering cross listed with Naval Architecture, Marine Engineering, Electrical Engineering and Engineering Management programs. In addition, a new senior-level course in Management of Ship Life Cycle covers various aspects of reliability, safety and risk assessment, from human and organization error to reliability-centered maintenance. The University of Michigan has two graduate-level elective courses in System and Structural Reliability. California State University offers an undergraduate-level course in Safety and Reliability in Systems. The University of California at Berkeley introduces basic concepts in reliability and failure modes in its sophomore-level course, Theory of Ship Structures.

TABLE I. ABET-accredited curricula

Institution	Naval Architecture	Marine Engineering	Ocean Engineering
University of New Orleans[a]	X	X	—
University of Michigan[a]	X	X	—
Webb Institute of Naval Architecture[a]	X	X	—
University of California, Berkeley	X	—	—
SUNY Maritime, Ft Schuyler	X	X	—
US Naval Academy	X	X	X
Massachusetts Institute of Technology	—	—	X
Texas A&M University	—	X	X
US Coast Guard Academy[a]	X	X	—
California State University, Long Beach	—	—	X
Florida Atlantic University	—	—	X
Florida Institute of Technology	—	—	X
US Merchant Marine Academy	—	X	—
California Maritime Academy	—	X	—
Virginia Polytechnic Institute and State University	—	—	X
Maine Maritime Academy	—	X	—

[a]Combined degree in Naval Architecture and Marine Engineering.

2.2 History of Reliability and Risk Assessment Education in the US

In the US, there are three institutions that have academic programs in reliability and maintainability: University of Maryland, University of Arizona and New Jersey Institute of Technology. In this section, the programme at University of Maryland is summarized.

The graduate Reliability Engineering programme at the University of Maryland was initiated by faculty in the Nuclear Engineering programme in the mid-1980s as a logical outgrowth of their work on reliability and safety issues in nuclear power plants. In 1988–89 an interdisciplinary MS and PhD programme in Reliability Engineering was established and approved by the State Board of Higher Education. In 1992 courses were offered by satellite to several companies involved in the space programme and commercial electronics development. In addition to a large local enrollment from full-time students and local companies and government laboratories, courses have continued to be offered via different distance-learning options. In 1996 General Motors selected the University of Maryland to be its host university for the MS in Reliability Engineering and receives the courses via videotape. In the last year, two new course options have been created—Microelectronics Reliability and Software Reliability.

The programme is designed to meet industry needs for engineers who can design and develop new products and systems that meet high reliability, safety and quality requirements. An undergraduate degree in engineering or science is desirable, and some background in probability and statistics is helpful. Course work emphasizes a basic physics-of-failure approach to the design of electronic and mechanical systems, and the prediction of reliability and life based on the variability of materials properties and manufacturing tolerances.

Six full-time faculty members are dedicated to the programme. Also, support is provided by other faculty in Civil Engineering, Mechanical Engineering, Aerospace Engineering, Electrical Engineering and the College of Business and Management. The MS programme requires 31 credit hours and includes the following core courses:

- Mathematical Methods in Reliability Engineering
- Reliability Engineering
- Reliability Analysis
- Advanced Reliability Engineering or
- Advanced Reliability Modeling
- Failure Mechanisms and Effects Laboratory
- Seminar

Other course offerings include: Fundamentals of Failure Mechanisms; Accelerated Testing: Risk Assessment for Engineers; Structural Reliability; Microelectronic Reliability; Reliability of Electronic Packaging; and System Safety Engineering.

Reliability-related research activities are underway in many departments of the University. They include:

(1) Functional modeling of complex systems—development of goal tree–success tree models as a basis for the analysis of reliability, safety and maintainability of systems.
(2) Failure mechanisms in microelectronic devices.
(3) Failure mechanisms in the first three levels of electronic packaging and advanced package design for high reliability.
(4) Reliability data collection and analysis—software development and incorporation of appropriate statistical models employing Bayesian methods of analysis.
(5) Software reliability.
(6) Structural reliability—with emphasis on probabilistic design codes.
(7) Communication system reliability modeling and optimization.
(8) Smart sensors for reliability and safety monitoring.

The University of Maryland is playing an active role in the development of risk-based regulation for the USCG by using its experience in the nuclear industry and the US Navy.

3. Needs of the Maritime Industry

In the past, ship designs focused on minimizing first acquisitions costs. However, in recent years awareness of total life cycle performance of ships and cost of ownership has been increasing. Hence, there is a major trend to optimize reliability, safety and the control of operating costs throughout the entire life cycle of ships more systematically. The following developments are major indicators of this trend.

The International Maritime Organization (IMO), which sets safety regulations in the shipping industry, has developed the International Safety Management (ISM) code. ISM certification has been required from all tanker operators since 1 July 1998 and will be required from other types of vessels by 1 July 2002. Article 10.3 of the ISM code requires that "the company should establish procedures in SMS (Safety Management System) to identify equipment and technical systems the sudden operational failure of which may result in hazardous situations. The SMS should provide for specific measures aimed at promoting the reliability of such equipment or systems. These measures should include the regular testing of stand-by arrangements and equipment or technical systems that are not in continuous use".

During the development of the ISM code ISO 9000 requirements had a major influence. Many shipping companies now acquire joint ISM and ISO 9000 certificates, since with the implementation of a few additional procedures ISM certification can be upgraded to satisfy ISO 9000 requirements. Shipping companies report significant improvements from implementing ISO 9000 and ISM requirements [5, 6].

Recently, IMO has also approved draft interim guidelines for the application of formal safety assessment (FSA) to the rule-making process at IMO, so that trial applications of FSA can be carried out to assess its worth.

FSA is described as a rational and systematic process for assessing the risks associated with any sphere of maritime activity and for evaluating the costs and benefits of different options for reducing those risks. Hence, it enables an objective assessment of the need and content of safety regulations.

FSA consists of five steps:

(1) identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes);
(2) assessment of risks (evaluation of risk factors);
(3) risk control options (deriving regulatory measures to control and reduce the identified risks);
(4) cost benefit assessment (determining cost effectiveness of each risk control option); and
(5) recommendations for decision-making (information about the hazards, their associated risks and the cost-effectiveness of alternative risk control options is provided).

In parallel to this development, major classification societies announced that they were in the process of moving towards risk-based/reliability-centered rules and regulations. The United Stated Coast Guard (USCG) issued its guidelines for risk-based decision-making. USCG also requested quantitative RAM assessments for its new boat designs [7, 8].

The US Navy has required quantitative RAM assessments during the conceptual design phase for more than 30 years. For its LPD-17 Amphibious Assault Vessels, the US Navy envisages total life cycle support from a shipyard to optimize continually reliability and cost of ownership by revising maintenance practices. The Avondale-UNO Maritime Technology Center of Excellence, will be used jointly by Avondale Industries and the UNO faculty to develop, install and begin utilizing advanced, world-class, computer-based design and manufacturing technologies that meet the design and life cycle objectives of the LPD-17.

The US marine transportation industry can improve its process for designing its systems, subsystems and components on which its operations depend by utilizing risk-based methods and tools. In an environment of increasingly complex engineering systems, concern about the operational safety of these systems continues to play a major role in both their design and operation. A systematic, quantitative approach for assessing the failure probabilities and consequences of engineering systems is needed. A systematic approach allows an engineer to evaluate expediently and easily complex engineering systems for safety and risk under different operational conditions with relative ease. The ability to evaluate quantitatively these systems helps cut the cost of unnecessary and often expensive re-engineering, repair or replacement of the system. The results of risk analysis can also be utilized in decision analysis methods that are based on cost–benefit tradeoffs. The marine industry needs in these areas were discussed recently by Ayyub [9].

These developments indicate a major trend to use reliability and risk assessment in ship design, operation and regulation much more frequently than in the past. Eventually, educational institutions will have to respond to the needs of the maritime industry in these areas.

4. Conclusions and Recommendations

In this paper, we first examined current ABET accreditation requirements of Naval Architecture and Marine Engineering (NAME) programs in the US. Subsequently, we discussed the reliability engineering programme at the University of Maryland. Then new trends in the maritime industry were summarized.

Our study indicated that reliability, maintainability and risk are not covered adequately in the required courses of NAME programs in the US. On the other hand new trends in the merchant marine industry demand basic knowledge in these areas for successful implementation. ABET requirements can be revised if professional organizations such as the Society of Naval Architects and Marine Engineers take action and apply to ABET. However, considering the fact that changing ABET guidelines is a very slow process, the authors encourage NAME programs to make quantitative reliability and risk assessment an integral part of their required curriculum.

REFERENCES

[1] THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS (1993) Careers in the Maritime Industry.

[2] PERAKIS, A.N. & INOZU, B. (1990) Reliability analysis of Great Lakes Marine Diesels: state-of-the-art and current modeling, *Marine Technology*, pp. 237–249.

[3] SNAME (1971) *Reliability and Maintainability Engineering in the Maritime Industry*, SNAME Panel M-22, Technical and Research Bulletin No. 3-22.

[4] ENGINEERING ACCREDITATION COMMISSION ACCREDITATION BOARD FOR ENGINEERING AND TECHNOLOGY (1995) Criteria for Accrediting Programs in Engineering in the United States Effective for Evaluations During the 1996–97 Accreditation Cycle.

[5] COWLEY, J. (1995) The concept of the ISM code, *Proceedings of IMAS 95*, The Institute of Marine Engineers, pp. 3–37.

[6] AKSOY, Y. & SCHAEDEL, P.G. (1997) ETC measures the impact of ISO 9002 on corporate quality, *Interfaces*, 27, pp. 84–92.

[7] ABS (1997) ABS Press Release.

[8] USCG (1997) Risk Based Decision Making Guidelines.

[9] AYYUB, B.M. (1997) *Guidelines for Probabilistic Risk Analysis of Marine Systems*, Technical Report, USCG Project, Center for Technology and Systems Management, University of Maryland at College Park.