Ocean Engineering 136 (2017) 129–140

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Review

Warship reliability evaluation based on dynamic bayesian networks and numerical simulation

Xiao Feng Liang[a], Hong Dong Wang[a,*], Hong Yi[a], Dan Li[b]

[a] State Key Laboratory of Ocean Engineering, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration(CISSE), Shanghai 200240, PR China

[b] School of Environmental Science and Engineering, Shanghai Jiao tong University, Shanghai 200240, PR China

ARTICLE INFO

Keywords:
Warship
Dynamic system
Overall reliability
Reliability evaluation
Numerical simulation
Dynamic Bayesian network

ABSTRACT

The systematic implementation of reliability engineering is a necessary measure to improve warship reliability. In warship reliability engineering, reliability evaluation is a key step because it reveals whether warships feature an acceptable level of reliability. Current reliability evaluation methods, such as the analytic method, multilevel synthesis method and numerical simulation method, are all based on static logic. However, warships are typical dynamic systems, and their reliability cannot be evaluated using the aforementioned methods. On the basis of the characteristics of warships, including their small sample system and dynamic and multistage missions, this study proposed a new reliability evaluation method based on dynamic Bayesian networks and numerical simulation. The proposed method is the inheritance and development of current methods for reliability evaluation based on numerical simulation. Hence, it overcomes the limitations of the analytic method and multilevel synthesis method, as well as provides an effective means for the reliability evaluation of warships. The proposed method is suitable for the overall reliability evaluation not only of warships but also of other complex dynamic systems.

1. Introduction

In the evaluation of warship reliability, trial information is utilised in the development, production and actual application stages. Mathematical statistics, numerical simulation or other methods are then employed in the interval estimation of warship reliability indexes under given conditions. In warship reliability engineering, reliability allocation, prediction and analysis are design processes aimed at improving the reliability of warships using effective measures under the current technological and economic conditions (Liang et al., 2015). Reliability evaluation aims to test whether the reliability of warships is at an acceptable level.

Along with the development of reliability theory, the reliability evaluation methodology is constantly being improved. In general, reliability evaluation is divided into the unit level, the system level and the overall level.

Reliability evaluation technology at the unit level is studied extensively, and the relevant methods are relatively mature. Three methods are generally used in reliability evaluation at the unit level: confidence interval method, Bayes method and Fiducial method (Friday and Patil, 1977; Mann et al., 1974; Martz and Waller, 1982; Zhou and Weng, 1990). The confidence interval method is also known as the classical method, which is widely used in interval estimation. In theory, the confidence interval method can be fully incorporated into probability theory under the Kolmogorov axiom. The Bayes method is easy to employ using current test information and prior information. However, choosing the appropriate prior distribution with the Bayes method is difficult. The Fiducial method does not relate to the prior distribution of parameters and instead determines parameter distribution according to observation samples. However, such distribution is only reliable at a certain range depending on the obtained sample information.

At the system level, reliability evaluation can be performed using three methods.

(1) Analytic method

The premise of using the analytical method is that the relationship between the system and its unit is clear and that the reliability distribution function of the system can be found. System reliability is the function of unit reliability. For binomial and exponential units, the analytic expression of unit probability density can be given (Springer and Thompson, 1966; Springer and Thompson, 1967; Springer and Thompson, 1969). For

* Corresponding author.

http://dx.doi.org/10.1016/j.oceaneng.2017.03.023
Received 29 February 2016; Received in revised form 15 December 2016; Accepted 13 March 2017
0029-8018/

normal units, the posterior density of reliability cannot be expressed explicitly but should instead be expressed by a double integral. For Weibull distribution and log-normal distribution, the posterior density of reliability cannot be expressed explicitly (Papadopoulos and Tsokos, 1975; Zhou and Weng, 1990). In this case, the distribution function of system reliability is difficult to obtain, and the reliability distribution function is impossible to acquire, especially for complex systems such as warships.

(2) Multilevel synthesis method

According to the logical structure of system reliability, the multilevel synthesis method utilises the theories of information entropy, moment fitting and others to convert test information from the unit level to the system level and subsequently evaluate system reliability (Zhou and Weng, 1990). This method can be easily understood, but its application has certain limitations. Firstly, the multilevel method is only suitable for the reliability evaluation of static systems and not of dynamic systems. For systems with time series, such as reservation systems and sequence-related systems, the logical structure of reliability can be described with a dynamic fault tree(DFT) model. However, converting test information from the unit level to the system level in reliability evaluation remains difficult. For maintainable systems, the description of the reliability model is difficult to derive, and the conversion of test information from the unit level to the system level cannot be achieved. Secondly, multilevel synthesis inevitably leads to test information loss, which in turn affects the objectivity of evaluation conclusions. A large amount of information tends to be lost when system reliability features numerous logical levels. Such condition yields reliability evaluation results with low credibility.

(3) Numerical simulation method

In the 1960s, Burnett and Wales began to use a numerical simulation method to evaluate the lower limit of system reliability (Burnett and Wales, 1961). With the rapid development of computer technology, numerical simulation methods have gradually become a means to solve the reliability problem of complex systems (Efron, 1979; Ghahramani and Rasmussen, 2002; Levy and Moore, 1967; Moore, 1965). In recent years, reliability evaluation based on numerical simulation has become a research hotspot in the field of reliability. Scholars have carried out extensive research in this field and proposed several methods for reliability evaluation, such as the Bayes Monte Carlo method (Locks, 1975; Locks and Gregson, 1978), Bayes bootstrap method (Efron, 1979; Rubin, 1981), and double Bayes Monte Carlo method (MacDonald, 1982). For a number of static systems with a simple logical structure of reliability, such as series systems, parallel systems and R/N systems, the aforementioned methods feature good applicability. However, they are not suitable for the reliability evaluation of time series systems and maintainable systems.

Thus far, no study has explored overall reliability evaluation in the context of warships.

In warship reliability engineering, reliability evaluation is a key step. Given the limitation of existing methods, evaluating warship reliability objectively remains difficult.

Fortunately, despite their defects, traditional reliability evaluation methods based on numerical simulation feature a complete theoretical basis with wide applications. Such theoretical basis provides a direction for the reliability assessment of complex systems (Wang and Pham, 1997). In the present work, we adopted existing theories and proposed an applicable method for warship reliability evaluation that fully considers the dynamic and multistage missions that are characteristic of warships.

2. Key problems and solutions in warship reliability evaluation

2.1. Small sample problem

Reliability data are the basis of reliability engineering. Reliability data usually originate from reliability tests and are thus the most effective data for reliability evaluation. However, conducting a large number of reliability tests on highly complex warships is not reasonable. Hence, data from such tests are limited and are far from enough to meet the requirements of warship reliability evaluation. Therefore, a key problem in warship reliability evaluation is how to obtain effective and adequate data.

A warship is a typical small sample system. 'Small sample' should be understood from two aspects:

1) From the perspective of the system itself, warships feature complex structures, broad systems small batches. Hence, repeating reliability tests on warships is highly unlikely. Under this condition, corresponding test data become extremely limited.
2) From the perspective of system composition, test information on warships is limited at the system level but abundant at the unit level. If the related multisource test information is fully utilised, the small sample problem of warships can be readily solved. Multisource test information on warships includes reliability test information during development, sea trial information, environmental testing information, joint debugging test information, mooring trial information and others.

2.2. Dynamic problem

The dynamic problem of warships includes two aspects: time sequence and maintainability. Time sequence mainly refers to fault tolerance, sequence enforcement, redundancy and other characteristics featuring dynamic stochastic failures. Maintainability refers to the reparability of failed units without stopping system operations.

For maintainable systems, their characteristics are typically described with a Markov model (Kitchin, 1988; Sharma and Bazovsky, 1993). However, Markov models have an inherent weakness in terms of their state space explosion. For the time sequence problem, the dynamic fault tree model is used to describe the logical structure of reliability (Dugan et al., 1992). However, the solution of the dynamic fault tree model is based on the Markov model. Therefore, the occurrence of the state space explosion problem is inevitable.

A Bayesian network is a directed acyclic graph that expresses the potential correlation between variables using a simple graphical model (Zhang and Guo, 2006). A dynamic Bayesian network is an expansion of the Bayesian network in terms of time and can effectively solve the problems of time sequence and maintainability. In the model description of dynamic system reliability, dynamic Bayesian networks show great potential (Weber and Jouffe, 2006; Langseth and Portinale, 2007). Moreover, mature reasoning algorithms and tools are available to support dynamic Bayesian networks (Jensen et al., 2002; Madsen et al., 2005; Murphy, 2001).

2.3. Multistage mission problem

Warships are also characterised by multiple stages of tasks (Liang, 2011). Therefore, the model of overall warship reliability must consider the dynamic and multistage mission characteristics of warships. The basic ideas for model construction are as follows:

1) To solve the dynamic problem, a dynamic Bayesian network is employed in the construction of a reliability model.