Ocean Engineering 110 (2015) 195–204

Contents lists available at ScienceDirect

Ocean Engineering

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

Integrated allocation of warship reliability and maintainability based on top-level parameters

Xiao Feng Liang [a], Lu Yun Chen [a,*], Hong Yi [a], Dan Li [b]

[a] State Key Laboratory of Ocean Engineering, Shanghai Jiaotong University, Shanghai 200240, PR China
[b] Occupational Health & Safety Assistances Inc., Shanghai 200030, PR China

ARTICLE INFO

Article history:
Received 14 May 2015
Accepted 30 September 2015
Available online 30 October 2015

Keywords:
Integrated allocation
Reliability
Maintainability
Warship
Top-level parameter

ABSTRACT

In warship design and development, reliability should be allocated from top-level requirements to subsystem and equipment levels using an effective allocation method. Mission reliability and inherent availability are top-level reliability parameters of a warship; these parameters do not only involve factors of reliability, but also those of maintainability. Therefore, extensively used reliability allocation methods cannot address the reliability allocation of warships. A warship is a typical repairable system. Based on warship characteristics, this study proposed an integrated reliability and maintainability allocation method for warships. In the comprehensive allocation process, reliability and maintainability factors that affect the top-level reliability parameters of a warship were measured quantitatively. The synergistic principle of the reliability and maintainability indexes was discussed to solve the synergistic problem between the reliability and maintainability parameters of a unit. The top-level reliability indexes of a warship were reasonably allocated to all levels using optimisation methods. The proposed method is not only suitable for warship reliability allocation but also for other complex repairable systems.

Contents

* Corresponding author.

http://dx.doi.org/10.1016/j.oceaneng.2015.09.056
0029-8018/

1. Introduction

Reliability demonstration, reliability design and analysis, reliability test and evaluation, operational reliability assessment and improvement are the basic aspects of reliability engineering (GJB450A, 2004). Reliability allocation is generally the first step in warship reliability design and analysis. Other processes, such as reliability prediction and the identification of critical components, are based on reliability allocation (Yi et al., 1994). Mission reliability and inherent availability are top-level parameters that reflect the overall reliability of a warship. Reliability allocation aims to allocate mission reliability and inherent availability reasonably to each level of a warship as well as to use the allocation results as bases for reliability design and equipment selection at each level.

In recent decades, scholars and engineers have exerted tremendous effort to research theory and practice for reliability, such as prognostics and health management (PHM), reliability prediction and modelling, reliability mathematics, reliability estimation techniques, etc. (Kapur and Pecht, 2014; Lisnianski and Frenkel, 2012; Patrick and Kleyner, 2011; Pham, 2008). A series of achievements has been attained in reliability and maintainability allocation research. These achievements have considerably enriched theory of reliability. However, reliability and maintainability allocations are performed separately whether in theory or in practice (Liang, 2011). Consequently, currently available reliability allocation techniques only consider the effect of a narrow range of reliability factors, such as importance and complexity factors, but disregard the influence of maintainability factors on system reliability.

The equal apportionment allocation method, the proportional allocation method and the Advisory Group of Reliability of Electronic Equipment (AGREE) are some basic reliability allocation methods for a simple system (Debnath, 1976; GJB450A, 2004; Yi et al., 1994). Based on these basic reliability allocation methods, new reliability allocation methods were deduced. These include the integrated factor method (De Felice et al., 2010; Falcone et al., 2002), the maximum entropy ordered weighted averaging method (Chang et al., 2009), the optimisation allocation method (Baun Iii, 2009; Khalili-Damghani et al., 2013; Tavakkoli-Moghaddam et al., 2008) and the comprehensive reliability allocation method (Wang et al., 2001; Yang et al., 2015). Existing allocation approaches can satisfy the requirements of reliability allocation for simple or specific systems. However, they have many limitations when applied to warship reliability allocation. The most important reason for such limitations is that the aforementioned allocation methods only consider a narrow range of reliability factors, but disregard the influence of maintainability factors on system reliability. Therefore, such allocation methods are not applicable to the reliability of a warship.

Some methods are used in maintainability allocation, such as the equal apportionment allocation method, the failure rate allocation method (GJB/57-94, 1994), the statistical approach (Perry, 1971), the weighted maintainability allocation method (Gan and Wu, 1995), the optimal maintainability allocation method (Calabria et al., 1995; Farouk et al., 2014; Govil, 1992) and the fuzzy maintainability allocation method (Hao et al., 2011). Existing methods can satisfy the demands of maintainability allocation for specific systems. However, these methods exhibit deficiencies in maintainability allocation for complex systems, such as warships, because of the following reasons: (1) system complexity is one aspect that affects maintainability in warships. Meanwhile, other aspects, such as fault detection and isolation, accessibility and removability, also significantly influence maintainability, (2) the premise for applying the aforementioned maintainability allocation methods is that the maintainability index (MTTR) of a system and the failure rate λ_i of a unit should be known. However, reliability allocation is still at its beginning stage in warship design. At this stage, equipment selection has not yet been determined, and the failure rate λ_i of a unit remains unknown.

Mission reliability and inherent availability are two typical parameters used to evaluate the overall reliability of a warship (Liang, 2011; Yi et al., 2002,1994). These parameters do not only include reliability factors, but also suggest maintainability factors. A warship is a typical repairable system. In such system, maintenance has two definitions. The first definition refers to preventive or corrective maintenance, whereas the second refers to site repair, that is, the faulty unit can be repaired within the permitted downtime range. Traditional reliability allocation methods, which disregard the influence factors of maintainability, are unsuitable for large complex systems such as warships.

Based on warship characteristics, we should aim to solve the following problems in the process of reliability allocation.

1. Isolating maintainability indexes from overall reliability indexes in warship comprehensive reliability allocation. This process denotes comprehensively considering the effects of reliability and maintainability factors in the allocation process.
2. The coordination problem between unit reliability indexes (such as MTBF) and maintainability indexes (such as MTTR) in optimising allocation. The key principle to coordinate reliability and maintainability is to gain the minimum value of MTBF and the maximum value of MTTR, which can satisfy the requirements of a given mission reliability R_m and inherent availability A_I.

Based on the preceding ideas, this study proposed an integrated reliability and maintainability allocation method to implement reliability allocation in warships. In this method, the reliability and maintainability factors that affect the top-level reliability parameters of warships were considered comprehensively. Combined with the reliability logical structure of a system, optimal allocation was conducted to make the overall reliability index reasonably allocated to each warship level.

2. Methodology for integrated reliability and maintainability allocation for a warship

Given the complex system composition and mission of warships, achieving allocation results with absolute precision is impossible in reliability allocation in warships. On the one hand, many factors influence the reliability and maintainability of a warship. On the other hand, an “absolutely precise” standard cannot be established. Hence, three main aspects should be considered in the integrated allocation of warship reliability and maintainability.

1. Highlighting the relative degree of reliability of the units and the difficulty degree of maintainability. By quantifying these factors, a relative value, i.e. reliability and maintainability factors, can be used to describe the relationship between the reliability and maintainability indexes of the units.
2. Fully considering the combination of reliability factors, maintainability factors and the reliability logical structure of a system. Applying optimal allocation denotes achieving the overall reliability index that can be reasonably allocated to each warship level.
3. Employing the allocated results to predict the mission reliability and inherent availability of a warship to verify the correctness of the results.