A Model-Based Requirements Analysis Approach for Ship-Equipment Suitability Using Department of Defense Architecture Framework

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ABSTRACT

Traditional ship-equipment suitability design focuses more on design solutions than design requirements, especially actual requirements, which primarily restricts the quality of ship design. Model-based systems engineering (MBSE) can be a good solution. This paper aims to present a model-based requirements analysis approach for ship-equipment suitability using the Department of Defense Architecture Framework (DoDAF). First, the conceptual connotation of actual requirements is analyzed, and the formal descriptions adapted to DoDAF meta-models (DM2) are established. Then, based on the mapping relationship with DM2 elements, the applicable DoDAF models are selected, and the adapted DoDAF modeling approach is developed based on DM2 constraints. Finally, an activity-centered requirements decomposition approach is proposed to obtain well-defined ship-equipment suitability requirements. The case study of carrier-based aircraft transport operation reveals that the proposed methodology potentially improves the completeness and rationality of the ship-equipment suitability requirements and can be applied to more process-oriented requirements analysis tasks.

KEY WORDS: Requirements analysis; model-based systems engineering (MBSE); ship-equipment suitability; Department of Defense Architecture Framework (DoDAF); DoDAF meta-models (DM2); requirements decomposition.

INTRODUCTION

Large ship development is a complex, iterative, and multifaceted systems engineering process, where ship-equipment suitability is a core design task critical to shipborne equipment's operational safety and efficiency. Unfortunately, the inherent complexity of large ships makes it challenging for ship designers to generate excellent ship-equipment suitability design solutions. The main reason is that the traditional ship-equipment suitability design focuses more on the design solutions than design requirements, resulting in incomplete requirements elicitation, non-standard requirements description, unreasonable requirements decomposition, insufficient requirements verification, etc. As a result, the technical requirements of the ships to be developed are not systematic, and the evaluation decision of alternative ship designs is unreasonable, which primarily restricts the effectiveness and advancement of ship design. From the design point of view, the key reason for the above problems is that with the increasing complexity of large ships, the traditional systems engineering approaches, which only rely on knowledge, experience, and documents, can no longer effectively support the requirements analysis of complex ships.

With the development of computer and information technology, the methods of using models instead of documents as information carriers and virtual verifications instead of physical tests have been widely used, which provides significant support for the innovation and development of the top-down design paradigm of complex systems (Jia and Wang, 2016). Model-Based Systems Engineering (MBSE) has changed the paradigm from document-centric to model-centric and supported system R&D activities, including requirements, design, analysis, verification, and validation through the continuous evolution of formal models. Through the establishment of an integrated model framework, the information and data in system R&D activities are organized, managed, and presented to different stakeholders in different views, which ensures the normative description, consistent understanding, complete verification, and accurate transmission of requirements, and the rapid response of requirement changes. It also provides an intuitive design interaction platform for related personnel and promotes efficient iteration in the design process.

Currently, MBSE methods have been applied to many engineering projects. Anderson, Cole, Yntema et al. (2014) studied the irregularity of the arrangement of the ionospheric plasma field in the CubeSat project and verified the feasibility of MBSE methods in actual space missions. Bindschadler, Smith, Valerio et al. (2016) jointly developed the MBSE basic framework and applied it to design the spacecraft mission operating system. As a result, the cost and risk of the project were reduced, and the tradeoff analysis of airborne and ground systems was effectively promoted by model reuse in the design phase. Bindschadler, Delp, and McCullar (2012) also applied MBSE methods to a series of advanced projects, revealing that MBSE methods can solve various project challenges. Carrion, Delp, Illsley et al. (2010) discussed how to design complex system architecture, define practical