International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 23 (2018) pp. 16199-16203

Software Architecture of a Reliability Prediction System

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Abstract

Proposed in this paper is the software system architecture of a reliability prediction system to support the reliability prediction procedure of a given target system. The reliability prediction of a target system is important for various activities happening in the product lifecycle management, such as feasibility evaluation, comparing competing designs, identifying potential reliability problems, planning maintenance and logistic support strategies. To support the reliability prediction procedure in an effective way, we propose a software system architecture consisting of four major functional modules, four utility modules and four databases. The four major functional modules includes; 1) Bill of materials management module, 2) Reliability block diagram management module, 3) Component failure rate computation module, and 4) Sub-system failure rate computation module. The proposed architecture has been implemented and tested with various examples.

Keywords: Software system architecture, Reliability prediction, Failure rate, Reliability function

1. INTRODUCTION

Reliability engineering is an essential component of a product lifecycle management, and its goal is to predict the reliability of a product and pinpoint potential areas for reliability improvement. Although, reliability is a broad term that focuses on the ability of a product to perform its function, it can be defined as the 'probability' that the product (or system) performs a specified function under specified operational environmental conditions throughout a specified time (Kao 1956; Denson 1998; Bowles 1992; Cho et al. 2017).

Historically, the necessity of the reliability engineering has emerged with the production of electronic tubes in 1950s, because the early electronic tubes were very unreliable, and this observation led to the reliability prediction of a system. The first standard procedure for the reliability prediction was MIL-HDBK-217F which was published by the US Navy in 1962. The purpose of MIL-HDBK-217F is to establish and maintain consistent and uniform methods for estimating the inherent reliability of military electronic equipment and systems. While MIL-HDBK-217F were updated several times, other agencies were developing various reliability prediction models including Bellcore RPP, NTT Procedure, British Telecom HRD4, CNET Procedure, and Siemens Procedure (MIL-HDBK-217F Notice 1 1993; MIL-HDBK-217F Notice 2 1995; MIL-HDBK-338B 2007; Telcordia SR-332 Issue 2 2006).

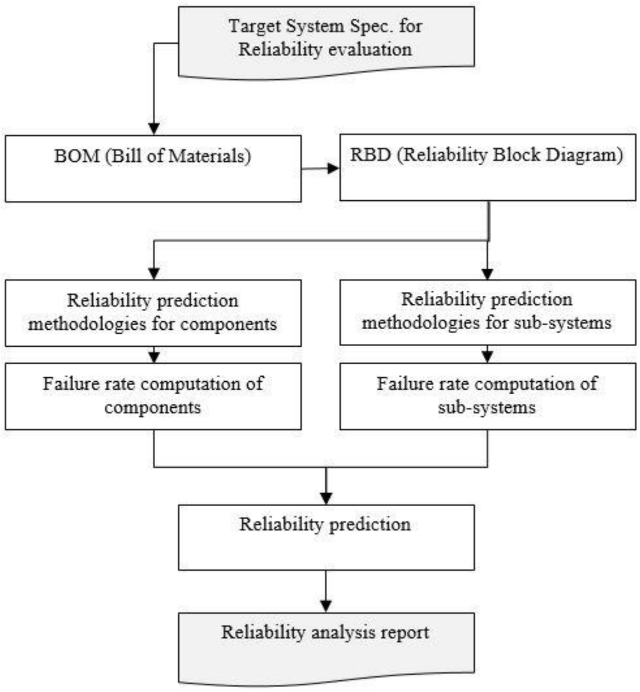

Figure 1. Reliability prediction procedure

Reliability prediction procedure starts with the target system specification, as shown in Figure 1. From the system specification, it is necessary to extract the BOM (Bill of Materials) and the RBD (Reliability Block Diagram) showing how component reliability contributes to the success or failure of the target system. Once the RBD is obtained, we need to computes the failure rates of all components or sub-systems. At this time, we may use various reliability prediction models including MIL-HDBK-217F, Bellcore RPP, and Siemens Procedure. The objective of this paper is to propose a 'software system architecture' (the architecture of a reliability prediction

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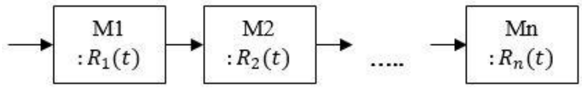
system) to support the reliability prediction procedure shown in Figure 1.

Previous research results on the reliability engineering can be categorized into two groups. One group of researchers are system engineers who are devoted to the tasks of specifying, allocating, predicting, and demonstrating reliability (Sun et al. 2018; Jones and Hayes 1999; Pecht et al. 2002; Lee et al. 2006; Andrews et al. 2013; Habchi and Barthod 2016). The other group of researchers are physics-of-failure engineers who are devoted to identifying & modeling the physical causes of failure (Li et al. 2018; Mortin et al. 1995; Stathis 2001; Hall and Strutt 2003). Although, there have been numerous research results on the reliability prediction, there are few research results on the effective architecture of a reliability prediction system.

In this paper, we propose the architecture of a reliability prediction system which can support the reliability prediction procedure in an effective way. The overall structure of the paper is as follows. In section 2, the architecture of a reliability prediction system is proposed by considering various user requirements. Section 3 shows a prototype reliability prediction application software system based on the proposed architecture. Finally, concluding remarks are addressed in Section 4.

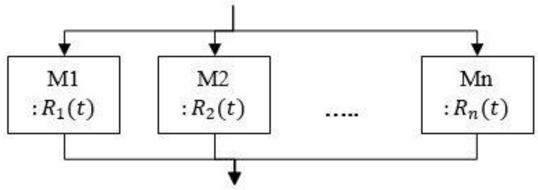
2. ARCHITECTURE OF A RELIABILITY PREDICTION SYSTEM

To support the reliability prediction procedure, shown in Figure 1, the reliability prediction application needs to four major functional modules; M1) BOM management module, M2) RBD management module, M3) Component failure rate computation module, and M4) Sub-system failure rate computation module. The BOM management module needs to provide various interfaces enabling users to input & edit a BOM model which is extracted from the target system specification. For reliability evaluation, it is necessary to converter the BOM model into a RBD model, which is the main functionality of the RBD management module.



$$R(t) = R_1(t) \cdot R_2(t) \cdots R_n(t) = \prod_{i=1}^{n} R_i(t)$$

(a) RBD for a series system



$$R(t) = 1 - \big(1 - R_1(t)\big) \cdot \big(1 - R_2(t)\big) \cdot \cdots \cdot \big(1 - R_n(t)\big)$$
$$= 1 - \prod_{i=1}^{n}(1 - R_i(t))$$

(b) RBD for a parallel system

Figure 2. Reliability block diagrams & reliability functions

The RBD shows how component (or sub-system) reliability contributes to the success or failure of the target system, and it has been used to identify potential areas of poor reliability and where improvements can be made to lower the failure rates for the target system. As shown in Figure 2, the RBD shows the logical connections of components within the target system. The target system may consist of multiple components/sub-systems in series, parallel and a combination of the two. Once a RBD is constructed, it is necessary to compute the failure rates of components/sub-systems which are performed by the two failure rate computing modules.

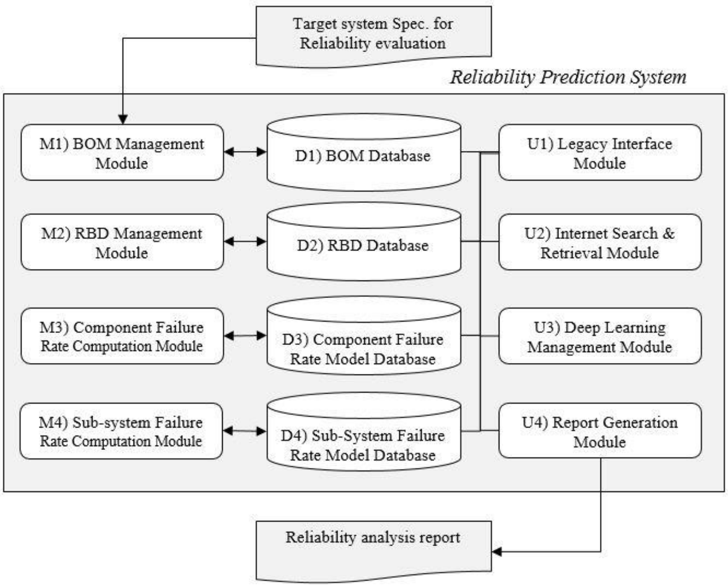


Figure 3. Reliability prediction system architecture consisting of eight modules and four databases

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Other than the four major functional modules (M1~M4), we provide four additional utility modules to improve user convenience; U1) Legacy data interface module, U2) Internet search & retrieval module, U3) Deep learning management module, and U4) Report generation module. The reliability prediction is not a one-time activity, it needs to be performed in both the design and operational phase to identify poor reliability and provide targeted improvements. Because of the reason, we need four databases; D1) BOM database, D2) RBD database, D3) Component failure rate model database, and D4) Sub-system failure rate model database.

3. DEMONSTRATION OF RELIABILITY PREDICTION SYSTEM

To demonstrate the proposed system architecture of a reliability prediction system, a prototype application has been implemented and test with various examples. Figure 4 shows the BOM related functionalities. There are two different ways for a user open a BOM model; 1) loading an existing BOM model from the BOM database, and 2) creating a new BOM model based on the target system specification. Once a BOM model is opened, a user may edit the BOM model to complement additional information which may be required for the reliability evaluation.

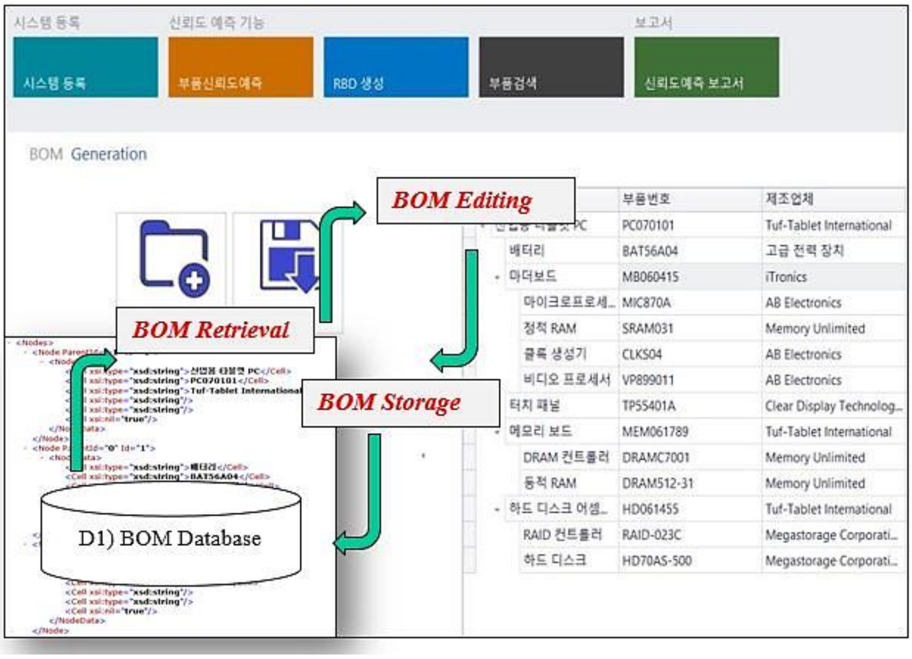

Figure 4. BOM retrieval & editing demonstration

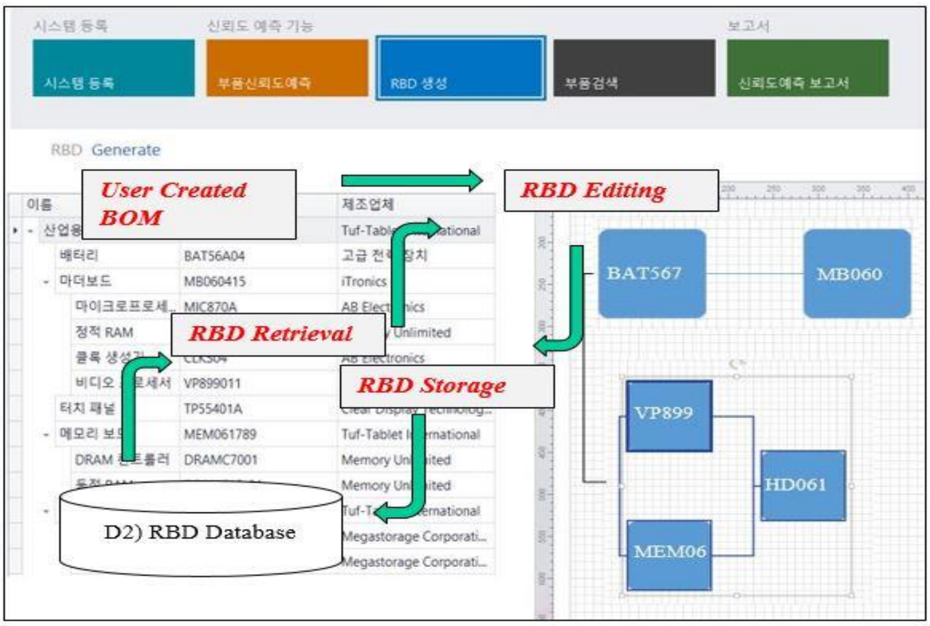

Figure 5. RBD retrieval & editing demonstration

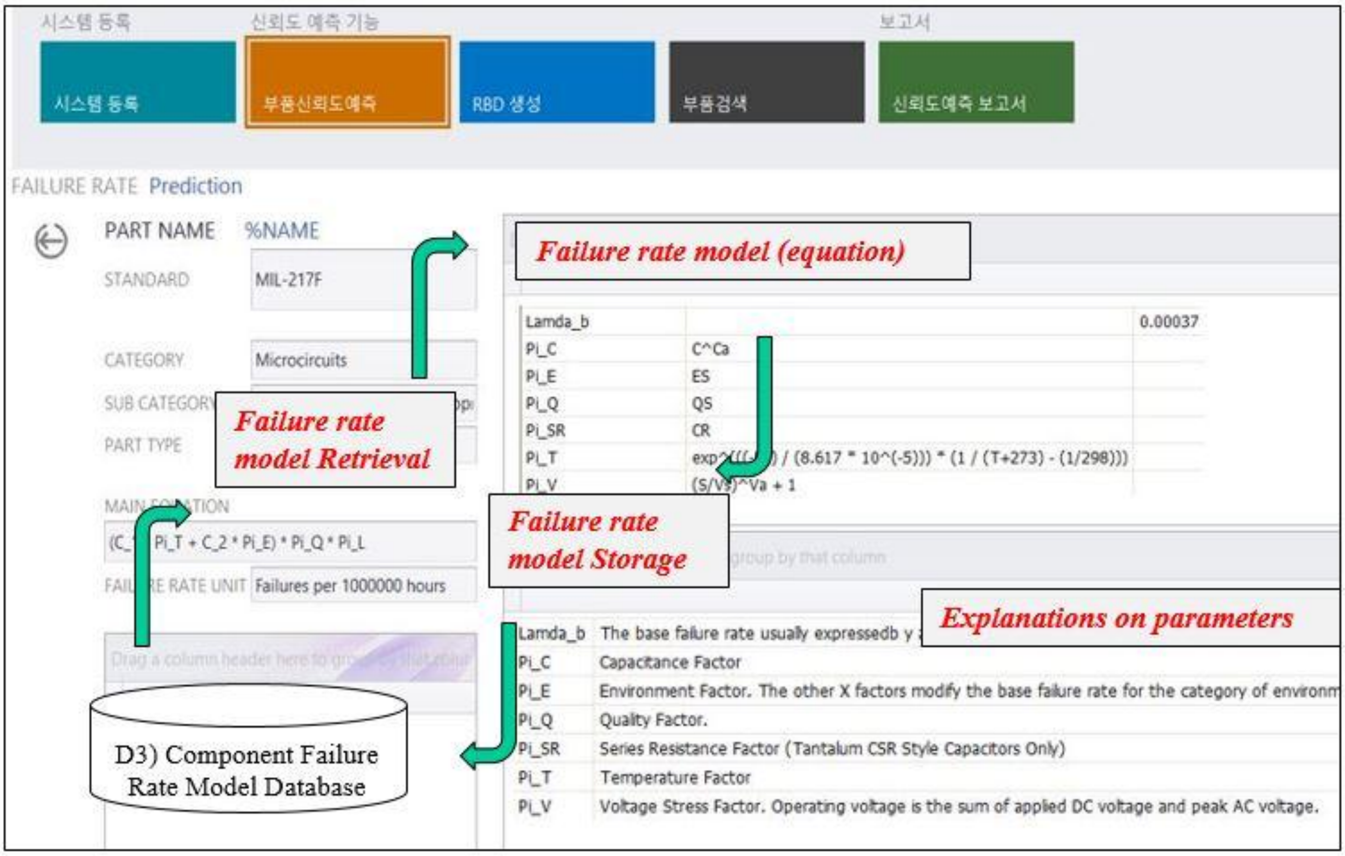

Figure 6. Failure rate computing demonstration

To predict the reliability of a given target system, it is necessary to construct a RBD model by using the BOM model. While a BOM model only shows the component list in the target system, a RBD model shows the 'logical connections of components' within the target system. The target system may consist of multiple components/sub-systems in series, parallel and a combination of the two, as shown in Figure 5. Once a RBD is constructed, it is necessary to compute the failure rates of components/sub-systems which are performed by the two failure rate computing modules. To predict the reliability of a given target system, it is necessary to define the reliability function of each component within the target system. The reliability function of a component gives the probability of the item operating for a certain amount of time without failure. Let *T* denotes the time to failure of a facility, and *f(t)* is the probability distribution function of *T*. At this time, the reliability of the facility at time *t* can be defined as the probability that the facility fails after time *t* ($t > 0$), and the reliability function can be stated as $\mathrm{R(t)} = P(T > t) = 1 - \int_0^t f(x)dx$. In reliability engineering, the exponential distribution is popularly used, and this paper also assumes that $f(t) = \lambda e^{-\lambda t}$, where the parameter λ (a failure rate) is such that $\frac{1}{\lambda}$ is the mean time to failure. Figure 6 shows the failure rate (λ) computing demonstration to define the reliability function of each component within the target system.

4. CONCLUSIONS

The reliability prediction of a target system is essential for various activities; 1) feasibility evaluation, 2) comparing competing designs, 3) identifying potential reliability problems, 4) planning maintenance and logistic support strategies, and 5) input to other studies such as life-cycle cost analysis or order selection. Previous research results on the reliability engineering can be categorized into two groups; 1) System engineers who are specifying, allocating, predicting, and demonstrating reliability, and 2) Physics-of-failure engineers who are identifying & modeling the physical causes of failure. Although, there have been numerous research results on the reliability prediction, there are few research results on the effective architecture of a reliability prediction system.

In this paper, we propose the software system architecture of a reliability prediction system to support the reliability prediction procedure of a given target system. To implement the effective reliability prediction procedure, we propose a software system architecture consisting of four major functional modules (BOM management module, RBD management module, Component failure rate computation module, and Sub-system failure rate computation module.), four utility modules and four databases. To demonstrate the proposed system architecture of a reliability prediction system, a prototype application has been implemented and test with various examples.

ACKNOWLEDGEMENTS

This work was partially supported by the Defense Acquisition Program Administration and the Agency for Defense Development (UD180018AD). Also, the research was supported by a grant (Ref. No. 20002772) from the Ministry of Trade, Industry and Energy, Korea.

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