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Extended Abstract

Obtaining Reliability Insights during a Product's Conceptual Design Process through Bayesian Network Modeling

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Abstract

The philosophy of Build-In-Reliability (BIR) or Design for Reliability (DFR) emphasizes the value of reliability prediction at a product's conceptual design stage. Due to the lack of reliability data, reliability assessment of a new design is not usually performed at this stage. In this paper, we propose a methodology to provide the reliability insight of a new design concept. The methodology consists of three major processes: functional analysis, cognitive map and Bayesian network modeling. A case study is given to demonstrate our proposed method.

Keywords:

Product's conceptual design; Bayesian network

Introduction

Accurate early reliability prediction becomes a common requirement for new product's development as systems have grown to be more complex. However, in the design phase of a new product there are not physical samples to assess or prove reliability. On the other hand, under the philosophical influence of Design for Reliability (DFR) or Build-In- Reliability (BIR), significant efforts had been put on reliability improvement by product design. For example, the use of computer support analysis (i.e., computer simulation) by designers is widely spread. Also, as complements to these computer simulation tools, qualitative and quantitative information from similar existing designs are also important to BIR. In recent years with the aid of new computational technologies, several design approaches have been proposed with the use of Bayesian reliability. Bayesian methods for system reliability analysis have been studied extensively in the work by Hamada et al., Wang et al., Pan and Rigdon.

Methodology

In order to assess a new product's reliability, it is necessary to take into consideration many product-specific factors such as product definition, design purpose, the level of change from previous designs, etc. In other words, the analysis methods and the tools to be used should be determined on the case-by-case basis. However, our proposed methodology presents a general approach to gaining reliability insights regardless of these factors.

Concept and functions

The methodology starts in the conceptual design phase, when a concept has been selected. Since there are not physical design representations at this time, the requirements are translated to functionalities of the new product. Therefore, either new functions or already established ones are identified and/or defined as the outcome of this phase.

Function to failure structures

Once the system functions are defined a functional analysis needs to be conducted. The first step consists in the identification of the primary or main function(s) and all the sub-functions involved. Secondly, the relationships between them need to be depicted. It is recommended to use a graphical representation when performing both steps to define the functional structures.

In order to have a reliability structure (or failure structure) in the early design process it is important to identify failure modes even when physical components have just been conceptualized. In this instance, using the function to failure approach creates the possibility to define a failure when a function is not executed as expected.

A Case Study

In order to better demonstrate and validate the proposed methodology, a case study is introduced in

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this section to explore and clarify the concepts presented in the methodology section. This case study was derived from a real engineering design process in a major heavy equipment manufacturing company in U.S. Note that to avoid disclosing sensitive information, the values presented in this case study were masked and certain variables were removed. The parameter values given in the graphical model were elicited from domain experts by following the guidelines provided in Cooke, Mejia Sanchez and Pan.

Discussion

The proposed methodology can be summarized in three major steps in the conceptual design phase. The first step is functional analysis, in which the function to failure process will be defined. Once determined the functionalities, the next step is to identify and establish the relationships between functions. This task is performed by constructing a cognitive map, which formalizes those relationships in the form of a functional structure. Finally, by adding a quantitative aspect, cognitive map is transformed to a Bayesian network, with which designers have the ability to evaluate different reliability scenarios, measure functional impact of changes, or verify that product requirements are met. Thus, obtaining an insight into the reliability of a new product in its conceptual phase has been made possible by this methodology.

One of the main advantages of the proposed methodology is the graphical representation of the functional and failure structures through the CM and BN. It exposes the interactions be- tween functions and facilitates the decision making process when dealing with a complex concept. Furthermore, having a reliability insight of a system in its conceptual design phase has its own advantages. For example, the necessities of some design requirements can be cross-validated and any early design changes would be much less expensive than later changes.

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