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Use of Bayesian Networks for Qualification Planning: Early Results of Factor Analysis

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Abstract

This paper discusses the factor analysis that provides the basis for development and use of Bayesian Network (BN) models to support qualification planning in order to predict the suitability of Six Degrees of Freedom (6DOF) vibration testing for qualification. Qualification includes environmental testing such as temperature, vibration and shock to support a stochastic argument about the suitability of a design. Qualification is becoming more complex because it involves significant human expert judgment and relies on new technologies that have often never been fully utilized to support design assessment. Technology has advanced to the state where 6DOF vibration tests are possible, but these tests are far more complex than traditional single degree of freedom tests. This challenges systems engineers as they strive to plan qualification in an environment where technical and environmental constraints are coupled with the traditional costs, risk and schedule constraints. BN models may provide a framework to aid Systems Engineers in planning qualification efforts with complex constraints. Previous work identified a method for building a BN model for the predictive framework. This paper discusses validation efforts of models derived from the factor analysis and summarizes some recommendations on the factor analyses from industry subject matter experts.

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Keywords: Bayesian network, qualification, vibration, systems engineering, 6DOF, multi-axis, decision model, factor analysis

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1. Introduction

This paper discusses the early results of the factor analysis generated when developing a Bayesian Network (BN) model to aid qualification planning. Qualification is defined in the Systems Engineering Book of Knowledge as "evidence that the design will survive in its intended environment with margin. The process includes testing and analyzing hardware and software configuration items to prove that the design will survive the anticipated accumulation of acceptance test environments, plus its expected handling, storage, and operational environments plus a specified qualification margin. Qualification testing usually includes temperature, vibration, shock, humidity, software stress testing, and other selected environments"[1].

Developing a qualification plan is a complex Systems Engineering problem. The traditional programmatic factors of cost, schedule and risk are combined with an increasing array of technical factors to create a multi-dimensional problem space. The problem space has become so complex it cannot be easily visualized and suggests the need for an improved decision framework.

While cost, schedule, and risk are factors affecting qualification planning, the technical factors can be the key driver. To date, research in systems engineering qualification planning focused on addressing the cost, schedule, risk and quality aspects of the problem[2]. This research proposes to add technical factors to the decision space. This research focuses on a subset of qualification requirements in order to be manageable, though the proposed concept could be expanded to all aspects of qualification. For the initial stages of research, the problem is narrowed to a subset of qualification planning: vibration – with an emphasis on including multi-axis or six degrees of freedom (6DOF) vibration testing in the traditional single degree of freedom (SDOF) solution space. The method for the research involves utilizing a BN model to develop the framework that takes advantage of the decades of knowledge of vibration tests as well as the causal technical factors in the current problem space. The remainder of this paper discusses the process and the factors selected for the BN model.

2. Background

2.1. Need for a Qualification Decision Aid

Today program plans are developed in the initial stages of the program lifecycle and require systems engineers and program managers to commit to estimates for the remaining stages of the program. These commitments are formulated early in the program bid process based on decisions made before the full technical staff is available. The plans are further adjusted as estimates are scrubbed for cost reductions through accepting a reasonable amount of risk. Cost, schedule, risk and technical factor trade-offs are a necessity[3]. The resulting problem is that it is difficult to plan qualification. The risk of making a poor decision may not be realized until the end of a program when the qualification evidence is not sufficient to support the requirements. At this point, returning to re-test, re-analyze and/or re-design is exponentially more expensive[4]. Rework at a late stage in the program often exceeds 20 percent of the initial development cost[5].

The qualification planning problem is difficult to address without a useful decision aid to consider the multi-faceted problem space or a method to update the qualification plan as issues arise. Plans are bad, started too late or too constrained to adjust during the course of the program.

There is a gap in the literature for qualification planning that incorporates technical factors along with cost, risk, schedule and quality. In the literature, qualification-planning (or verification and validation) research has resulted in various decision models or frameworks that do not consider technical factors[2]. A predictive framework and method for making qualification decisions, based on quantitative and qualitative data for technical factors, is needed to address this problem.

2.2. Vibration Qualification Problem Space

Vibration tests are common activities in many qualification plans. The tests have become increasingly complex with advances in technology affecting the test article, sensors, vibration machines and their controllers[6]. Advances in vibration machines and controllers have led to simulations of the environment (tests) in multiple degrees of freedom