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ScienceDirect

Procedia Computer Science 61 (2015) 133 – 140

Procedia Computer Science

Complex Adaptive Systems, Publication 5
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2015-San Jose, CA

Use of Bayesian Networks for Qualification Planning: A Predictive Analysis Framework for a Technically Complex Systems Engineering Problem

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Abstract

This paper discusses the viability of using 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 and restricted yet available new technologies are not fully utilized. Technology has advanced to the state where 6DOF vibration shakers and control systems capable of high frequency tests are possible, but the problem using these systems is far more complex than traditional single degree of freedom (SDOF) tests. This challenges systems engineers as they strive to plan qualification in an environment where technical, environmental, and political constraints are coupled with the traditional cost, risk and schedule constraints. New technologies are also available for systems engineers to combine technical understanding with cost, risk and schedule factors to aid in decision making for complex problems such as qualification planning. BN models may provide the framework to aid Systems Engineers in planning qualification efforts with complex constraints. This paper discusses related work, the current approach and results of this research.

Peer-review under responsibility of scientific committee of Missouri University of Science and Technology

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

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Peer-review under responsibility of scientific committee of Missouri University of Science and Technology
doi:10.1016/j.procs.2015.09.173

1. Introduction

Qualification as it pertains to weapon systems is defined 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].

Qualification planning is a complex Systems Engineering problem. Besides the programmatic factors of cost, schedule and risk, technical factors 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.

Prior research in systems engineering qualification planning focused on addressing the cost, schedule, risk and quality aspects of the problem. This research proposes to add technical factors to the decision space given that technical factors can be the key driver in qualification planning. 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 Bayesian Network (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.

A perspective on the complexity of the problem can be characterized by factors that can affect a qualification decision, such as: cost, schedule, risk, performance, program phases, environmental constraints, political constraints, destructive vs. non-destructive test, ability to measure desired responses during the activity, Concept of Operations (CONOPs), physical environment, standard environments, margin assessment, size of system, weight of system, system materials, interfaces, variability, failure mechanisms, hazards, availability of test facilities, uncertainties, values or priorities, ability to update the qualification plan, alternatives, completion definition, and the use of an Earned Value Management System (EVMS). Any of these factors can become drivers in the qualification planning process.

Nomenclature

6DOF	Six Degrees of Freedom	EaVa	Early Validation
ADS	Aeronautical Design Standards	EVMS	Earned Value Management System
ANSI	American National Standards Institute	ISO	International Organization for Standardization
BN	Bayesian Network	NASA	National Aeronautics and Space Administration
CEaVa	Continuous Early Validation	PoF	Physics of Failure
CONOP	Concept of Operations	SDOF	Single Degree of Freedom
COTS	Commercial Off The Shelf	SME	Subject Matter Expert
DOD	Department of Defense	SNL	Sandia National Laboratories
DOE	Department of Energy	WSMR	White Sands Missile Range

2. Background

2.1. Systems engineering role in qualification

There are four main qualification techniques: inspection, analysis, demonstration and test[2]. For every customer requirement, one or more qualification techniques must be selected and implemented. These qualification techniques are exercised throughout the life of the program in order to compile the body of evidence required to show all requirements have been satisfied[3].

Systems engineers and program managers are routinely called upon to develop and commit to plans and estimates for qualification in the initial stages of the program lifecycle. The decisions are typically made early in the program bid process before the full technical staff is available. The demands for programs and qualification seem to be changing; programs are constrained with short schedules, smaller budgets, more test restrictions, and political and