Designed for Six Sigma (DFSS): Improving and Quantifying Hardware Test and Software Test Coverage

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The described procedure can useful when effort is given to making a product Designed for Six Sigma (DFSS) quality. Capturing integration problems during hardware testing and software testing is getting more difficult as time progresses because the number of possible user applications and situations is growing at an increasing rate. In many instances it is impossible to test all possible combinations of input parameters when attempting to insure that there is no combination that can cause failure. The following described methodology can, for example, reduce test resources significantly, while improving the test coverage and effectiveness of hardware test and software test evaluations. This methodology can, for example, efficiently detect a computer product design failure condition that occurs when a particular video driver is used in conjunction with a highly loaded serial port and a new supplier's modem. Supplied also is a test coverage statement (e.g., 90%) for this and other similar failure considerations.

There are many applications, including the System Test of computers before first customer shipment, where this test strategy can yield significant savings. One user reports savings of $30,000 from a reduction in personnel needs and scheduling time. Another user reports with a typical product this approach now reduces prototype costs by an average of $50,000, reduces test labor by $5,000, and gets products to market by an average of 3 days earlier.

To illustrate the basic approach, consider the following, which is described in more detail in reference 1. A company is considering buying several new personal computers to replace its existing equipment. The company has some atypical configurations for its computers; hence, the company wishes to conduct a test to verify that the product will work with its existing peripheral equipment and software. The company believes that there will probably be no future problems if it can find no combination of the levels of three factors that cause failure. Test considerations are to be the type of printer, display, word processor, database manager, spreadsheet, plotter attachment, and network type. Often organizations consider testing each factor individually; however, this approach does not address the above concerns of three factor levels causing a problem. In lieu of a one-at-a-time approach let's first consider only two-level extreme conditions for each factor. This leads to 128 test trials for the two-level combinations from these seven factors (two to the power of seven = 128), which is typically not a reasonable test to conduct using normal test time and resource constraints.

An alternative approach to assessing all combinations of factor levels is to use a Design of Experiments (DOE) or Multivariable Testing (MVT) matrix to define a subset of all possible combinations. Table M from reference 1 describes the tests for 8-test trial combinations from the 128 test trial possibilities, while Table O quantifies the 3-factor test coverage to be 90% for this particular test. In general Table M from Reference 1 describes test matrices and Table O describes the corresponding test coverage where:

- up to 7 two-level factors can be assessed in 8 trials
- up to 15 two-level factors can be assessed in 16 trials
- up to 31 two-level factors can be assessed in 32 trials
- up to 63 two-level factors can be assessed in 64 trials

Example:

A product will be "put together" (i.e., configured) in many different ways by a customer. Because of possible design flaws, it is of interest to discover when things will not work together before first customer shipment. In many situations the number of test combinational possibilities can be very large (i.e., 10,000 and more). A DOE or MVT matrix can expedite this test process.

Consider that for this example the system can be comprised of the factors levels in the following table. For example, a customer might have a Mother board with a Network Interface Card, SCSI hard drive, Tape backup from supplier B, slow speed CD-ROM, a fast modem speed, Normal video memory size, and monitor from supplier A.

Factor	Levels	
A. Mother Board	w/ Network Card Interace	w/o Network Card Interface
B. Hard Drive	SCSI	IDE
C. Tape Backup	Supplier A	Supplier B
D. CD-ROM	Slow Speed	Fast-Speed
E. Modem Speed	Slow Speed	Fast Speed
F. Video Memory	Normal Size	Large Size
G. Monitor	Supplier A	Supplier B

Consider now that it was unknown to the test group that a configuration failure would occur when the Mother board has a Network Interface Card and is used in conjunction with a monitor from supplier B and a large video memory size.

A one-at-a-time approach to test these factors (e.g., evaluating the Mother board's Network Interface Card, Monitor suppliers, and then video memory size) would not typically detect this type of problem. However, chances are that a DOE and MVT matrix of only 8-trials would detect this problem. The following describes this approach.

An eight-trial Design of Experiments (DOE) and Multivariable Testing (MVT) matrix (from Table M2, [1]) takes the form

Trial #	A	B	C	D	E	F	G
1	+	-	-	+	-	+	+
2	+	+	-	-	+	-	+
3	+	+	+	-	-	+	-
4	-	+	+	+	-	-	+
5	+	-	+	+	+	-	-
6	-	+	-	+	+	+	-
7	-	-	+	-	+	+	+
8	-	-	-	-	-	-	-

In general Table M [Reference 1] describes test matrices for the following:

- up to 7 two-level factors can be assessed in 8 trials
- up to 15 two-level factors can be assessed in 16 trials
- up to 31 two-level factors can be assessed in 32 trials
- up to 63 two-level factors can be assessed in 64 trials

For example, trial 3 in the above matrix would be:

Trial #	A	B	C	D	E	F	G

3	+	+	+	-	-	+	-

Which physically is described in the following table with bold faced type.

Factor	Levels	
A. Mother Board	w/ Network Card Interace	**w/o Network Card Interface**
B. Hard Drive	SCSI	**IDE**
C. Tape Backup	Supplier A	**Supplier B**
D. CD-ROM	**Slow Speed**	Fast-Speed
E. Modem Speed	**Slow Speed**	Fast Speed
F. Video Memory	Normal Size	**Large Size**
G. Monitor	**Supplier A**	Supplier B

The question is whether the test will capture the problem described (i.e., a mother board with a Network Interface Card will not perform satisfactorily with monitors from supplier B and a large video memory size). The answer to this question is yes. To illustrate why this is true, the failure would occur when A = -1 (Mother board with Network Interface Card), F= +1 (large size video memory), and G = +1 (Monitor supplier B). This combination of factor levels exists for trial 7; hence, trial 7 would fail. Reference 1 describes a search pattern strategy that could next be followed, if necessary, to determine why this particular trial failed.

Table O within reference 1 can be used to determine the test coverage when no fails occur, along with the number of possible combinations of three factor levels. For the group of concern (i.e., three) the test coverage is 90%.

	Number of Groups					
	2	**3**	**4**	**5**	**6**	**7**
Percentage of coverage	100	90	50	25	12	6
Number of possible combinations	84	280	560	672	448	128

A computer program [2] extends this basic concept to test designs where any number of factors and levels can be assessed efficiently with calculated test coverage.

Design of Experiments (DOE) and Multivariable Testing (MVT) techniques are also useful to efficiently create test performance models [3]. With this approach someone can, with only a few tests, describe the performance of a computer system or processor relative to user configurations and/or design changes/modifications.

Additional information and a roadmap for integrating measurements with process improvement activities can be found within Implementing Six Sigma: Smarter Solutions using Statistical Methods, Forrest W. Breyfogle III, John Wiley and Sons, New York, NY, 1999. The wise integration of hardware/software testing and other Six Sigma tools is described within our training. Focus during the training is given to building effective implementation procedures that have bottom line results for the application situations described by attendees.

Reference

1. *Implementing Six Sigma: Smarter Solutions using Statistical Methods,* Forrest W. Breyfogle III, Wiley 1992.
2. For more information about a computer program that expedites the creation of test configurations contact Forrest Breyfogle, Smarter Solutions, Austin, Texas (forrest@smartersolutions.com, 512-996-8288).
3. "Improving Processes Using Multivariable Testing (MVT) and Design of Experiments (DOE) Matrices" Forrest W. Breyfogle III, Available at http://www.smartersolutions.com.