Excerpt from Chapter 32:
Example 32.2: A DOE Development Test

Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard

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32.8   Example 32.2: A DOE Development Test

The techniques of DOE are often related to process improvement. This example presents a method that can be used in the development process to assess how well a design performs.

Consider that a computer manufacturer determines that "no trouble found (NTF)" is the largest category of returns that they get from their customers. For this category of problem, a customer had a problem and returned the system; however, the manufacturer could not duplicate the problem; hence the category description NTF. This manufacturer did some further investigation to determine that there was a heat problem in the system. Whenever a system heated up, circuit timing would start to change and eventually cause a failure. When the system cooled down, the failure mode disappeared.

A fix for the problem in manufacturing would be very difficult because the problem was design related. Because of this, it was determined to focus on this potential problem in the design process so that new products would not exhibit similar problems. A test was desired that could check the current design before first customer shipment.

The problem description is a new computer design that can fail whenever module temperature exceeds a value that frequently occurs in a customer environment with certain hardware configurations and software applications. The objective is to develop a strategy that identifies both the problem and risk of failure early in the product development cycle.

Computers can have different configurations depending upon customer preferences. Some configurations are probably more likely to cause failure than others. Our direction will be first to identify the worst-case configuration using DOE techniques and then stress a sample of these configured machines to failure to determine the temperature guardband.

From a brainstorming session, the following factors and levels were chosen

	Level	
Factor	−1	1
System type	New	Old
Processor speed	Fast	Slow
Hard-drive size	Large	Small
Card	No card	1 card

Memory module	2 extra	0 extra
Test case	Test case 1	Test case 2
Battery state	Full charge	Charging

Table 32.6 shows the design selected. Temperature was measured at three different positions within the product. An analysis of the data for processor temperature yielded the following mean temperature model:

$$\text{Processor temperature (est.)} = 73.9 + 3.3(\text{system type}) - 3.5(\text{processor speed}) - 0.9(\text{memory module}) - 0.8(\text{test case})$$

Consider that we want to determine the configuration that causes the highest temperature and to estimate the mean component temperature at this configuration. From the modeling equation for the processor, the mean overall temperature is 73.9°. Temperature is higher for some configurations. For example, the processor module temperature would increase 3.3° if system type were at the +1 level, i.e., old system type. The worst case levels and temperatures are

Average	73.9
System type = 1 (old)	3.3
Processor speed = –1 (fast)	3.5
Memory module = –1 (2 extra)	0.9
Test_case = –1 (test case 1)	0.8
Total	82.4

Table 32.6: DOE Results

Trial	System Type	Processor Speed	Hard Drive Size	Card	Memory module	Test case	Battery state	Temp. Processor	Temp. Hard Drive Case	Temp. Video Chip
1	-1	-1	-1	-1	-1	-1	-1	76	58.5	72.8
2	1	1	-1	-1	-1	1	-1	73.7	63.3	71.3
3	-1	-1	1	-1	-1	1	1	73.8	67.2	75.2
4	1	1	1	-1	-1	-1	1	74.8	58.3	73.2
5	1	-1	-1	1	-1	1	1	81.3	66.2	70.9
6	-1	1	-1	1	-1	-1	1	67	56.1	69.1
7	1	-1	1	1	-1	-1	-1	84.1	61.1	69.7
8	-1	1	1	1	-1	1	-1	67.5	63.6	71.7
9	1	-1	-1	-1	1	-1	1	79.4	58.2	65.5
10	-1	1	-1	-1	1	1	1	65.6	62.3	69.6
11	1	-1	1	-1	1	1	-1	78.7	59.2	68.1
12	-1	1	1	-1	1	-1	-1	68.6	61.3	71.5
13	-1	-1	-1	1	1	1	-1	71.6	64.6	74.5
14	1	1	-1	1	1	-1	-1	73.7	56.8	69.8
15	-1	-1	1	1	1	-1	1	74.4	64.2	74.2
16	1	1	1	1	1	1	1	72.3	57.4	69.5

In this model, we need to note that mean temperature is modeled as a function of various configurations. Product-to-product variability has a distribution around an overall mean. If the mean temperature of a configuration is close to an expected failure temperature, additional product-to-product evaluation is needed.

We now have to select a worst-case configuration to evaluate further. In this model, we note that the new system type has a lower temperature than the old system type. Because we are most interested in new products, we would probably limit additional evaluations to this area. We also need to consider that failure from temperature might be more sensitive in other areas of the product, e.g., hard drive.

The model created from the DOE experiment is a mean temperature model. For any configuration we would expect product-to-product temperature variability as shown in Figure 32.11. However, we would not expect all products to fail at a particular temperature because of the variability of electrical characteristics between assemblies and other factors. Hence there would be another distribution that describes temperature at failure because of this variability of product parameters. The difference between these distributions would be the margin of safety for a machine, as shown in Figure 32.12, where the zero value for temperature is an expected customer ambient temperature. This figure indicates that roughly 5% of the products would fail when the internal operating
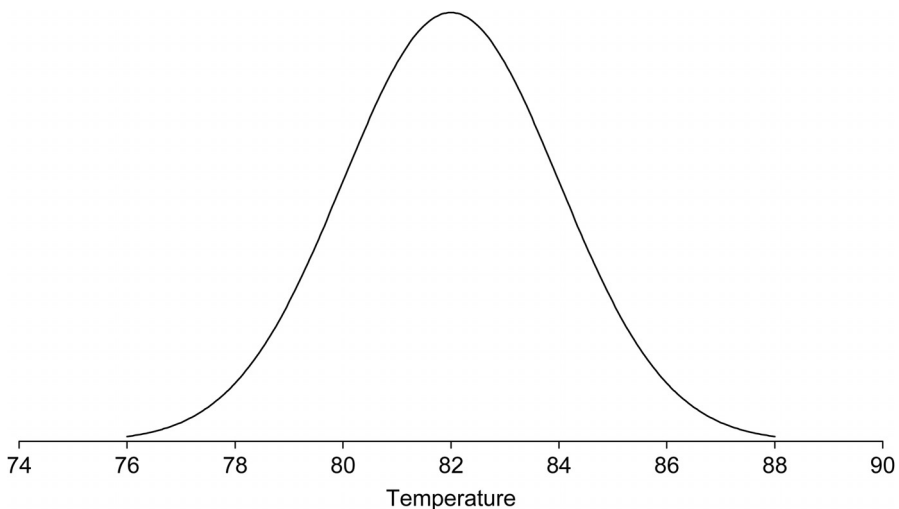

Figure 32.11: Potential product-to-product processor temperature variability.

temperatures of the worst-case configured machines reach a steady-state temperature; i.e., approximately 5% of the area of the curve is below the zero value, which is ambient temperature.

We need next to build a plan that estimates this margin of safety for temperature. One approach would be to select randomly a sample of machines that have a worst-case configuration. This sample could then be placed in a temperature chamber. The chamber could initially be set below the normal ambient temperature chosen. All machines would then be exercised continually with an appropriate test case. After the machines reach their normal internal operating temperature, the chamber temperature would then be gradually increased. Chamber temperature is then documented when each machine fails. Ambient temperature is subtracted from these temperatures at failure for each of the products under test. A normal probability plot of these data can yield the percentage value shown conceptually in Figure 32.12. The resulting percentage is an estimate of the margin of safety for temperature. This information can help determine whether changes are needed.

32.9 Fold-Over Designs

Consider the situation in which a resolution III experiment is conducted. After looking at the results, the experimenters wished that they had initially conducted a resolution IV experiment
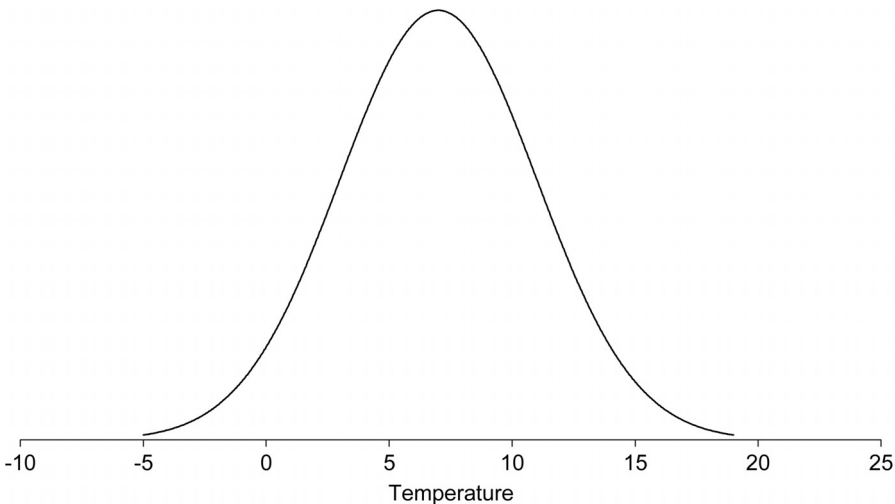

Figure 32.12: Product design margin for temperature.

Description of the Integrated Enterprise Excellence Book Series

In the book *The Integrated Enterprise Excellence System: An Enhanced Approach to Balanced Scorecards, Strategic Planning and Business Improvement*, illustrations exemplify how traditional business systems can lead to undesirable activities and then presents an IEE alternative. Table of Contents

In the three-volume series, *Integrated Enterprise Excellence: Beyond Lean Six Sigma and the Balanced Scorecard*, there is both further elaboration on the shortcomings of traditional systems and the details of an IEE implementation. Volumes of this series build upon each other so that readers can develop a true appreciation and understanding of IEE benefits and its implementation. When explaining the concepts to others, readers can reference volumes or portions of volumes at the other person's level of understanding or need. Series volumes make reference to other volumes or *Implementing Six Sigma* (Breyfogle 2003) for an expansion of topic(s) or a differing perspective. These volumes are written to stand alone; however, there are some volume overlaps in the building of this IEE methodology series progression.

A content summary of this volume series is:

- *Integrated Enterprise Excellence Volume I - The Basics: Four Golfing Buddies Going Beyond Lean Six Sigma and the Balanced Scorecard* --An IEE onset story about four friends who share their experiences while playing golf. They see how they can improve their games in both business and golf using this system that goes beyond Lean Six Sigma and the balanced scorecard. The story compares IEE to other improvement systems.   Table of Contents

- *Integrated Enterprise Excellence Volume II - Business Deployment: A Leaders' Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard* --Discusses problems encountered with traditional scorecard, business management, and enterprise improvement systems. Describes how IEE helps organizations overcome these issues utilizing an enterprise process define-measure-analyze-improve-control (E-DMAIC) system. Systematically walks through the execution of this system. Table of Contents

- *Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard* --Describes IEE benefits and its measurement techniques. Provides a detailed step-by-step project define-measure-analyze-improve-control (P-DMAIC) roadmap, which has a true integration of Six Sigma and Lean tools. Table of Contents