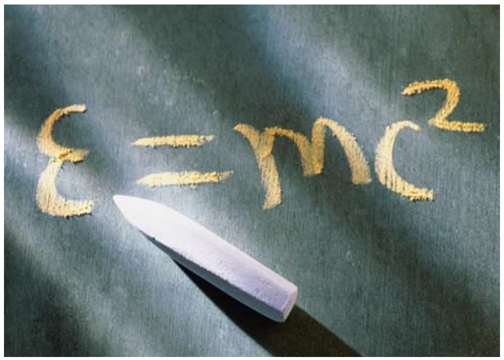
DFSS RELIABILITY SYSTEM THINKING ASSESSMENT



Forrest W. Breyfogle III
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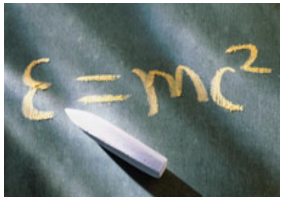
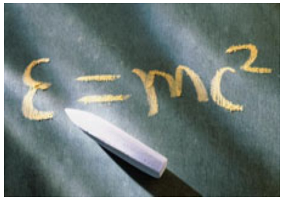
Example 43.3 *Implementing Six Sigma*, 2nd edition



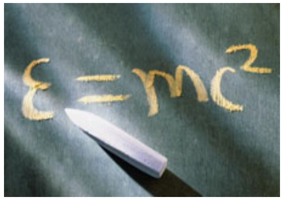
Objective

- Compare traditional reliability testing to a Smarter Six Sigma Solutions (S^4) alternative
- In this S^4 alternative, a unique Design of Experiments (DOE) analysis technique is described, which can provide more insight to potential future product customer issues than traditional reliability testing
- These benefits are achieved with much less test effort and could be used as a component of an organization’s DFSS development process



Test Definition

- A power supply has sophisticated design requirements
  - In addition, the specification indicates an aggressive MTBF (mean time between failures) criterion of 10×10^6 hr
- A test organization is to evaluate the reliability and function of the non-repairable power supply
- Tests of this type seem to be directed toward emphasizing testing the failure rate criterion by exercising enough units long enough to verify the criterion
  - Considering that the failure rate of the units is constant with age, as the criterion implies

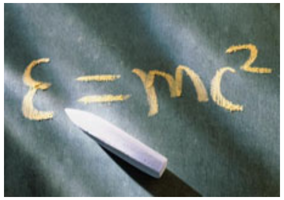


Reliability Failure Criteria Testing

- Table K in *Implementing Six Sigma,* 2nd edition can be used to determine a factor for determining the total number of test hours needed
- If we desire 90% confidence with a test design that allows no failures, then the factor would be 2.303, which would yield a total test time of

$$T = 2.303\,(10 \times 10^6) = 23.03 \times 10^6 \text{ hr}$$

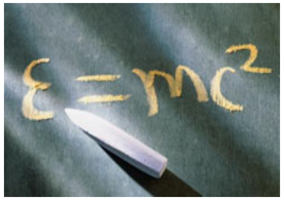
If had a hypothesis test where tried to protect both α and β the test hours could be over 600,000,000 hrs



Reliability Failure Criteria Testing

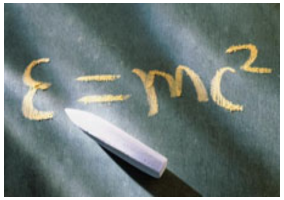
- Consider that the expected annual number of power-on hours for the power supply is 5000 hr, and each unit is tested to this expected usage
  - This test would require 4605 (i.e., $23.03 \times 10^6/5000 = 4605$) units,
  - While a 5-year test would require 921 units [i.e., $23.03 \times 10^6/(5000)(5) = 921$])

Accelerated test alternatives can be helpful to reduce test duration; however, the same basic problems still exist with less magnitude



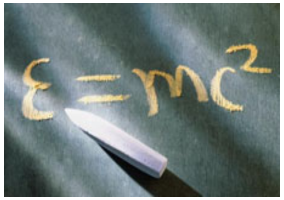
Reliability Failure Criteria Testing

- For most scenarios involving complex assemblies, neither of these two test alternatives are reasonable
  - since the unit costs would be prohibitive, the test facilities would be very large,
  - the test would be too long, and
  - information obtained late in the test would probably be "too late" for any "value added”



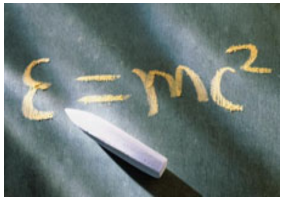
Reliability Failure Criteria Testing

- Even if the time and resources are spent to do this test and no failure occurs, customer reliability problems can still exist
- Two basic assumptions are often overlooked with the preceding test strategy
  - The first assumption is that the sample is a random sample of the population
    - If this test were performed early in the manufacturing process, the "sample" may be the first units built, which is not a random sample of future builds that will go to the customer
    - Problems can occur later in the manufacturing process causing field problems, which this test will not detect since test samples were from an earlier production vintage



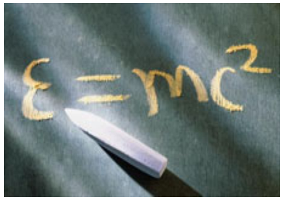
Reliability Failure Criteria Testing

- The second assumption is that the test replicates customer usage
  - If a test does not closely replicate customer situations, real problems may not be detected
  - For example, if the customer turns off a system unit that contains the power supply each evening and our test units are just exercised continuous operation, the test may miss some thermal cycling component fatigue failures



Reliability Failure Criteria Testing and DOE Reliability Alternative

- Or, another example could be that the customer puts more electrical load on the system than was done on the test system
  - The test may again miss a failure mode caused by this additional loading
- Perhaps a fractional Design of Experiments (DOE) could better define how the power supplies should be loaded and exercised when trying to identify customer reliability problems

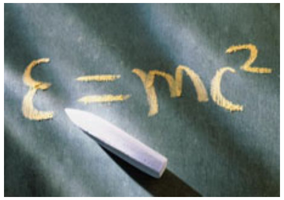


DOE Reliability Assessment: Design

- For the preceding test, one pre-production unit could be functionally tested at the extremes of its operating environment using a fractional factorial test strategy
- The following is such a strategy where input factors are evaluated for their effect on the various important output characteristic requirements of the power supply

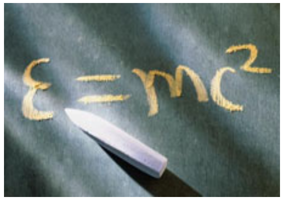
Inputs			
		Levels	
	Factors	-	+
A:	Ambient Temperature	47 deg C	25 deg C
B:	Input ac voltage range	110V	220 V
C:	Mode of programmable output	3.4 V	5.1 V
D:	ac line voltage (within range in B)	Min	Max
E:	Frequency at ac input	Min	Max
F:	Load on -12 V output	Min	Max
G:	Load on -5 V Output	Min	Max
H:	Load on 12 V output	Min	Max
I:	Load on 5.1 V output	Min	Max
J:	Load on 3.4 V output	Min	Max
K:	Load on programmable output	Min	Max

Outputs		
Output voltage on each output (-12V, -5V, 12V, 5.1V, 3.4V, programmable volt output		
Ripple/noise		
Noise		
Input (power factor)		
Efficiency		
Line current		
Line power		



DOE Reliability Assessment: Design

- From Table M4 (*Implementing Six Sigma*, 2nd edition), a 32-trial resolution IV design was chosen
  - With this design, the main effects would not be confounded with two-factor interactions
    - however, there would be confounding of two-factor interactions with each other
- The 11 contrast columns from Table M4 were assigned alphabetical factor designations from left to right (A - K)

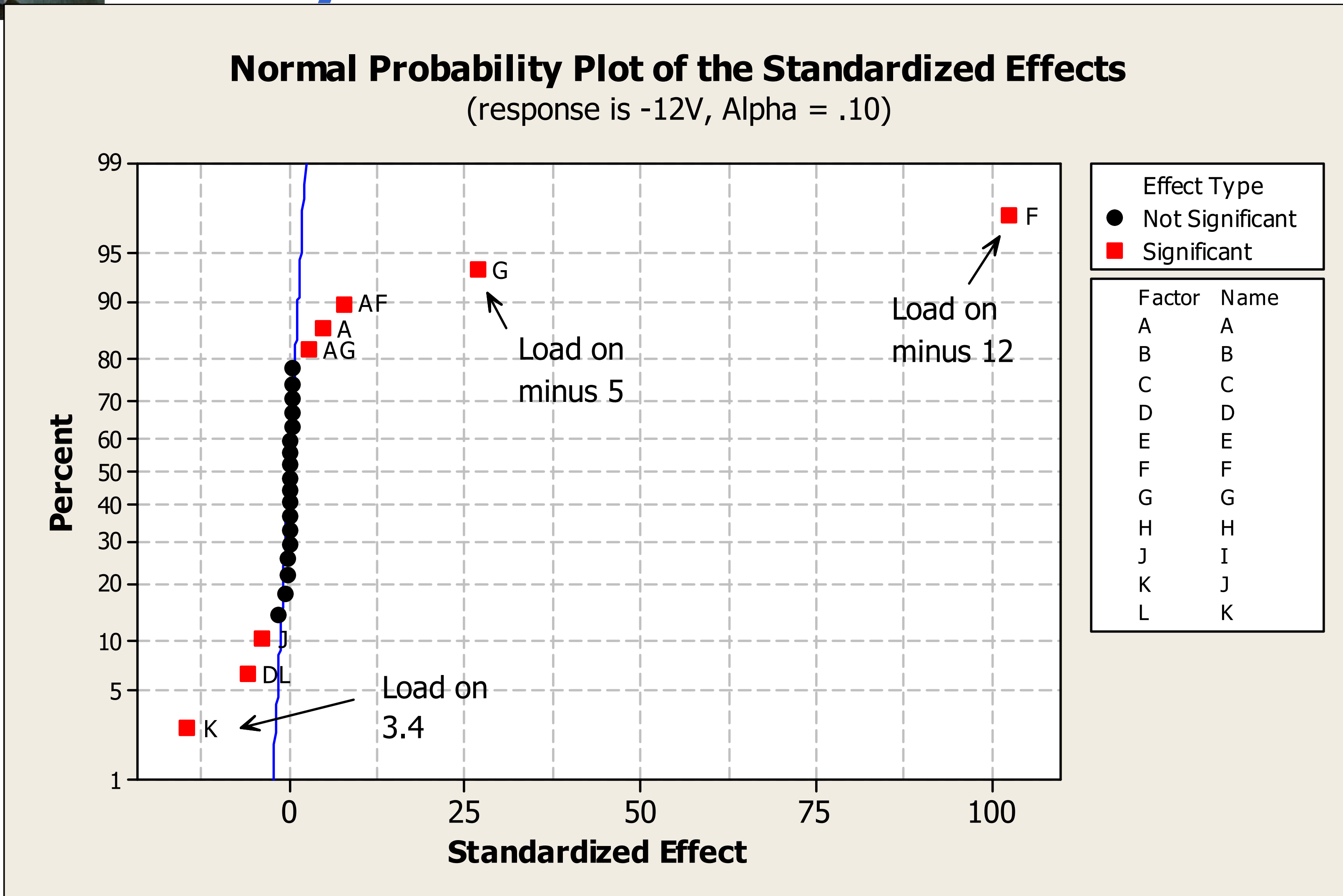


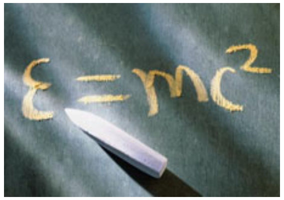
DOE Reliability Assessment: Results

- Example data from these test trials, along with two of the experimental trial outputs (-12 and 3.4 voltage level outputs) are:

Trial	A	B	C	D	E	F	G	H	I	J	K	-12V	3.4V
1	+	-	-	-	+	+	+	+	-	+	-	-11.755	3.1465
2	+	+	-	-	-	+	+	-	+	-	-	-11.702	3.3965
3	+	+	+	-	-	-	+	+	-	+	+	-12.202	3.147
4	+	+	+	+	-	+	-	+	+	-	-	-11.813	3.4038
5	+	+	+	+	+	+	+	+	+	+	+	-11.761	3.1537
6	-	+	+	+	+	-	+	-	+	+	-	-12.2	3.1861
7	-	-	+	+	+	-	-	+	-	+	+	-12.325	3.1902
8	+	-	-	+	+	+	-	+	+	-	+	-12.292	3.398
9	+	+	-	-	+	+	-	-	+	+	+	-11.872	3.1498

DOE Reliability Assessment: -12V Analysis





DOE Reliability Assessment: -12 V Analysis

Fractional Factorial Fit

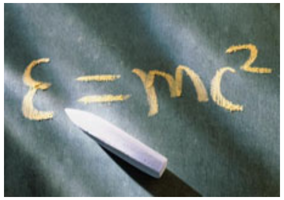
Estimated Effects and Coefficients for -12V (coded units)

Term	Effect	Coef	StDev Coef	T	P
Constant		-12.02	0.001804	-7E-03	0.000
A	0.02	0.01	0.001804	5.54	0.000
B	0.00	0.00	0.001804	0.42	0.683
C	0.00	0.00	0.001804	0.42	0.683
D	0.00	0.00	0.001804	0.17	0.864
E	0.00	0.00	0.001804	0.69	0.497
F	0.43	0.22	0.001804	120.03	0.000
G	0.11	0.06	0.001804	31.35	0.000
H	-0.01	-0.00	0.001804	-1.80	0.088
I	-0.02	-0.01	0.001804	-4.54	0.000
J	-0.06	-0.03	0.001804	-17.08	0.000
K	0.00	0.00	0.001804	0.66	0.519
A*F	0.03	0.02	0.001804	9.01	0.000
D*K	-0.03	-0.01	0.001804	-6.96	0.000

Smaller magnitudes

Load on -12V

Load on -5V



DOE Reliability Assessment: -12 V Analysis

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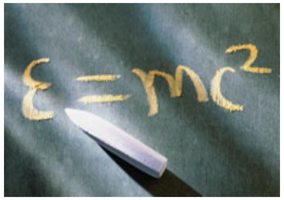
C	0.00	0.00			
D	0.00	0.00			
E	0.00	0.00			
F	0.43	0.22			
G	0.11	0.06			
H	-0.01	-0.00			
I	-0.02	-0.01			
J	-0.06	-0.03			
K	0.00	0.00			
A*F	0.03	0.02			
D*K	-0.03	-0.01	0.001804	-6.96	0.000

- The effect of the - 12-V loading (factor F), for example, on the - 12-V output level is simply the difference in average output response for the trials at the high load to those at low load, which is:

Average effect on –12-V output by –12-V load (F effect)

$$= \frac{(-11.755 - 11.702, \ldots)}{16} - \frac{(12.202 - 12.200, \ldots)}{16}$$

$$= -0.43 \text{ V}$$

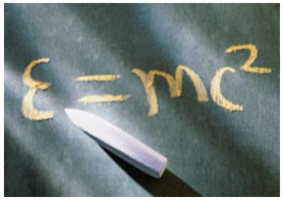


DOE Reliability Assessment: -12 V Analysis

Analysis of Variance for -12V (coded units)

Source	DF	Seq SS	Adj SS	Adj M	F	P
Main Effects	11	1.63935	1.63935	0.149032	1E+03	0.000
2-Way Interactions	2	0.01350	0.01350	0.006750	64.80	0.000
Residual Error	18	0.00187	0.00187	0.000104		
Total	31	1.65473				

- Consider where the error estimate coming from
  - Response: Other two-factor and higher interaction term effects



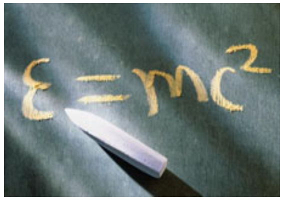
DOE Reliability Assessment: -12 V Analysis

Alias Structure (up to order 2)

I
A
B
C
D
E
F
G
H
I
J
K
A*F + B*I + C*D + E*J
D*K + E*H + F*G

- Consider what the resolution is for this design
  - Response: Two-factor interactions are confounded with each other but not with the main effects

- A subset model of only the significant factors would next be appropriate; this analysis would show
  - Because of the design balance the effects do not change
  - The changes in probability value would not affect our basic decision
  - The residual plots would not change much

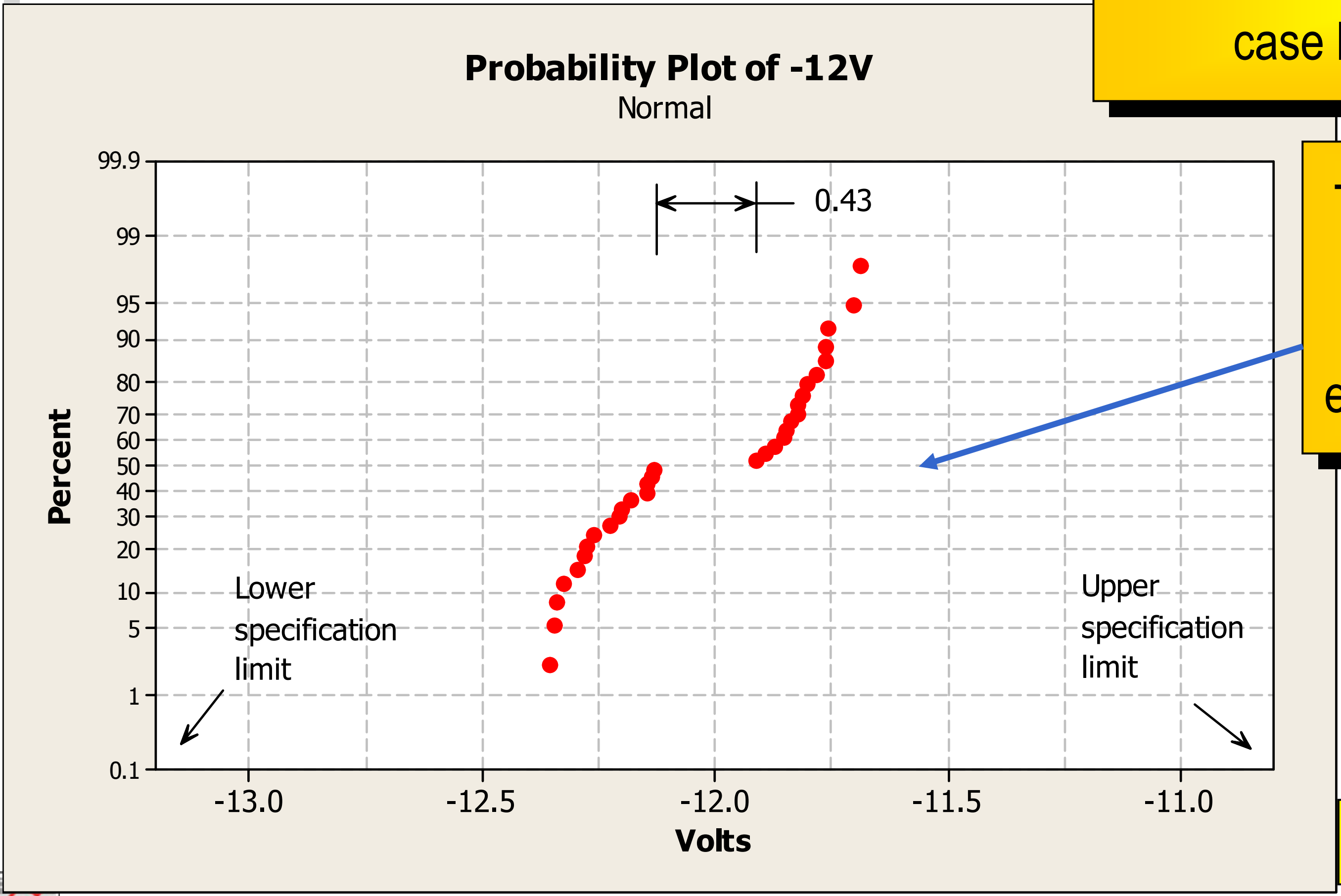


DOE Reliability Assessment: -12 V Analysis

- The results of statistical analyses are commonly presented as significance statements
  - However, a practitioner may be interested in the overall effects relative to specification limits
- One approach to size this consideration is to make a probability plot of the outputs of the 32 trials and include the specification limits on the plot
  - however, note that this plot is not a true random sample plot of a population
- This approach is call DOE Collective Response Capability Assessment (DCRCA)

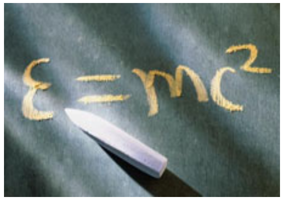
DOE Reliability Assessment: -12 V Analysis

This plot reflects the variability of one machine, given various worst-case loading scenarios



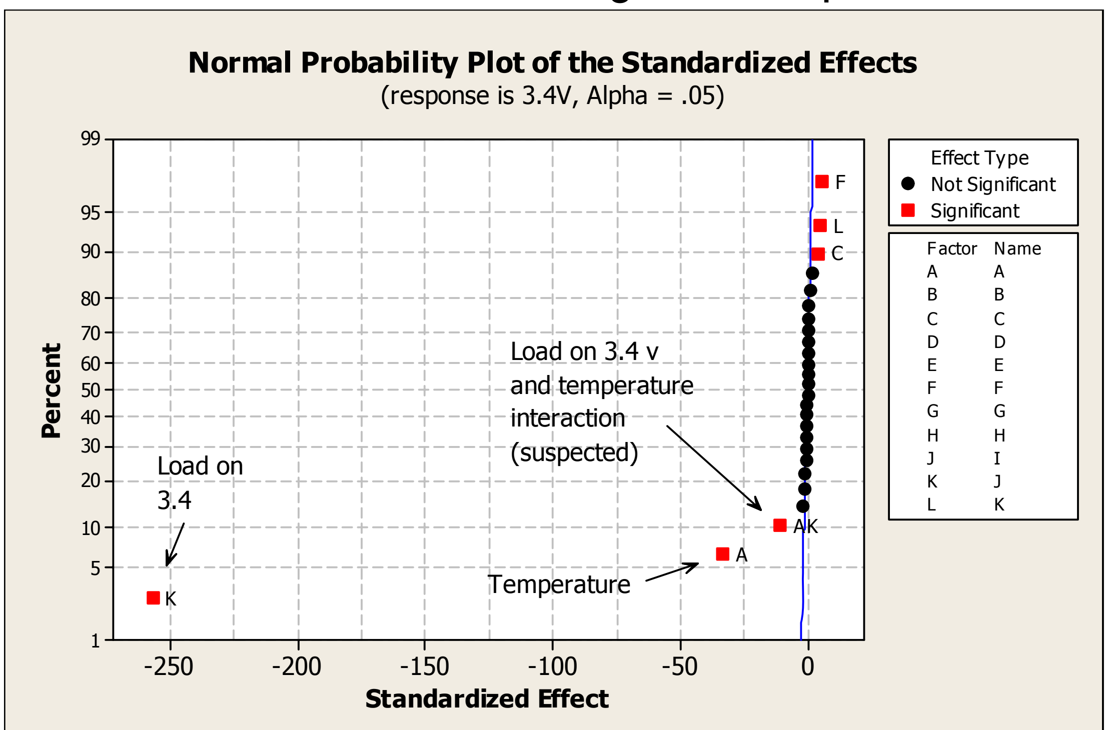
The gap between points is approximately the same magnitude as the effect from circuit loading

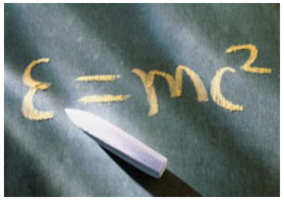
More on next slide



DOE Reliability Assessment: 3.4 V Analysis

- The 3.4-V loading effect appears most significant, followed by the temperature effect
  - The third most significant effect is noted to be a suspicion of an interaction between this loading and temperature





DOE Reliability Assessment: 3.4 V Analysis

Fractional Factorial Fit

Estimated Effects and Coefficients for 3.4V (coded units)

Term	Effect	Coef	StDev Coef	T	P
Constant		3.2891	0.000399	8238.12	0.000
A	-0.0317	-0.0159	0.000399	-39.70	0.000
B	-0.0017	-0.0009	0.000399	-2.19	0.041
C	0.0045	0.0022	0.000399	5.59	0.000
D	-0.0007	-0.0004	0.000399	-0.94	0.359
E	-0.0004	-0.0002	0.000399	-0.47	0.644
F	0.0055	0.0028	0.000399	6.93	0.000
G	-0.0002	-0.0001	0.000399	-0.28	0.781
H	0.0000	0.0000	0.000399	0.05	0.963
I	0.0002	0.0001	0.000399	0.30	0.769
J	-0.2447	-0.1224	0.000399	-306.50	0.000
K	0.0049	0.0025	0.000399	6.15	0.000
A*J	-0.0100	-0.0050	0.000399	-12.55	0.000

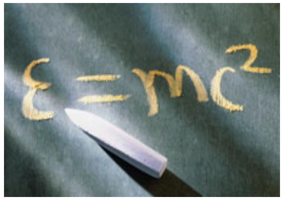
Temperature

Smaller Effects

Temp*Load 3.4 V suspected

Load on 3.4 V output

DOE Reliability Assessment: 3.4 V Analysis



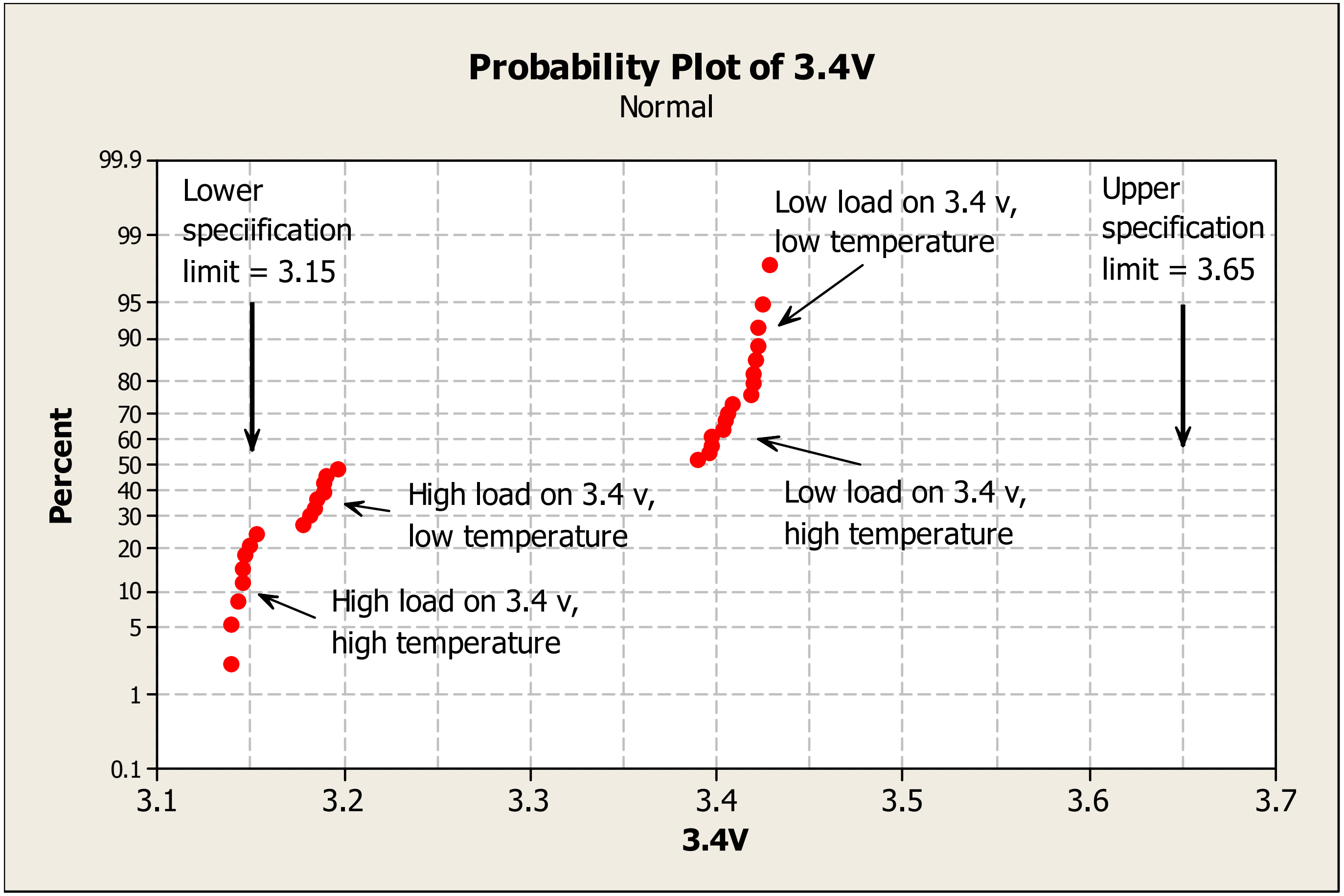
Fractional Factorial Fit
Estimated Effects and

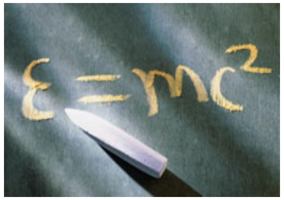
Term	Effect				
Constant					
A	-0.0317				
B	-0.0017				
C	0.0045				
D	-0.0007				
E	-0.0004				
F	0.0055				
G	-0.0002				
H	0.0000				
I	0.0002				
J	-0.2447				
K	0.0049				
A*J	-0.0100	-0.0050	0.000399	-12.55	0.000

- Two-factor interactions are confounded within this resolution IV experiment design
  - This factor is in reality contrast column15 (see the design matrix in Table M4)
- Table N2 indicates that contrast 15, in general, has many interactions that are confounded
  - However, the number of interaction possibilities is reduced, since this experiment had only 11 factors (designated A through K)
    - because of this the number of possibilities is reduced to EF, GH, AJ, and BK
- Of these possibilities we believe that the AJ interaction is the significant one

DOE Reliability Assessment: 3.4 V Analysis

- Similarly to the –12-V analyses, let's next create a probability plot of the 32 trial outputs
  - remembering that this plot is not a true random sample plot of the population

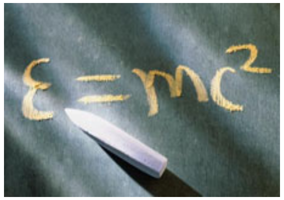




DOE Reliability Assessment: 3.4 V Analysis

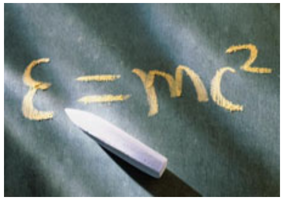
- However, some of the data points fall below the lower specification limit
  - It appears that the supplier is adjusting the power supply to a 3.4-V output under a low-load condition
    - However, with additional load, the output decreases to a value that is close to the specification limit
- It is apparent from the out-of-specification condition that the voltage adjustment procedure at the supplier should be changed to "center" the high/low loading conditions within the specification limits

Note, this power supply could cause an intermittent problem (i.e., failure at high load when it heats up)



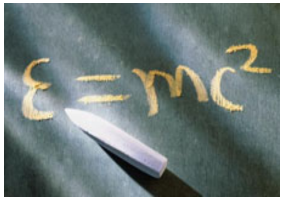
DOE Reliability Assessment: 3.4 V Analysis

- The next question of concern is whether there are any other parameters that should be considered
  - One possible addition to the variability conditions is circuitry drift with component age
    - Another is variability between power supply assembly units
- To address the between-assemblies condition, multiple units could have been used for these analyses
  - However, the test duration and resource requirements could be much larger
- An alternative is to consider an addition derived from historical information; however, this information is not often available
  - Another alternative is to evaluate a sample of parts, held at constant conditions, to assess the magnitude of this variability
    - This effort can also serve as a confirmation experiment to assess whether the conclusions that were drawn from the fractional factorial experiment are valid



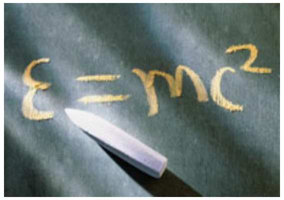
DOE Reliability Assessment: 3.4 V Analysis

- A test of 10 power supply assemblies is plotted
- The test data consists of two points for each assembly, taken at low load/low temperature and high load/high temperature on the 3.4-V output and
  - The plot indicated that approximately 99.8% of the population variability is within a 0.1-V range
- Allowance could be made for this 0.1-V variation adder in the 3.4-V analyses



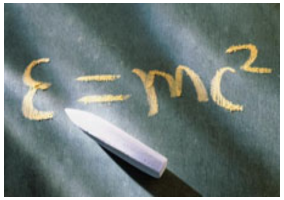
DOE Reliability Assessment: Benefits

- After the power supply qualification test process is completed satisfactorily,
  - information from this test can be used to determine which parameters need to be monitored within the manufacturing process
- If this problem escaped development tests, manufacturing would probably be reporting this issue as a "no trouble found" when failing units were returned by the customer
  - "No trouble found" issues can become very expensive problems for an organization



Summary

- The described methodology can help organizations improve their enterprise design process efficiency and effectiveness
- In a computer-industry DFSS Design-Measure-Analyze-Design-Verify (DMADV) process, a verify-phase application of this procedure can help reduce the number of future post-ship non-trouble founds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