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Calculating Probability of Failure of Electronic and Electrical Systems (Markov vs. FTA)

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Introduction

The author of this paper has given seminars to the FAA and commercial airlines on the subjects of Probability, Reliability, and Markov Analysis. This experience revealed some misunderstandings among the engineering community concerning Fault Tree Analysis (FTA) and Markov Analysis (MA). The confusion is not due to the community's lack of talent or interest, but primarily to a lack of good publications on these subjects written in a clear common language. FTA and MA are two major methods used for calculating the probability of failure (P_f) of electrical and electronic systems. In an attempt to eliminate some of the confusion, this paper compares the two methods and discusses why and when one should be used and not the other.

Calculating Probability of Failure

Four basic tasks for calculating system P_f are:

1. Clearly identify the undesired event.
2. Perform a qualitative analysis by constructing a model of the sequence of events leading to the undesired event. This model accurately describes the logic flow of the entire process leading to the event. Does the undesired event involve a component failure? Do two or more components need to fail in some sequence? Do certain components need to fail during a certain phase of the mission? In short, a qualitative model describes in detail the logic flow of the entire process leading to an undesired event.
3. Perform a Reliability Prediction for the component piece parts.
4. Perform a quantitative analysis by constructing a mathematical model (a set of equations based on the logic derived from the qualitative model), and calculating the probability of the undesired event over a specified time interval.

FTA Limitations

Traditionally, tasks 2 and 4 have been performed using FTA, the most commonly known and utilized method. However, what is not commonly known is that FTA has two major limitations. (Note: In order to understand one of these limitations, the engineer must understand the concept of combinatorial vs. non-combinatorial problems. One of the objectives of this paper is to enhance the reader's understanding of this concept with the help of example problems.)

The two major FTA limitations are:

1. With respect to electrical or electronic systems FTAs do an excellent job with tasks 2 and 4 with combinatorial problems. However, FTAs have difficulty with both when dealing with non-combinatorial problems.
2. With respect to systems utilizing mechanical devices, while FTAs can be used effectively for task 2, they have much difficulty with task 4. Calculating P_f of systems with mechanical devices requires other methodologies. It is a subject unto itself and is not addressed in this paper.

Pertinent Excerpts

The following excerpts pertain to calculating P_f of electrical and electronic systems.

Excerpt from FAA's ARP4761 Issue 1996-12:

a. It is difficult if not impossible to allow for various types of failure modes and

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dependencies such as transient and intermittent faults and standby systems with spares.

b. A fault tree is constructed to assess cause and probability of a single top event. In some situations it may be difficult for a fault tree to represent a system completely, e.g., repairable systems and systems where failure/repair rates are state dependent. Markov Analyses (MA) do not possess the indicated limitations. The sequence dependent events are included and handled naturally, and therefore cover a wider range of system behaviors.

The complexity and size of systems are rapidly increasing with new advances in technology.

Aircraft systems are relying more and more on fault tolerant systems. Such systems hardly ever fail completely because of continuous monitoring of their condition and instantaneous reconfiguration of the systems. Given this scenario of fault tolerance, the safety assessment process and evaluation of such a system may be more appropriately achieved by the application of the Markov technique.

Excerpt from NASA Reference Publication 1348

Traditionally, the reliability analysis of a complex system has been accomplished with combinatorial mathematics. The standard fault-tree method of reliability analysis is based on such mathematics. Unfortunately, the fault-tree approach is somewhat limited and incapable of analyzing systems in which reconfiguration is possible. Basically, a fault tree can be used to model a system with:

a. Only permanent faults (no transient or intermittent faults)
b. No reconfiguration
c. No time or sequence failure dependencies
d. No state-dependent behavior (e.g., state-dependent failure rates)

Because fault trees are easier to solve than Markov models, fault trees should be used wherever these fundamental assumptions are not violated.

Summary of Excerpts (Why Markov?)

Basically what the preceding excerpts are saying is that the FTA approach has difficulty handling problems that involve:

a. Transient or intermittent faults,
b. Reconfiguration,
c. Time or sequence failure dependencies,
d. State-dependent behavior (e.g., state-dependent failure rates).

From a mathematical point of view, a system employing any one of the above items a. through d. is considered a non-combinatorial type system. In other words, what the excerpts are claiming is that the FTA approach has difficulty handling non-combinatorial type problems, and suggests the use of Markov when analyzing these types.

Note: A pure combinatorial system (or circuit) is a system whose outputs are functions of its inputs only, with none of the characteristics a. through d.

Introduction to Markov Analysis

If a system or component can be in one of two states (i.e., failed, non-failed), and if we can define the probabilities associated with these states on a discrete or continuous basis, the probability of being in one or the other at a future time can be evaluated using a state-time analysis. In reliability and availability analysis, failure probability and the probability of being returned to an available state are the variables of interest. The best known state-space technique is Markov Analysis. The Markov method can be applied under the following constraints:

a. The probabilities of changing from one state to another must remain constant. Thus the method can only be used when a constant failure rate is assumed.
b. Future states of the system are independent of all past states except the immediately preceding one. This is an important constraint in the analysis of repairable systems, since it implies that repair returns the system to an "as new" condition.

Typical Markov Model

In the typical Markov model (see Figure 1):

- The model represents various system states
- The transition rate is a function of failure or repair rate
- The states are mutually exclusive
- The sum of the probabilities must equal 1

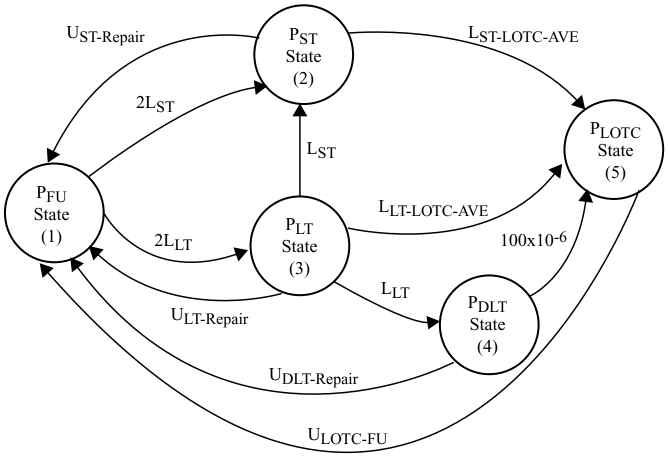


Figure 1. Example Markov State Diagram

Markov vs. FTA

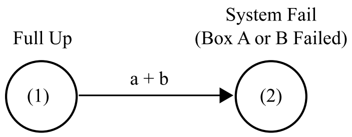
Markov and FTA differ in obvious ways. For example, Markov calculates probabilities of states, while FTA calculates probabilities of top level events. A less obvious difference is the ability to solve non-combinatorial type problems. Foregoing a rigorous mathematical discussion, it is sufficient to say that Markov can yield precise quantitative solutions to non-combinatorial problems, whereas FTA must resort to various approximation techniques. Both methods can be used for combinatorial problems and yield identical solutions. The examples that follow serve to illustrate the solution of combinatorial and non-combinatorial problems. They each involve calculating the P_f of electrical devices, and therefore assume constant failure rates. Markov solutions to these problems were derived using techniques for solving simultaneous differential equations.

Example 1: Two Components in Series (Combinatorial)

Two black boxes, A and B, with failure rates a and b, respectively, start operating at the same time. System operation requires both boxes be functional. Find P_f = Probability of System Failure.

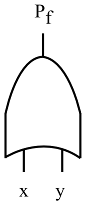
Note: Full Up State = all devices operating, (n) = State Number, P(n) = Probability of State (n).

Markov Model



$$P_f = P(2) = 1 - e^{-(a+b)t}$$

FTA Approach



$$x = 1 - e^{-at} \qquad y = 1 - e^{-bt}$$

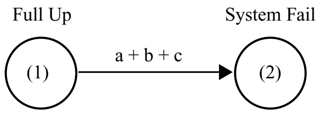
$$P_f = x + y - xy = 1 - e^{-(a+b)t}$$

Note the solutions (P_f) are identical in both methods.

Example 2: Three Components in Series (Combinatorial)

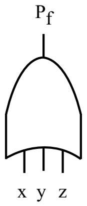
Three black boxes, A, B, and C, start operating at the same time. The failure rates are a, b, and c respectively. Successful system operation requires all boxes be functional. Find P_f .

Markov Model



$$P_f = P(2) = 1 - e^{-(a+b+c)t}$$

FTA Approach



$$x = 1 - e^{-at} \qquad y = 1 - e^{-bt} \qquad z = 1 - e^{-ct}$$

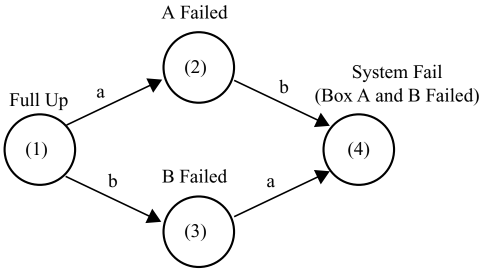
$$P_f = x + y + z - xy - xz - yz + xyz = 1 - e^{-(a+b+c)t}$$

Note again the identical solutions.

Example 3: Two Components in Parallel (Combinatorial)

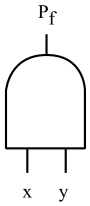
Two black boxes start operating at the same time. They have failure rates a and b, respectively. Successful system operation requires that either Box A <u>or</u> Box B be functional. Find P_f .

Markov Model



$$P_f = P(4) = (1 - e^{-at})(1 - e^{-bt})$$

FTA Approach



$$x = 1 - e^{-at} \qquad y = 1 - e^{-bt}$$

$$P_f = xy = (1 - e^{-at})(1 - e^{-bt})$$

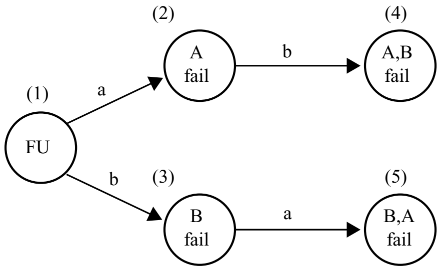
Note again the identical solutions.

Example 4: Two Components in Parallel with Required Order Factor (ROF) (Non-combinatorial)

Two black boxes start operating at the same time. Box A has failure rate a and Box B has failure rate b.

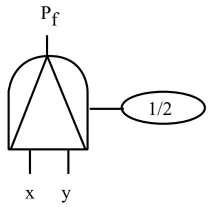
a. What is the probability that both Boxes fail and that A fails before B.
b. What is the probability that both Boxes fail and that B fails before A.

Markov Model



a. $P(4) = a/(a + b) + [b/(a + b)]\, e^{-(a + b)t} - e^{-bt}$
b. $P(5) = b/(a + b) + [a/(a + b)]\, e^{-(a + b)t} - e^{-at}$

FTA Approach



$x = 1 - e^{-at}$ $\quad$ $y = 1 - e^{-bt}$

a. $P_f = ½xy = ½\,(1 - e^{-at})(1 - e^{-bt})$
b. $P_f = ½xy = ½\,(1 - e^{-at})(1 - e^{-bt})$

This ROF problem has a sequence failure dependency, and consequently a non-combinatorial type problem. As can be seen, the above results are not the same. FTA has difficulty handling such problems.

Summary

Fault Tree Analysis is a very effective tool used for qualitative and quantitative analyses of combinatorial type problems. It uses approximation techniques when solving non-combinatorial types, and therefore should be used with caution and with full understanding of this limitation.

Markov Analysis is a very effective tool used for qualitative and quantitative analyses of combinatorial and non-combinatorial type problems. However, Markov Analysis Computer Programs tend to have a limitation on the number of "states" they can handle.

Remember that, with respect to quantitative analyses, both FTA and MA methods must be limited to constant failure rate items and therefore are not applicable to items characterized by a hazard function, e.g., mechanical components that wear out over time (increasing failure rate).

About the Author

Vito Faraci is a mathematician by education, and an electrical engineer by trade. He has 12 years of experience with qualitative and quantitative analyses of Reliability, Built-In-Test, and safety-related events. He has also served as a Reliability and Markov Analysis consultant for the Federal Aviation Administration and commercial airlines. Mr. Faraci is also an adjunct math professor at New York Institute of Technology.

Statistical Analysis of Reliability Data, Part 2: On Estimation and Testing

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Introduction

In the first article of this series, random variables (RV), distributions, and parameters were discussed, and an overview of the problems of data and outliers was presented. In this article, the problems associated with sampling, estimation and testing are discussed. We have seen that every random process (or RV) has two or more outputs that follow a distinctive pattern (its distribution). And we have seen how such a distribution can be uniquely specified by a set of fixed values or parameters. Once these two elements are known, we can answer all pertinent questions regarding the random process and thus take the necessary actions to control, forecast or affect its course.

Unfortunately, in almost every practical case, the underlying distribution and its associated parameters are unknown. In such cases, the best that we can do is to observe the process (i.e., sample) and then use these sample observations to:

- Reconstruct both the distribution and the parameters that generated them (estimation) or, alternatively,
- Confirm or reject some educated guesses previously formed about these distribution and parameters (hypothesis testing).

Sampling

Statistics is about making decisions under uncertainty. We deal with a random process (RV) whose distribution and parameters we would like to know because we then could define the optimal strategy vis-à-vis this random process. Hence, we observe the process for as long as we can afford (i.e., sampling). The first assumption in sampling is that the process is stable (the conditions prevailing during the observation period will remain the same during the extrapolation period). The sample must be random, so that it is "representative" of the population from which it comes [1].

Sampling can take several forms. For example, we can select n subjects at random from a finite population of N individuals (e.g., n light bulbs out of a batch of N). Or we can select them from an infinite population (e.g., roll n times a pair of dice, from the infinite population of all possible dice rolls). We can also sample with (or without) replacement according to whether we return (or do not return) each sample subject to the population, after each drawing. However, simple, random sampling schemes share two common qualities. First, all elements in the population (in sampling with replacement) or all possible samples (in sampling without replacement) must have the same probability of selection. Second, sampling is very expensive (either in time, or in money or in both). For this reason, sample sizes often are fairly small.

Once a sample of size n is obtained, we need to synthesize it, i.e., create a "statistic". For example, the sample average (denoted $\bar{x}$) is a widely used statistic. Since they are products of random sampling experiments, statistics are also RVs and have distributions and parameters. For example, assume we have a random and reasonably large (say, 30 or more) sample, from the same distribution (i.e., population) having unknown mean μ and a variance σ^2. Then, by the Central Limit Theorem (CLT), the distribution of the sample average $\bar{x}$ is distributed Normal, with the same mean μ and variance σ^2/n. This result is very significant. For it provides both the statistical table (distribution) we need to use (Normal Standard) and the necessary parameters (μ, σ) that standardize the sample average $\bar{x}$ (i.e., take it to Standard Normal form, i.e., $\mu = 0$ and $\sigma = 1$). Since every Normal RV can be standardized, we obtain the Standard Normal statistic z, via the transformation:

$$z = \frac{(\bar{x} - \mu)}{\sigma / \sqrt{n}} \qquad (1)$$

Because of the CLT, the sample average $\bar{x}$ and its standardization (z) are among the most frequently used statistics. However, there are many others and their use depends on the situation at hand. First, to apply the CLT to an average $\bar{x}$ we need a large sample size. Then $\bar{x}$ is an estimator of the population mean. And as discussed in our first article, mean and variance may become less informative, as the population distribution becomes less symmetric. In such cases we may want to use other sampling statistics that have associated other sampling distributions. Some of these other distributions are Student's t, Chi Square and F.

The distribution of Student's t:

$$t = \frac{(\bar{x} - \mu)}{s / \sqrt{n}} \qquad (2)$$

is obtained when the sample size is "small" (less than 30), the variance σ^2 of the population is unknown (and estimated by the sample variance s^2), and the parent (data) distribution is Normal. Student t distribution is "flatter" than the Standard Normal, with heavier tails. This is a consequence of having a larger uncertainty, since we have less information than before (i.e., smaller n and unknown σ). We now have to deal with the "degrees of freedom" (d.f.) parameter, which depends on the number of sample points (n) minus one (due to the estimation of both mean and variance from the same sample).

The variance estimator:

$$s^2 = \Sigma \frac{(x_i - \bar{x})^2}{n - 1} \qquad (3)$$

yields (via $(n - 1)s^2/\sigma^2$) a Chi Square Distribution that can be defined as the sum of "ν" independent, squared Standard Normal RV, has ν degrees of freedom associated with it and is denoted $\chi^2(\nu)$. The ratio of two independent Chi Square RV, χ_1 and χ_2 divided by their corresponding d.f. ν_1 and ν_2 is distributed $F(\nu_1, \nu_2)$ i.e., with ν_1 and ν_2 d.f.

$$F(\nu_1, \nu_2) = \frac{\chi_1(\nu_1)/\nu_1}{\chi_2(\nu_2)/\nu_2} \qquad (4)$$

Notice how, all three distributions (Student t, Chi Square, and F) require that the RV sample average $\bar{x}$ be "centered" (i.e., the population mean μ is subtracted from each observation). The corresponding non-central t, Chi Square and F distributions are obtained when the originating RV ($\bar{x}$) are not "centered" (e.g., when μ is no longer the expected value of $\bar{x}$). This difference (δ) is known as the "non-centrality parameter".

In reliability work [2, 3], we often take samples by placing "n" devices in a life test. Assume that the life X of an individual device is distributed Exponentially, with mean time to failure (MTTF) θ, denoted Exp(θ). Then an estimator of the (unknown) MTTF is $\tilde{\theta} = \Sigma X_i/n$ (the average of all the failure times).

When the sample is large ($n > 30$) the above CLT applies and $\tilde{\theta}$ ($= \bar{x}$) is distributed Normally. Hence, if we put 30 or more items on a life test, the average life is Normally distributed, independent of whether the individual devices lives are Exponential, Weibull, or other. When the sample is small, however, since each individual X_i is Exponentially (and not Normally) distributed, we cannot implement the t-distribution. The sum of n independent Exp(θ) RV (Total Test Time (TTT) or ΣX) is distributed

Gamma (with parameters θ, n). However, as we will see in the next section, an easy transformation allows us to use a distribution more flexible than the Gamma.

Summarizing, we first take a random sample of size n, from the population of interest. Then, according to our statistical objectives, we synthesize the data into a statistic (e.g., sample average, sample variance, etc.). Then, according to our sample size and the distribution of the data, we obtain the corresponding statistic sampling distribution (e.g., z, t, Chi Square, etc.) and use it for estimation or testing, as needed.

Estimation

During the initial observation of a random process or RV, we may not yet have formed an idea of what the distribution is, nor where its parameters lie. Our objective, then, is to "estimate" these parameters from the sample. (In this article, we discuss parameters. The case of distributions will be dealt with in a subsequent article.)

We could obtain a parameter point estimator (e.g., the sample average is a point estimator for parameter population mean). However, point estimators may vary widely from sample to sample. Consequently, interval estimators, i.e., random intervals that "cover" the fixed parameter with a prescribed probability, are more efficient. They provide a region where the parameter of interest may lie, with some pre-specified probability, namely the confidence interval (c.i.).

It is known, by the CLT, that for large samples, the interval ($\bar{x} - z_{\alpha/2}\, \sigma/\sqrt{n}$, $\bar{x} + z_{\alpha/2}\, \sigma/\sqrt{n}$) covers the mean μ with probability ($1-\alpha$), or at least $100(1-\alpha)\%$ of the time (α is defined as the non coverage probability). This can be illustrated in the following way. Let the (fixed but unknown) parameter μ be an invisible coin, sitting on top of a table. Let our c.i. be a plastic dish (of radius $z_{\alpha/2}\, \sigma/\sqrt{n}$) that we throw, trying to cover the coin. And let $\bar{x}$ be the table coordinates of the dish center of gravity every time it is randomly thrown on the table. Then (under certain conditions) the dish (falling on the table at position $\bar{x}$) would actually cover the coin at least $100(1-\alpha)\%$ of the time. The error 100α would be the percentage of times our dish would not cover the coin. Of course, the larger the dish radius (or c.i. half-width) the smaller the coverage error α. However, once covered by the dish, we no longer see where the coin, sitting under it, lies. So, a dish (c.i.) the size of the table would always cover the coin. Only that such dish (c.i.) now becomes useless. For we are back again in the same situation we started with (e.g., the coin can be on the entire table under the dish, but we do not know where).

The procedure for obtaining an interval estimator (c.i.) for μ, from a large sample, is based on the following. By the CLT, the distribution of the average ($\bar{x}$) of a sample of size n is Normal with (unknown) mean μ and standard deviation $\sigma/\sqrt{n}$. If we prescribe a "half width" or distance H, from both directions of μ, we obtain the population percentage included in this interval (μ - H, μ + H). Conversely, if we prescribe a percentage of the population (say 90%) to lie inside an interval (μ - H, μ + H), we consequently obtain the corresponding H. Hence, any random sample average $\bar{x}$ (of the population of all possible averages of samples of size n) will be in this interval with probability $1-\alpha$ (say, 0.9). Also, the furthest apart $\bar{x}$ can be from μ (either by excess or defect) and still lie in the prescribed interval is H. Hence, inverting the above process, we can equally say that the interval ($\bar{x}$ - H, $\bar{x}$ + H) centered in the random average $\bar{x}$, will "cover" or include the population mean μ, with probability $1-\alpha$, i.e., $100(1-\alpha)\%$ of the times. Again, it is important to emphasize that it is only the c.i. which is random, varies, and may or may not "cover" the fixed parameter μ.

Analogous philosophy underlies the calculation of c.i. for the mean, when using small ($n < 30$) samples, or for the variance, the ratio of two variances, etc. In such cases, we use some of the other above mentioned distributions and statistics (Student t, Chi Square, F, etc.) instead of the Normal Standard and z. But the philosophy of pre-establishing a coverage probability $1-\alpha$ and then "inverting" the process on the statistic distribution, remains the same as just explained.

It is important to realize that, all other factors remaining constant, the c.i. half width H is inversely proportional to the sample size. For example, in the large sample case:

$$(\bar{x} - H, \bar{x} + H) = \left(\bar{x} - \frac{z_{-\alpha/2}}{\sqrt{n}}, \bar{x} + \frac{z_{-\alpha/2}}{\sqrt{n}}\right) \Rightarrow H = \frac{z_{-\alpha/2}}{\sqrt{n}}$$

This equation determines the sample size n, required for a coverage $1-\alpha$, with precision H, when the natural variability of the RV is σ^2, as in the previously mentioned case.

Often, in reliability, we also require a $100(1-\alpha)\%$ c.i. for the MTTF of a device. It can be shown that, if the life of a device (X) is distributed Exp (θ), then the transformed variable $Y = 2X/\theta$ is distributed $\chi^2(2)$, i.e., as a Chi Square distribution, with two d.f. For the total time on test, TTT = $\sum X$ of the n devices:

$$\frac{2 \text{ x TTT}}{\theta} = \frac{2}{\theta} \Sigma_i X_i = \Sigma_i \frac{2\text{x } X_i}{\theta} = \Sigma_i Y_i \sim \chi^2 (2n)$$

Observe that 2 x TTT/θ is distributed as the sum of "n" independent Chi Squares, each having two d.f. This sum, $\sum Y$, follows a Chi Square distribution with 2n d.f. From this fact, we can derive the $100(1-\alpha)\%$ c.i. for the MTTF (θ) of a device, as:

$$\left(\frac{2 \text{ x TTT}}{\chi^2_{1-\alpha/2}} ; \frac{2 \text{ x TTT}}{\chi^2_{\alpha/2}} \right)$$

Finally, it is important to note the difference between confidence intervals and confidence bounds as well as between confidence and tolerance intervals and bounds. As seen above, a c.i. provides two bounds (lower/upper) within which the parameter is included 100(1-α)% of the times we do this. A confidence (upper/lower) bound is a value such that the parameter in question is (above/below) this bound at least 100(1-α)% of the times. Therefore, in a c.i. the coverage error α is equally divided between the regions above and below its upper/lower bounds. In a confidence bound, however, an error is committed only in one case. Hence, the entire error probability α is allotted to only one error region, either the upper or the lower region, but not both.

The main difference between tolerance and confidence intervals/bounds can be explained as follows. In a tolerance interval (bound) we are now concerned with the coverage of a percentage of the population, as opposed to the coverage of a parameter. Hence, when we say that (ξ_1, ξ_2) is a p-tolerance interval for a distribution (population) F, with tolerance coefficient γ, we mean that, with probability γ such random interval covers at least the pre-specified percentage (e.g., 100p%) of the population.

Testing

Often, we do have a preconceived idea or educated guess regarding the random process under study. For example, previous experience may have established that a parameter (say the population mean μ) is equal to a given value (say μ_0). And we would like to verify whether the current process (or RV) under study maintains this value or has changed. In such cases we are dealing with a hypothesis testing situation.

We first find a suitable estimator (say, large sample average $\bar{x}$ for the population mean μ) of the parameter for which we have made the conjecture. Based on our conjecture that the true population mean is μ_0 (i.e., the null hypothesis H_0: $\mu = \mu_0$), we derive the large sample distribution of test statistic z (given in (1) above). Under H_0, z will be distributed Normal Standard. When the sample size n is small, the parent distribution is Normal and the variance σ^2 is unknown but estimated by s^2 from the (same) sample, the test statistic becomes (2) and its distribution under hypothesis H_0 is Student t, with n-1 d.f. We can also assume that the distribution of the life X of a device is Exp (θ). Then, under the null hypothesis H_0: MTTF = θ_0 statistic 2 x TTT/θ_0 is distributed as a Chi Square with 2n d.f. and can be used to test this hypothesis.

The objective of hypothesis testing is to decide, based upon the result of the test, whether our conjecture (as defined in the null hypothesis H_0) is reasonable. Two outcomes may occur. The value of the test statistic (e.g., z or TTT) may be "mainstream" within its null distribution. Alternatively, the test result may constitute a "rare event" according to the hypothesized null distribution (i.e., this result has a very low probability of occurrence, under H_0). In such case, one of two possibilities exists. First, our conjecture H_0 (null hypothesis) is incorrect. Secondly, that we have been terribly unlucky and that such rare event has occurred precisely to us (something that would happen, under H_0, at most with probability α). Hence, the best course of action is to reject H_0 in favor of the "alternative hypothesis" H_1 (the negation of the null; in this example $\mu \neq \mu_0$ or MTTF $\neq \theta_0$) and absorb a probability α of (Type I) error.

The probability α, "size of the test" or significance level is the error we commit if we take the above wrong decision. This probability also determines the critical value and the critical region of the test. There are two types of wrong decisions, called Type I and II errors: rejecting H_0 when it is true and accepting H_0 when it is false, respectively. The probability α of committing Type I error is 0.05, if we are prepared to reject H_0 when it is true (in the long run) at most once in twenty times. If this α is too high, we may want to reduce it to say, one in a hundred, or 0.01, etc. As with the c.i., we can reduce Type I error to zero by adopting the decision rule "always accept H_0". But then, we would be maximizing Type II error (rejecting H_1 when it is true).

Once the test hypotheses, the test statistic, its distribution under H_0 and the significance level α are all defined, we obtain the critical value(s) and critical region(s) for the test. For our first example, we pre-specify $\alpha = 0.05$ and divide it symmetrically into the two (upper/lower) tails. This procedure defines $z_{\alpha/2}$. Hence, for the first example, both critical values $z_{\alpha/2}$ will be (from the Normal Standard tables) 1.96 and -1.96. The two critical regions are the semi intervals from $z_{\alpha/2}$ up, and lower than $-z_{\alpha/2}$. The decision to reject H_0 is taken if the value z of test statistic (1) falls in either one of these two rejection or critical regions. In any other case, we cannot reject H_0 (and hence we will assume it is reasonable value).

For the second example, assume we are testing that MTTF = θ_0 by placing n = 10 devices on a life test (had we put n > 30, we could have applied the CLT results and the methods in the previous paragraph). Assume that we can also accept an error $\alpha = 0.05$. Since, under H_0 the test statistic 2 x TTT/θ_0 is distributed as a Chi Square with 2n = 2 x 10 = 20 d.f., the two $\chi^2(20)$ critical values (from the Chi Square table) will be: 9.591 and 34.17. To empirically verify this, simulate one sample of exactly 30 (borderline between the large and the small sample cases) Exp (30) variates. Then, obtain two 95% c.i. by using both the CLT and Chi Square approaches. The c.i. in both cases should be very close.

An Illustrative Comparison

Let's explain the hypothesis testing process with an example from the judicial system (Table 1). In the well-known case of O.J. Simpson, Judge Ito plays the role of the statistician (he directs the process and interprets the rules). There are two hypothesis. The null (assumed) is that the defendant is innocent. Its negation or alternative is that the defendant is guilty (which must be proven beyond reasonable doubt). The evidence is the data. The Jury, which evaluate the evidence (data), plays the role of the test statistic. The Jury then reaches one of two possible decisions. It can declare the defendant guilty (reject H_0) when the evidence overwhelmingly contradicts the assumed defendant's innocence (null hypothesis). Or the Jury can declare the defendant not guilty, if

Table 1. Illustration of the Hypothesis Testing Process

Justice System	Statistical Hypothesis Testing
Presiding Judge (Ito)	Statistician
Jury (of 12 peers)	Test Statistic (e.g., formula (1) in the text)
Jury Task: process the evidence	Statistic Task: synthesize the (data) information vector
Defendant (O.J. Simpson)	Parameter tested (e.g., population mean)
Verdicts (Not Guilty and Guilty). Always assume the null (Not Guilty) is true unless disproved by data (beyond reasonable doubt).	Hypothesis (null and alternative). Assume the Null to obtain the statistic distribution.
Does evidence (glove, DNA test, etc.) overwhelmingly contradict the assumed null hypothesis beyond reasonable doubt?	Does data collected and analyzed require that we reject the null hypothesis?
Decision: Acquit or convict a defendant.	Decision: Reject or not reject the null hypothesis .
Possible errors Type I error: Risk of convicting an innocent defendant Type II error: Risk of acquitting a guilty defendant	Possible errors Type I error: Reject the null when it is true Type II error: Accept the null when it is false

they cannot convince themselves beyond reasonable doubt that the defendant is guilty. The Jury can commit two types of errors. They can convict an innocent (reject the null when it is true, Type I error), or acquit a guilty person (Type II error). Like the statistician, those who work in the Judicial system would like to minimize the probability of either of these two possible errors.

There are two types of hypothesis tests: two sided (as the one discussed in the example above) and one sided. Often, we are not interested in the exact value of a parameter (say that the true population mean μ is exactly μ_0). Instead, we may want to test whether the mean μ is greater or smaller than a given value (say μ_0). In such case, the null hypothesis H_0 becomes: $\mu \geq \mu_0$ or $\mu \leq \mu_0$, accordingly. These hypothesis tests are called one-sided and have a single critical value and critical region.

From the above discussion, we can see that there is a one-to-one relation between two-sided hypothesis tests and the derivation of confidence intervals, and one-sided hypothesis tests and the derivation of confidence bounds. For example, for a given sample and significance level α, if a two-sided test for μ_0 rejects hypothesis H_0, then the corresponding $100(1-\alpha)\%$ c.i. for μ does not cover μ_0 and vice-versa.

Two widely used hypothesis tests performance measures are the p-value and the Power. They both serve to assess our test decision, when taken on a specific sample with a specific test. The p-value is the probability of rejecting the null hypothesis H_0 with a test statistic value, as extreme or even more extreme, than the value we have obtained from our sample. The Power of the test is the probability of rejecting H_0, with the test statistic value that we have obtained from our sample.

The above hypothesis testing situations can only be guaranteed if all test assumptions (i.e., statistic distribution under the null, independence and distribution of the raw data, etc.) are met. For example, the z-test (1) for the mean requires that the population variance is known. However, in some cases one or more test assumptions may be relaxed (to a certain point) and the test results are still acceptable. In these cases we say the test is robust to (violations of) such assumption. For example, the z-test is robust to the variance assumptions, since the substitution of the sample variance s^2 for the population variance σ^2 still yields an approximately Normal Standard distribution for statistic z in (1). The t-test is robust to mild non-normality of the data.

When a hypothesis test is invalidated by serious violations of its assumptions, one can still resort to other procedures, such as transformations of the raw data, or to the use of distribution free (non parametric) tests. By transforming the raw data we may obtain a better fit to a more suitable distribution, that fulfills the test assumptions. An example of this was shown with the above transformation $Y = 2X/\theta$, that allowed us to use the tabulated Chi Square, instead of the non-tabulated Gamma distribution, to test MTTF.

Distribution free tests are no longer bound to distribution assumptions (e.g., Normality) which are sometimes difficult to obtain from data, even after transformation. However, distribution free tests are usually less powerful than their parametric counterparts. For example, they do not reject H_0 when it is false, as often as their parametric counterparts do, or they need a larger sample size. There is a trade-off involved in test selection, and care must be exercised.

Finally, there are many more types of tests than we have discussed here. Since our objective is to provide an overview of the fundamentals of hypothesis testing, only a few simple cases of two-sided tests, for a single parameter were presented. The reader is pointed to references [4, 5 and 6] for further information and examples.

Summary and Conclusions

In our first article we looked at some problems associated with the distribution of a RV. We also said that, once the RV distribution and its associated parameters were known, we could answer all necessary questions and define the best strategy in dealing with such RV (or in other words, with taking the best decisions under uncertainty).

In practice, however, the distribution of the RV and its parameters are usually unknown. Hence, to achieve our objective (of answering questions and defining the best strategies), we need to first establish the distribution and then to "estimate" its parameters. In this article, we discussed parameter assessment in which we observe the random process (RV) under study and then use these observations (sample) to form the best educated guess regarding its unknown distribution and associated parameters. If, due to previous experience we already have some idea regarding such distribution and parameters, we conduct hypothesis test. If we have no idea and want to start constructing a framework of reference, we make an estimate.

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Industry News

ASQ and AQP Affiliate

Within the United States, two organizations have been leaders in advancing quality methods and practice. These organizations are the American Society for Quality (ASQ) and the Association for Quality and Participation (AQP). The agreement to form an affiliation was first announced at AQP's annual spring conference and membership meeting held in Chicago, IL in the spring of 2001.

Of the proposed affiliation, Jennifer Powell, president of AQP, said, "The collaboration and shared vision of these organizations make them both more important and dynamic, resulting in a broader range of services for members." Gregory H. Watson, president of ASQ, added, "We share a common vision—the advancement of excellence through quality at all levels, in all areas, whether individual, organizational or community. Working together toward our common goal ensures a healthy future for the quality movement in the United States and worldwide."

For information on ASQ and AQP, visit their web sites at <http://www.asq.org/> and <http://www.aqp.org>, respectively.

A Nuclear-powered Aircraft in Our Future?

An idea that was first considered and then rejected several decades ago as impractical is being raised anew. At the Cranfield College of Aeronautics in the United Kingdom, Ian Poll believes that nuclear power, as well as other alternative fuels, must be considered by the aerospace industry. Mr. Poll, who is the new President of the Royal Aeronautical Society, has said that, "The projected growth in air traffic worldwide for the next several years is expected to be 5-7% per annum. If that growth rate continues for 25 years, it would involve the trebling of current aviation consumption levels of kerosene. I believe it is time to consider all the alternatives, and one is the use of nuclear power."

The United States Air Force (USAF) looked into the use of nuclear power for aircraft in its Aircraft Nuclear Propulsion (ANP) program. In 1946, interest in atomic aircraft developed into a long-lived project known as NEPA, for Nuclear Energy for the Propulsion of Aircraft. The NEPA project was controlled by the USAF and was therefore oriented towards developing both an atomic-powered long-range strategic bomber and high-performance aircraft. In 1951, the joint Atomic Energy Commission/USAF ANP project replaced NEPA. Although some progress was made, the political and technical challenges proved too formidable and in 1961, after a decade of work, the program was canceled.

If the idea is to fare better this time around, safety and reliability will undoubtedly be critical factors, regardless of the promise of economic (less reliance on fossil fuels) and environmental (no atmospheric emissions) savings.

Concorde Flies Again

On 25 July 2000, at 4:42 p.m. local time (2:42 p.m. GMT), Air France flight AF4590 began its takeoff roll on runway 26 at Paris' Charles de Gaulle airport. Just moments later, the pilots knew that this was not to be just another flight. Just one minute and 13 seconds after being cleared for takeoff, controllers frantically radioed the aircraft crew "(flight) 4590, you have flames, you have flames behind you!"

As the crew desperately continued their efforts to save the aircraft, firefighters assembled on the ground. The last recorded

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Product Liability in the New Acquisition Environment: A Topic Requiring a Partnered Solution from the Military and Its Contractors

By: Raymond B. Biagini, McKenna & Cunco, L.L.P., Washington, DC

Massive changes in Government contracting methods are rapidly transforming the procurement environment and raising questions about the vitality of the Government contractor defense, which extends the Government's sovereign immunity to contractors doing the Government's work. The defense, first recognized by the Supreme Court in 1940 and clarified in Boyle v. United Technologies, 487 U.S. 500 (1988), insulates contractors from liability for third-party tort claims, provided the contractor complies with reasonably precise Government specifications and informs the Government of all risks known to it. In other words, a contractor that can prove that "the Government made me do it" can share in the Government's sovereign immunity.

The new procurement revolution is placing more responsibility on the shoulders of contractors, requiring them to rely on their own management decisions and design concepts, and shrinking the Government's "footprint" and involvement in these activities. The Department of Defense has canceled thousands of military specifications and military standards, some decades old. The Federal Acquisition Streamlining Act of 1994 and the Clinger-Cohen Act of 1996, combined with an organic revision of the Government's basic contracting documents, require contractors to develop their own processes to complete the Government's work, and to adopt a more managerial, discretionary role throughout contract performance.

Many of these changes have been sought by contractors for years to lower barriers to entry and make Government and defense contracting more like the commercial contracting world. However, the new regime also casts doubt on contractors' ability to enjoy the Government contractor defense's protection.

These radical changes raise the question: Will procurement reform be the death-knell of the Government contractor defense, ending the hard-won product liability protections afforded Government contractors based on the Government's historical close involvement in product decision and design? Or can the Government contractor defense be saved?

This article concludes that the effect of the new procurement regime on product liability must be a topic of mutual interest to government contractors and the military because to the extent contractors' liability increases because of a weakened government contractor defense, the Government's liability increases in the form of higher contract costs and, worst yet, a reduction in contractors willing to bid on high-risk programs. The article also concludes that with the stakes higher than ever before, a "partnered solution" between the military and its contractors, creating a "joint shield" to minimize product liability risks, is necessary. Specifically, this article urges that at the outset of a contract performed under acquisition reform, the contractor and military selectively build the Government contractor defense into "high risk" aspects of the program. This teaming approach honors the key hallmark of acquisition reform – the promotion of industry/Government partnerships to ensure "better, faster, cheaper" and safer weapon systems.

Government Contractor Defense Background

The history of the Government contractor defense illustrates the unusual (and largely unique) law of Government contractor product liability, and provides background for understanding how changes in the underpinnings of the law may affect all Government contractors.

The King Can Do No Wrong: Government contractors have always been tempting deep pockets when a Government product causes injury or death, largely because the contractors may be the only target in sight. The really big game — the Government — is often protected by sovereign immunity, the Anglo Saxon common law notion that "the king can do no wrong." In other words, unless the Government decides to allow itself to be sued, it has no liability for its actions.

Neither Congress nor the courts have been anxious to permit such suits. In 1948, Congress passed the Federal Tort Claims Act, which permitted some tort suits to be filed against the Government, but upheld immunity for "discretionary functions" performed by the Government. Shortly thereafter, the Supreme Court ruled in *Feres v. United States*, 340 U.S. 135 (1950) that the Government does not waive immunity when a soldier is killed or injured incident to military service, since such suits would undermine military discipline, circumvent statutory remedies for soldiers, and insert the judiciary into discretionary Executive Branch decisions. This logic was largely repeated in *Stencel Aero Engineering Corp. v. United States*, 431 U.S. 666 (1970), in which the Supreme Court ruled that Government contractors sued by soldiers injured in service cannot sue the United States to recover damages paid, since such suits would "judicially admit at the back door that which has been legislatively turned away at the front door."

Even more recently, the Supreme Court ruled in *Hercules Inc. v. United States*, 116 S. Ct. 981 (1996) that Agent Orange manufacturers that paid $180 million to settle lawsuits brought by Vietnam veterans and their families claiming Agent Orange exposure maladies cannot recover litigation expenses and settlement costs from the Government. Thus, if a contractor is sued in tort and chooses to settle to avoid the expense and uncertainly of litigation, its partner, the United States, will be sitting firmly on its wallet when the bill arrives. When a soldier or civilian defense employee is injured or killed by a Government product, the contractors are often the only players left at the table.

The Beginnings Of the Contractor Defense: Into this uncertain mix of judicial hostility to direct negligence claims against the Government comes the Government contractor defense, built on the logic of sovereign immunity, and further shaped by the restrictive rules in *Feres, Stencel Aero,* and *Hercules*. The Supreme Court first addressed derivative immunity for contractors in *Yearsley v. W.A. Ross Const. Co.*, 309 U.S. 18 (1940), holding that a contractor could not be held liable for riparian damages caused in its execution of a dredging contract. In a statement that presaged the development of the modern Government contractor defense, the Court said that there was "no liability on the part of the contractor for executing [the Government's] will." Therefore, according to the *Yearsley* decision, if the Government told you to do it, and you did it right, there should be no contractor liability. If the contractor acts as the Government's arm, it should also be entitled to the Government's shield.

The *Yearsley* decision was followed by decades of conflicting lower court opinions that appeared to undermine that decision's logic. Indeed, in the Agent Orange litigation referred to above, the trial court issued conflicting decisions on whether the contractor defense would bar contractor liability, and the Government argued that the defense did not preclude third party tort claims against contractors. Compare *In re Agent Orange Prod. Liab. Litigation*, 597 F. Supp. 740, 749 (E.D.N.Y. 1984) (court finds contractors faced with "a possibility of an ultimate liability with claims totaling billions of dollars") with *In re Agent Orange Prod. Liab. Litigation*, 611 F. Supp. 1223, 1263-64 (E.D.N.Y. 1985), aff'd 818 F.2d 145 (2d Cir. 1987), *cert. denied* 487 U.S. 1234 (1988) (same court dismisses "opt out" claims based on Government contractor defense). Then came the Supreme Court's decision in *Boyle, supra*.

Boyle and the Modern Government Contractor Defense: In 1988, the Supreme Court cleared up much confusion with its landmark decision in *Boyle*. In that case, the Supreme Court considered whether a manufacturer of a helicopter could be liable in the death of a Marine Corps officer when his helicopter crashed off the coast of Virginia Beach. The survivors and estate of the Marine pilot alleged that the doors of the helicopter (which opened outward, rather than inward) were negligently designed, permitting water pressure to trap the soldier in his sinking aircraft.

After considering the public policy reasons for exempting Government contractors for product liability to third parties, the Court held that a contractor manufacturing products for the Government is not liable in tort to third parties if (1) the Government approved reasonably precise specifications; (2) the equipment conformed to those specifications; and (3) the supplier warned the Government about the dangers in the use of the equipment that were known to the supplier but not to the Government. The rationale for this common law defense is that the Government enjoys immunity from tort suits when it exercises its discretion in the design and acquisition of military products. The Supreme Court reasoned that a contractor implementing the Government's discretion is effectively an agent of the Government, not an independent operator, and thus should also be protected. Likewise, the Government contractor defense prevents Government procurement decisions from judicial second-guessing, and it avoids passing product liability costs to the Government in the form of increased contract prices.

Key Legal Battlegrounds: Although the *Boyle* decision clarified the existence and application of the Government contractor defense, it also left unanswered a number of critical questions. While a full discussion of these issues is beyond the scope of this article, some are identified in (1) – (3) below to illustrate the importance of advance planning to develop and maintain evidence to maintain the defense.

(1) "Approval of reasonably precise" specifications. The level of evidence necessary to show that the Government "approved" "reasonably precise specifications" has been hotly litigated. The trend in the case law is that a contractor need show only Government approval of the overall product design, and that "the Government need not deprive the manufacturer of all discretion pertaining to a particular design feature in order for the Government contractor defense to apply." *Carley v. Wheeled Coach*, 991 F.2d 1117, 1125 (3rd Cir.), *cert. denied*, 510 U.S. 686 (1993), 35 GC ¶ 324. *See also Stout v. Borg-Warner Corp.*, 933 F.2d 331, 336 (5th Cir.), *cert. denied*, 502 U.S. 981 (1991) (contractor need not show prohibition against incorporation of safety device for defense to apply); *Boyle*, 487 U.S. at 512 (contractor must show only that the design was "considered by a Government officer, and not merely by the contractor itself"). Further, an emerging trend on the issue of "approval" is that evidence of long-term Government use of a product, where the Government is aware of the alleged design flaws, establishes Government design approval. *See Ramey v. Martin-Baker Aircraft Co.*, 874 F.2d 946, 950-51 (4th Cir. 1989), 35 GC ¶ 274 (note) (Government's continued use of equipment after learning of potential design problem constitutes approval).

(2) Proving conformance with Government specifications**.** Regarding the second prong of the Government contractor defense, (i.e., conformance with specifications), courts have found DD250's issued by the military, in-process Government inspections and final acceptance testing, and Government approval of the contractors manufacturing, quality control, and assembly systems sufficient to prove the defense. The key dispute is whether proof of conformance with the Government requirements negates allegations that a manufacturing defect occurred. Several courts have ruled that it does. *See Zinck v. ITT Corp. v. ITT Corp.*, 690 F. Supp. 1331, 1334-35 (S.D.N.Y. 1988); *Harduvel v. General Dynamics Corp.*, 878 F.2d 1311, 1316, 1320 (11th Cir. 1989). If the defect is of a recurrent nature, common

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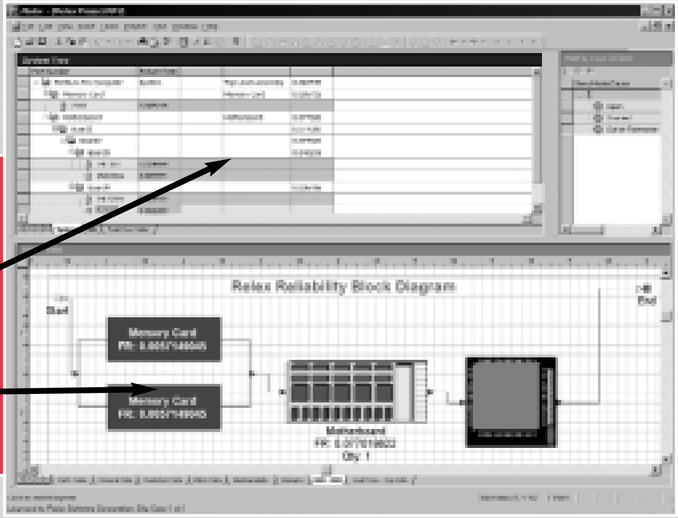

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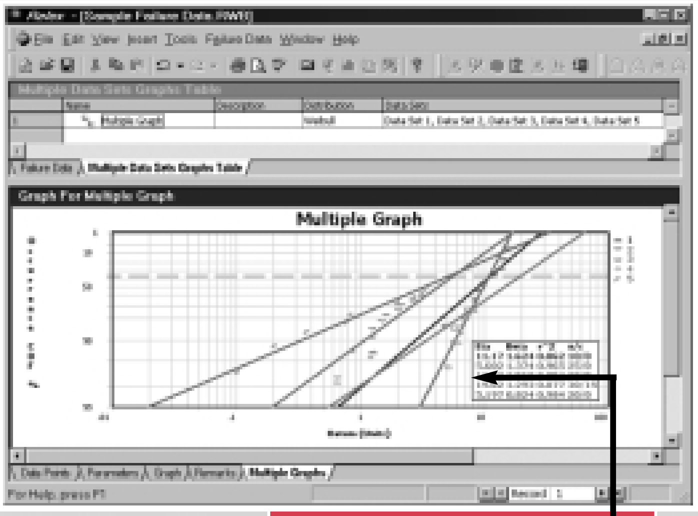

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to similar products, the courts are likely to conclude that it is a design weakness, not a manufacturing flaw, and they will apply the Government contractor defense.

(3) Duty to warn. Another battleground relates to the standard of proof necessary to show that the Government contractor defense defeats a failure to warn claim. There is a split in the U.S. Courts of Appeals on this issue. The Second, Ninth, and Eleventh Circuits found in a trio of cases involving asbestos suppliers that the defense will apply in failure to warn cases only if the contractor can show that the Government affirmatively prohibited warnings beyond those specified in the contract. See *In re Hawaii Federal Asbestos Cases,* 960 F.2d 806, 812-13 (9th Cir. 1992), 35 GC ¶ 96 (note) (Government must affirmatively prohibit warnings); *Dorse v. Eagle Picher Industries,* 898 F.2d 1487, 1489 (11th Cir. 1990) (Government must impose a "prohibition against health warnings"); *In re Joint Eastern-Southern District New York Asbestos Litigation,* 897 F.2d 626, 630-33 (2d Cir. 1990) (Government must dictate content of warnings). By contrast, the Sixth and Seventh Circuits have held that the defense defeats a failure to warn claim as long as the contractor can demonstrate that the Government exercised some discretion over the warnings. *Tate v. Boeing Helicopters*, 55 F.3d 1150, 1157 (6th Cir. 1995), 37 GC ¶ 410; *Oliver v. Oshkosh Truck Corp.*, 96 F.3d 992, 1003 (7th Cir. 1996), *cert. denied*, 65 U.S.L.W. 3625 (U.S. Mar. 17, 1997).

A further issue under the third prong of the Government contractor defense is whether the contractor has a *continuing* duty to warn of alleged dangers following contract performance. Few courts have addressed this issue. The Supreme Court of Washington in *Timberline Air Serv. v. Bell Helicopter-Textron, Inc.*, 884 P.2d 920 (Wash. 1994), found that a state statute imposed a continuing duty to warn after delivery of the product even where the accident arose from commercial use of military hardware. By contrast, two U.S. District Courts have found that the cut-off point for measuring the contractor's knowledge for purposes of the Government contractor defense is at the completion of contract performance or Government acceptance of the product. *Hendrix v. Bell Helicopter-Textron Inc.*, 634 F. Supp. 1551, 1557 (N.D. Tex. 1986); *Niemann v. McDonnell Douglas Corp.*, 721 F. Supp. 1019, 1028 (S.D. Ill. 1989).

A post-delivery duty to warn should not often apply to a Government contractor where the Government assumes or maintains control over the product. In a commercial setting, where the user typically does not possess the same level of expertise in the repair, retrofit or maintenance of a product as does the manufacturer, imposing such a duty might be appropriate. By contrast, where the Government assumes control over a product, it effectively displaces the contractor as the entity which is responsible for the operation and repair of the product, and the contractor (which may have been required to give all data and records to the Government) should have no further responsibility unless it takes on a contractual obligation to do so.

Impact of Recent Procurement Changes

The ground supporting the Government contractor defense began to shift in June 1994, when Defense Secretary Perry issued a memorandum entitled "Specifications and Standards," which directed a change in Pentagon procurement policy to promote performance rather than design specifications in Government contracting. His goal, which the Pentagon has pursued ever since, was to bring more commercial practices to the defense industry. Since that time, FASA and the Clinger-Cohen Act have created preferences for commercial items in federal procurement. The Pentagon has rewritten its organic procurement procedures, including DoD Regulation 5000.2-R, which states that there is to be a "minimum volume of mandatory guidance" and an emphasis on the use of "customary commercial practices." Additionally, Regulation 5000.2-R mandates that Government-unique requirements are to be replaced with "common, facility-wide systems," and that contractors are permitted to use their own "preferred quality management process" and "best practices" in production of Government goods.

What do these changes mean for the contractor? In many ways, the news is good, as contractors can develop systems and processes that are most efficient. Unfortunately, the organic changes in development also create an increased risk of product liability. That is because the reform process, which focuses on minimizing mandatory Government control over the procurement process, also diminishes Government involvement in product design. Courts, which over decades have developed protections for Government contractors, have based this protection on the rationale that a contractor was following direct Government orders. The procurement revolution of the last two years diminishes this rationale, as contractors are given fewer and fewer guidelines and more and more discretion.

Preserving Contractor Defenses in the New Environment

Unlike their commercial counterparts, Government contractors historically have not taken an active interest in product liability issues. Most contractors have little product liability planning in place that will assist them in preparing for the new era in Government contracting. Therefore, it is advisable for contractors to focus on the product liability issues that arise in the new procurement environment, so that opportunities to preserve the Government contractor defense are not lost. In short, contractors should team with the military at the outset of an acquisition reform contract to build the Government contract defense selectively into the program in key "high risk" areas to create a retrievable recovery should a tort suit arise later. This effort will not only enhance the contractors' ability to assert the Government contractor defense but will assist the military in its assertion of it discretionary function exception if it is sued in tort.

Keeping the Government Involved: The first and foremost priority for Government contractors is to keep the Government involved. It is imperative to create as significant a Government footprint as possible by aggressively utilizing the new mechanisms available to contractors. For example, newly-rewritten DoD Regulation 5000.2-R establishes a teaming arrangement with the Government which can help to maintain contractor protections.

Among the many new mechanisms available to contractors to keep the Government involved are:

(1) *Concept Papers,* which are used to obtain Government review and approval of new procedures. Such procedures should be described in sufficient detail to constitute "reasonably precise specifications" and should include an identification of hazards associated with the proposed procedures.

(2) *Integrated Product Teams,* which are used to establish the "back-and-forth" exchange of design information between the Government and the contractor, so as to have evidence of meaningful Government review and approval of reasonably precise specifications.

(3) *Four Milestone Acquisition Procedures,* which are used to obtain information relevant to the Government contractor defense. DoD Regulation 5000.2-R provides that for major defense acquisition programs the four milestones consist of obtaining approval to (a) conduct concept studies, (b) begin a new acquisition program, (c) enter engineering and manufacturing development, and (d) produce or field/deploy equipment.

(4) *Component Acquisition Executive,* meaning Government employees who review and determine the final disposition of all safety hazards and establish acceptable risk levels. Executive approval should be sought by the contractor to ensure Government review and resolution of all identified safety hazards. Such information is directly relevant to the third prong of the Government contractor defense.

Contractors should strive, through these new mechanisms, to have all important manufacturing and design processes approved by the Government. These processes should also be reviewed for content, i.e., did they describe in sufficient detail the proposed processes and did they identify associated hazards? At the same time, contractors should establish protocols addressing the gathering of key evidence to ensure that all Government approvals are documented, and to avoid harmful admissions.

Establishing a Product Liability Prevention Program

The goal of limiting third party product liability can best be addressed by establishing a formal product liability prevention program. The purpose of such a program is to provide training to raise employee knowledge and awareness, and to provide structures to ensure appropriate evidence of Government approval is created and retained for each product, from "cradle to grave." Key personnel such as members of the integrated products team, authors of concept papers, members of the management council and safety engineers must identify and document potential liability issues from the ground up so as to maximize the application of Government contractor defense. A well-executed prevention program must also ensure that contractors develop products and services which incorporate reasonable measures to prevent accidental injuries and illnesses to customers or damage to the environment. A fully operational prevention program must focus not only on maximizing the specialized Government contractor defenses but also ensuring that general defenses to product liability claims are preserved.

In sum, acquisition reform, like all revolutions, creates new risks, but also brings new opportunities. A true partnership between the military and its contractors can establish a joint shield to product liabilities that will arise from performance of Government contracts. Vigilant contractors and military personnel must exploit the many opportunities presented in the new contracting environment to minimize product liability.

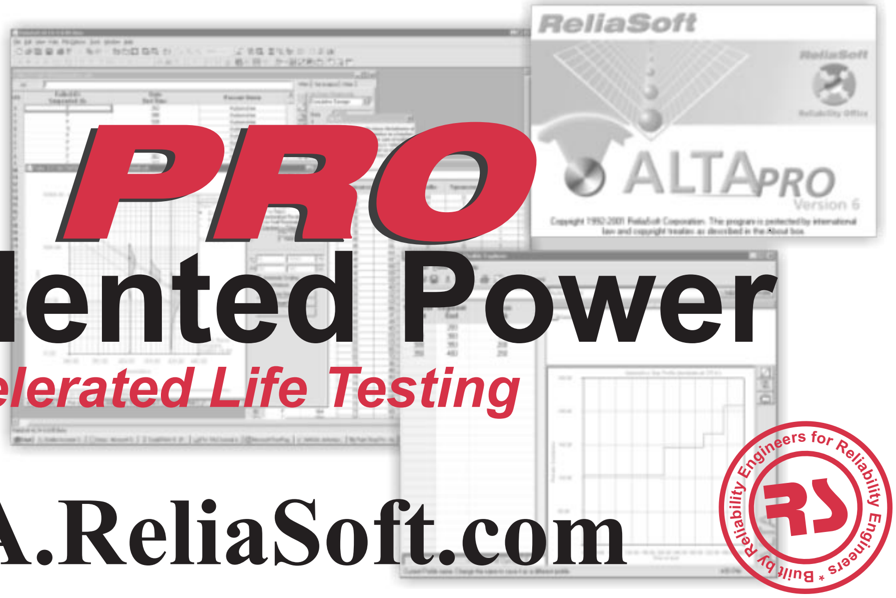
About the Author


Raymond Biagini

Raymond Biagini is a partner in McKenna & Cuneo's Washington, DC office. He joined the firm in 1980 and is a member of the firm's Management Committee. Mr. Biagini's practice focuses on product liability litigation, and he has substantial trial and litigation experience. As a leader of the firm's product liability/toxic tort practice, he has defended manufacturers of Agent Orange, asbestos, radiation equipment and pesticides in federal and state product liability cases. He also lectures and authors articles in the areas of products liability/toxic torts, and provides seminars on minimizing a manufacturer's product liability risks.

Mr. Biagini has broad litigation and counseling experience in government contracting matters, including contract formation, performance, subcontracting, claims preparation and negotiation, defective pricing litigation, and privatization. He also has substantial experience in the defense of complex white collar procurement fraud investigations.

Mr. Biagini was a law clerk to the Honorable Phillip Nichols, U.S. Court of Appeals for the Federal Circuit. He received his J.D. in 1979 from the University of Notre Dame where he was a Thomas J. White Scholar and a member of the Center for Constitutional Studies.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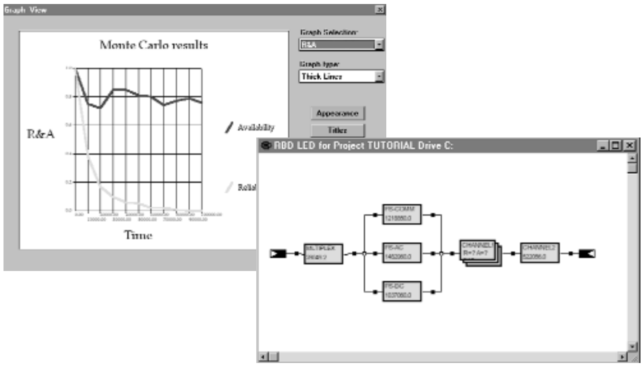

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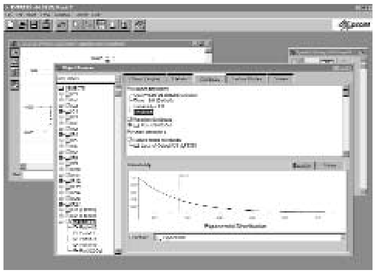

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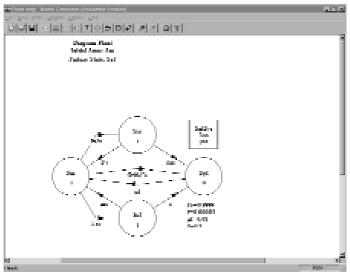

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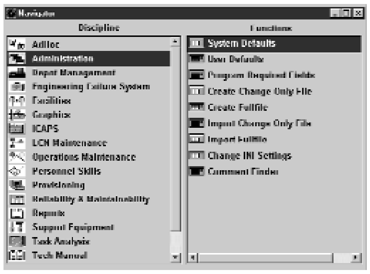

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Industry News

(continued from page 9)

words from the plane came from co-pilot Jean Marcot: “Negative, we’re trying Le Bourget.” But their skill and experience could not overcome the severe damage to the aircraft. The crew was unable to gain height or increase speed and could not retract the undercarriage.

Seconds later, the plane hit the ground near the town of Gonesse, plowing through a small hotel. In all, 109 passengers and crew were killed, together with four people on the ground.

For almost a full year, 12 Concordes owned by British Air and Air France sat on the ground while experts first tried to understand what had caused the accident and then to decide if and how the Concorde would ever fly again.

On January 18, 2001, just six months after the tragedy at Charles de Gaulle, an Air France Concorde did fly. But the flight was more symbolic than anything. It made a control flight from Paris and back at subsonic speed in advance of flying to southern France for a series of tests and to have new tires fitted.

On July 17, 2001, the Concorde took a big step closer to resuming service after British Airways completed its first supersonic test flight of the aircraft since the Air France crash. During the three-hour and 20-minute flight, the test pilot, Capt. Mike Bannister, took the plane out over the Atlantic Ocean after leaving from London’s Heathrow airport at 2:18 p.m. GMT. British Air Concorde did fly.

Engineers had made several key modifications to the test aircraft specifically aimed at preventing the type of accident that befell AF4590. These are:

- Addition of flexible liners of Viton, a heat-resistant rubberized sealant, and Kevlar to protect the fuel tanks.
- New tires. At the request of European Aeronautic Defence and Space (EADS), one of Concorde’s developers, Michelin has developed a new tire technology for Concorde, the radial NZG, banded with Aramid, a composite similar to Kevlar. This new aircraft tire technology, christened NZG for “Near Zero Growth,” offers higher damage resistance than the previous tire.
- Braided stainless steel and Teflon “armoring” of electrical leads on the undercarriage. The armoring helps ensure the leads will survive a blown tire and will not ignite any fuel that does leak out of the wing.
- Armored hydraulic lines. The hydraulic lines that deploy the H undercarriage have also been armored against blown tires, since the aircraft cannot land on its belly.

The British Air Concorde fleet has been undergoing a £17m ($24 million) safety overhaul since the Air France crash.

NEWS

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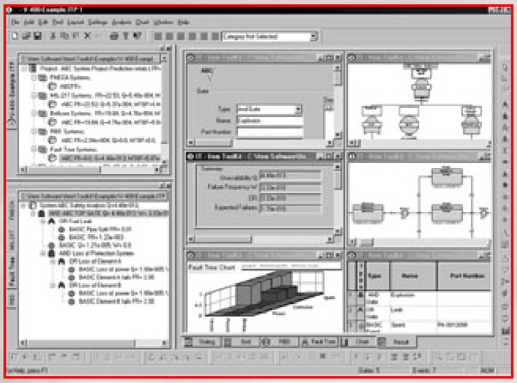

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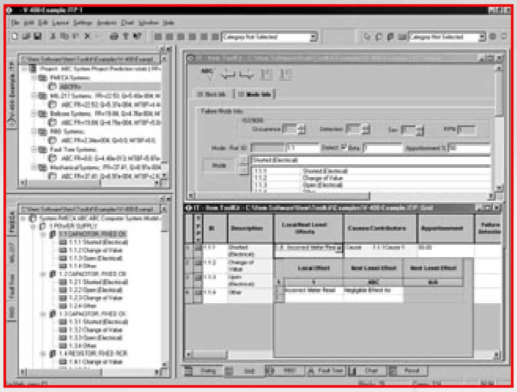

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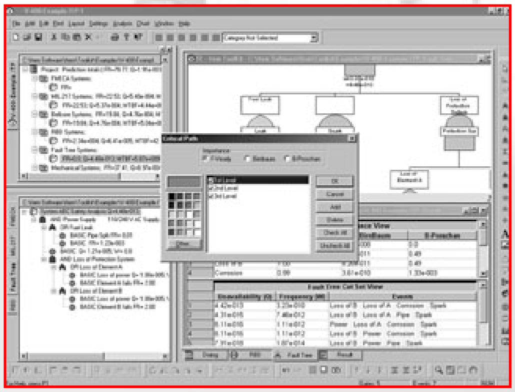

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4th Annual Systems Engineering & Supportability Conference

October 22-25, 2001
Dallas, TX
Contact: Phyllis Edmonson
National Defense Industrial Assoc.
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Fax: (703) 522-1885
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On the Web: <http://www.asminternational.org/content/Conferences_Expos/ASMConference_ExpoCalendar/istfa.htm>

39th Annual Reliability Engineering & Management Institute

November 12-15, 2001
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Contact: Dr. Dimitri Kececioglu
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From the Editor

Ned H. Criscimagna

Meaningful Measures

In one of a myriad of journals, newsletters, and magazines I read, I found an article that considers the six-sigma approach as a wasteful and questionable practice. The main point of the article is, however, not the subject of my editorial (for those interested, the article appeared on page 5 of the January 2001 issue of the Quality Connection, the Official Newsletter of the Baltimore Section, ASQ). Instead, I would like to focus on one issue raised by the author in the article – the basis of measurement or comparison.

In the article, the author points out that by judicious selection of the basis of measurement when calculating an improvement index, one can decrease the numerator or increase the denominator. The result is an "improved" improvement index, even though nothing has really improved. As an example, the author cites how the safety of air travel is most often compared with that of automobile safety. In this case, safety measures are usually stated in terms of incidents per mile traveled. So, for example, if a safety incident occurs every 5,000 miles for automobile travel and every 100,000 miles for airline travel, we are prone to claim that traveling by air is 20 times safer than traveling by automobile.

On its web site, Boeing states that "In 1998, the world's commercial jet airlines carried approximately 1.3 billion people on 18 million flights while suffering only 10 fatal accidents. . . . In the United States, it's 22 times safer flying in a commercial jet than traveling by car, according to a 1993-95 study by the U.S. National Safety Council comparing accident fatalities per million passenger-miles traveled. The number of U.S. highway deaths in a typical six-month period — about 21,000 - roughly equals all commercial jet fatalities worldwide since the dawn of jet aviation four decades ago. . . ."

The obvious question is, of course, whether or not passenger miles traveled is the best measure of risk exposure. What are our alternatives? We could use the number of trips. From Table 1 (the table is based on information from the WWW at: <http://www.safe-skies.com/safety_by_the_numbers.htm>), airlines had 0.0432 fatal accidents per 100,000 departures in the U.S. Correspondingly, in 1993 (figures could not be found for later years), 3 trillion passenger miles were driven in the U.S. alone. Using the death rate for automobile accidents cited by Boeing of 21,000 per six months, about 42,000 people were killed in the course of those 3 trillion miles, a rate of 23 fatal accidents per million passenger miles. If we assume 50 passenger miles per trip, then the rate was 23 fatal accidents per 20,000 trips or one per 870 trips. On that basis, airline travel looks considerably safer than when passenger miles were used.

Other ways in which airline safety is measured are shown in the Table 1.

Table 1. Fatal Airline Accident Rates for 1982-1999

Per 100,000 Flight Hours	Per Million Miles	Per 100,000 Departures
0.0299	0.00074	0.0432

From the same site on which I found Table 1, I learned that the average number of passengers killed in all airline accidents from 1988-1997 was 54. If this average number of deaths were used in Table 1 instead of the number of accidents, Table 2 would result.

Table 2. Airline Fatality Rates for 1982-1999

Per 100,000 Flight Hours	Per Million Miles	Per 100,000 Departures
1.6146	0.03996	2.3328

What if we use total fatalities (vice accidents) and the number of hours (vice flights or miles) that a passenger is exposed to the risk of a safety incident as our basis of comparison? For airlines, from Table 2, that figure is 1.6146 fatalities per 100,000 flying hours. Using the previous figure of 23 fatalities per million passenger miles for automobiles, and assuming an average speed of 45 miles per hour, the fatality rate for autos is 103.5 fatalities per 100,000 driving hours. On the basis of hours of exposure, air travel is 64 times (103.5/1.6146) safer than auto travel.

All of these statistics, regardless of the basis of measure, show that airline travel is much safer than automobile travel. But changing the basis of measurement may have decidedly different results for other comparisons. The point of going through all of these statistics is to emphasize that we do have to be very careful in selecting the most appropriate basis for measurement in using statistics in our work. It is too easy and tempting for us to use statistics in a way that shows our product or program in the best light. Our critics, on the other hand, can always do the reverse and find a way to use the numbers to make us look bad. After all, according to an overused adage, figures don't lie, but liars can figure!

Correction: On page 7 of the Second Quarter 2001 issue of the Journal, the E-mail address given for Mr. Alazel Jackson [Finding Answers to Space Industry's Top 10 Reliability Problems] is incorrect. His correct E-mail address is <Jacksona@jps.net>. We apologize for the error.

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