CALIBRATION INTERVALS, A MANUFACTURER'S PERSPECTIVE

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Abstract - The analysis tools that are currently available for Calibration Intervals focus on setting intervals to achieve a desired reliability target. This paper suggests there is another perspective that these tools do not currently address; consequence cost or accumulated liability. A case is made that sometimes the reliability target is a secondary consideration to managing this consequence cost. The paper also addresses how manufacturers establish calibration intervals. The paper presents, and defends, the practice of using no analysis whatsoever in establishing the manufacturer's recommended calibration interval.

INTRODUCTION

Documentary standards such as ANSI/NCSL Z540 and ISO/IEC 17025 prescribe that measuring and test equipment needs to be calibrated at regular intervals as part of a quality assurance program. The most frequently used calibration interval is one year, the manufacturer's most commonly recommended calibration interval for precision test equipment. It is implausible that an interval of 1 year is optimum for so many users of so many types of equipment. Some owners of large quantities of test equipment in military and aerospace use advanced models to manage calibration intervals but most users do not use these tools.

There are several reasons simplistic methods are used to establish calibration intervals when quite sophisticated methods are available:

- Some consider the tools too complex.
- Some adopt the manufacturer's recommendation without a great deal of analysis.
- Some consider the risk analysis tools incomplete for their needs.

It is mainly the third objection this paper addresses. However, the second point will be briefly considered first.

MANUFACTURER'S RECOMMENDED INTERVALS

Is it credible that most recommended calibration intervals are one year? One would think if the manufacturers were truly analyzing calibration intervals for their products, there would be more variation in published intervals. This author defends manufacturer's recommendation of the one year interval, contending that it is the result of the design community being given the target one year specifications as a design goal. However, because of the variability in the performance of individual instruments and the stress to which they are subjected, individual product reliability is very difficult to predict.

RELIABILITY TARGET

It is to this difficult task the metrology academic community has applied itself for the past decade or two. The result has been analyses and models that can describe the reliability function with much more precision than previously was thought possible. The goal is to estimate the in-tolerance reliability, P_{intol}, as a function of the calibration interval, T. This relationship is illustrated in Eq. 1 and Figure 1. This paper uses a simple

Eq. 1 $$P_{Intol} = f(T)$$ **Eq. 2** $$P_{Intol} = e^{-\lambda T}$$

exponential reliability model, Eq. 2, to describe the relationship between the reliability target P_{intol}, and the calibration interval. λ is the daily failure rate, the inverse of the mean time between failures (MTBF) stated in days. This model was chosen for illustrative purposes and is not intended to depreciate others' valuable efforts to describe the function of Eq. 1 and the corresponding equation that solves for the optimum calibration interval given a reliability target. Using this approach, the user states his target reliability and the function is solved for the optimum calibration interval, T. For the reliability function shown in Figure 1, if the reliability target is 70%, the calibration interval should be approximately 1 year. However, if a reliability of 85% is desired, a six month interval should be chosen.

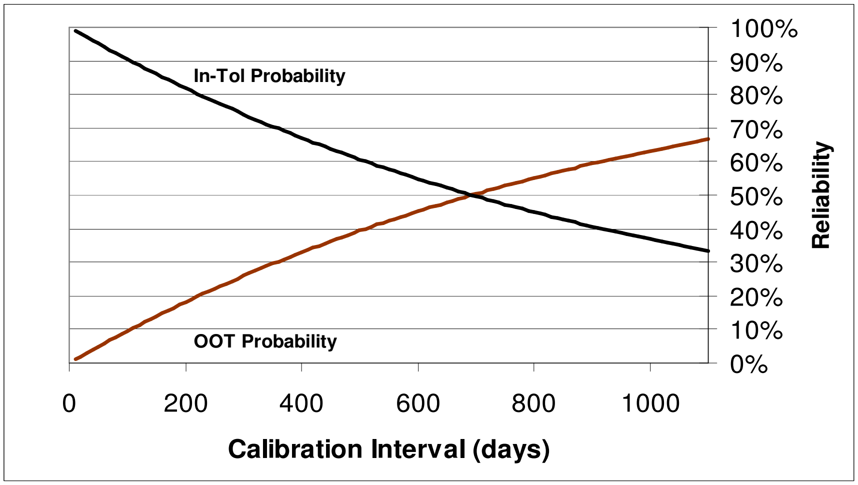

Figure 1 Exponential Reliability Model

It is recognized that different circumstances call for considerably different reliability targets. Here the burden is put on the user. How does the user know what reliability target to choose? This is a critical decision and one where the academic community has given far less guidance. Fluke Corporation has traditionally chosen a very high reliability target of 95%for the equipment used in its factories and Service Centers. The goal has been achieved, and significantly exceeded, as shown in Figure 2. But is it appropriate and cost effective to set the target this high? Could calibration costs be reduced by lengthening calibration intervals?

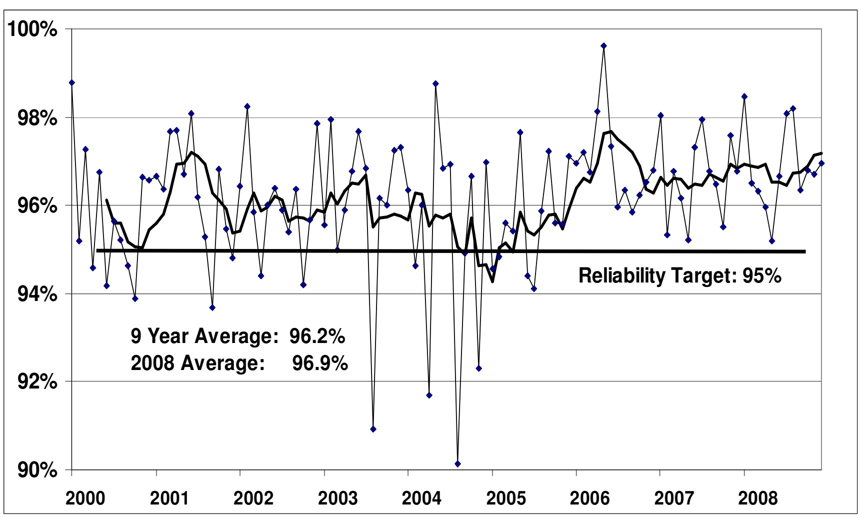

Figure 2 Fluke Reliability Target and P_{intol}

COST MODEL

In this section, a cost model in conjunction with the reliability model, is proposed as an improved means of optimizing the calibration interval. It begins with the concept of accumulated liability. The consequences of an out-of-tolerance condition for the calibration standards grows with time. Longer calibration intervals have a higher consequence cost associated with a given standard because more calibrations have been performed before it is re-calibrated and found to be in-tolerance or out-of-tolerance. Consequence costs may include a reverse traceability analysis to identify the items that have been calibrated by the standard, an investigation of the impact on their performance given the magnitude of the standard's out-of-tolerance, customer notification, suspension of accreditation, product recall and intangible factors such as the lab's reputation. For this paper, a very simple model is assumed; a linear accumulation of consequence cost with time as shown in Figure 3. The Liability Exposure is this accumulated cost multiplied by the probability of an out-of-tolerance condition. The total annualized cost, S, is the sum of the annualized calibration cost plus the liability exposure due to the accumulated liability. The calibration cost includes the cost of the calibration itself, the loss of the use of the standard while it is removed from service for calibration, spares that may be maintained as replacements during the calibration of the standard and any other appropriate costs. Eq. 3-5 describe these costs for the models chosen for this paper.

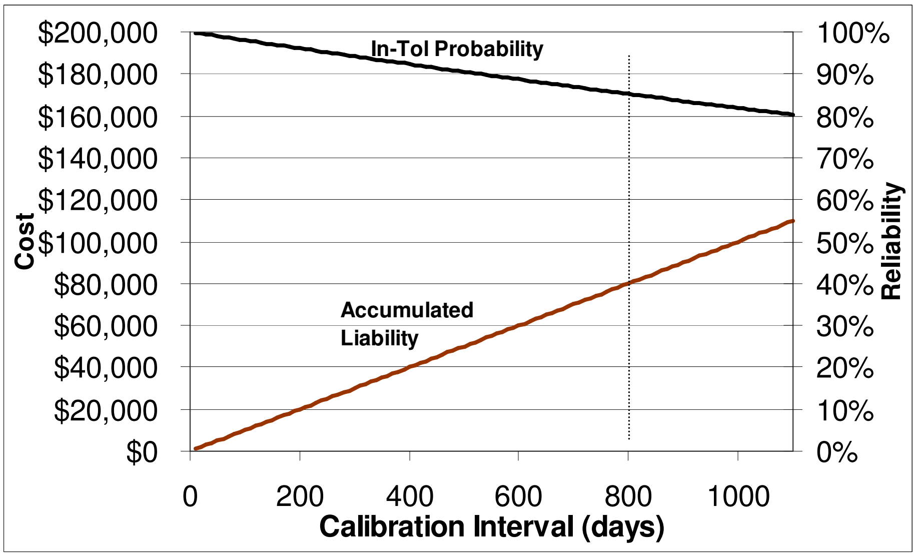

Figure 3 Reliability and Accumulated Liability

Eq. 3 $$S = CalCost + LiabilityExposure$$

Eq. 4 $$S = \frac{365}{T} \bullet (C + L \bullet P_{OOT})$$

Eq. 5 $$S = \frac{365}{T} \bullet [C + lT \bullet (1 - e^{-\lambda T})]$$

where,
C = Cal Cost
Poot = Out-of-Tolerance Probability
T = Cal Interval (days)
l = Liability Accumulated Daily
L = lT = Accumulated Liability during the Cal Interval

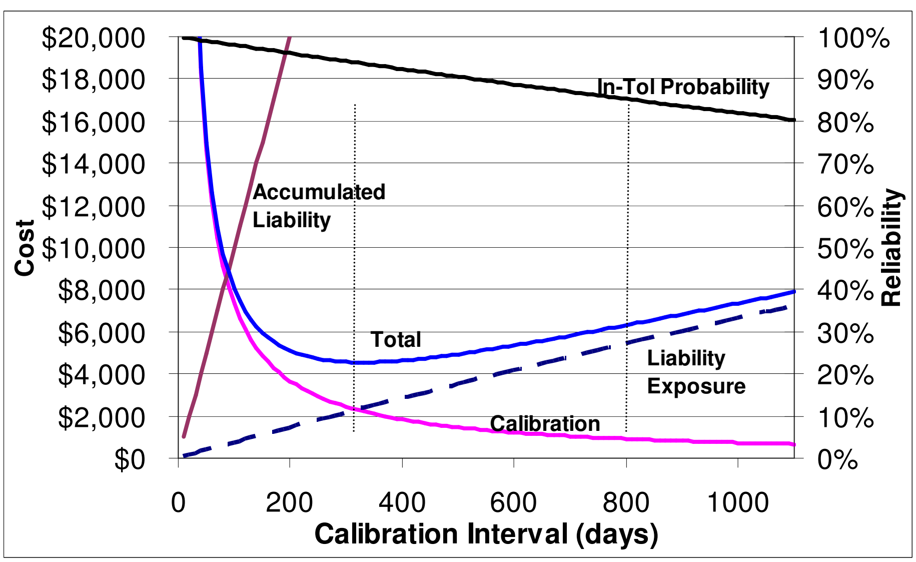

Figure 4 Total Cal & Liability Cost ($100/day Liability Accumulation)

Figure 4 shows the individual cost components of Eq. 5 and the total cost, S. If the calibration interval is too short, calibration costs dominate. If the interval is long, the liability costs dominate. The optimum cal interval is the interval for which the sum of the cal costs and liability costs are minimum. This can be calculated by differentiating Eq. 5 resulting in Eq. 6, and setting the derivative equal to zero. The optimum interval is the one which satisfies Eq. 7.

Eq. 6 $$\frac{dS}{dT} = 365 \bullet [-\frac{C}{T^2} + l\lambda e^{-\lambda T}]$$

Eq. 7 $$For \frac{dS}{dT} = 0, C = l\lambda T^2 e^{-\lambda T}$$

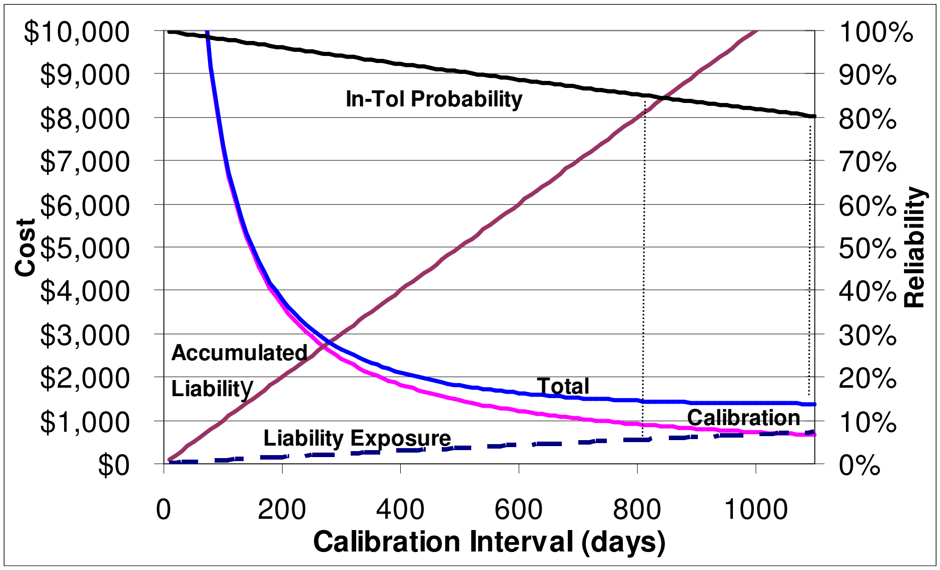

Figure 5 Total Cal & Liability Cost ($10/day Liability Accumulation)

Eq. 7 is not easily solved in closed form but can easily be solved numerically. For this paper, the solve function of Excel® was used to compute the optimum calibration interval at 327 days, approximately 1 year, corresponding to an in-tolerance probability of about 93%. If we had arbitrarily chosen a reliability target of 85%, we would have chosen a calibration interval of 800 days (2.2 years) which would not have optimized the cost model.

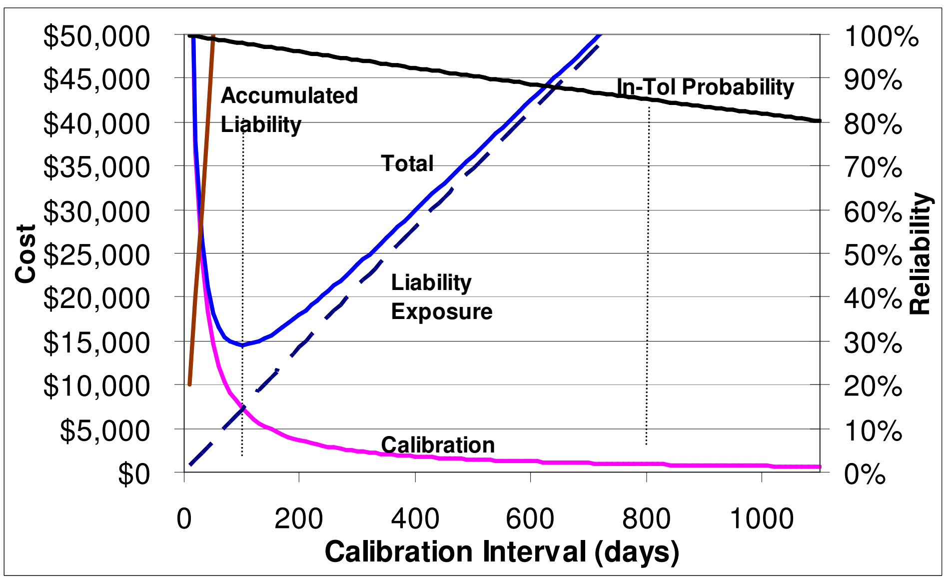

Figure 6 Total Cal & Liability Cost ($1000/day Liability Accumulation)

Figure 5 shows the curves for a daily liability accumulation of $10/day. The optimum calibration interval in this case would be about 3 years.

Figure 6 considers the situation where liability accumulates at the rate of $1000 per day. The optimum calibration interval for this example would be about 90 days.

All three of these examples use the same reliability model but yield optimum calibration intervals of 90 days, 1 year and 3 years when combined with different rates of liability accumulation.

The optimum calibration intervals calculated for the examples in Figures 4-6 are summarized in Table 1.

Liability/Day	Cal Interval	Pintol
$10	3 Years	80%
$100	1 Year	93%
$1000	90 Days	98%

Table 1 Summary of Optimum Calibration Intervals for Three Liability Accumulation Rates

INSURANCE MODEL

It may be advisable for some users to calibrate more often than the cost optimization model would suggest. This is for cases when an insurance model more accurately describes the lab's situation. Figure 7 illustrates that the accumulated liability is zeroed each time a calibration is performed and that longer calibration intervals result in larger maximum liability accumulations. The illustration is for the $100/day accumulated liability example. If we had chosen the 800 day interval corresponding to an 85% P_{intol}, $80,000 of liability would have been accumulated during the calibration period. The Liability Exposure is $80k x 0.15 or $12,000. However, at the end of the interval, the result is either zero or $80,000. For some laboratories, the consequences of incurring such an expense may severely impact the laboratory for a long time or even result in bankruptcy. In such cases, insurance may be warranted.

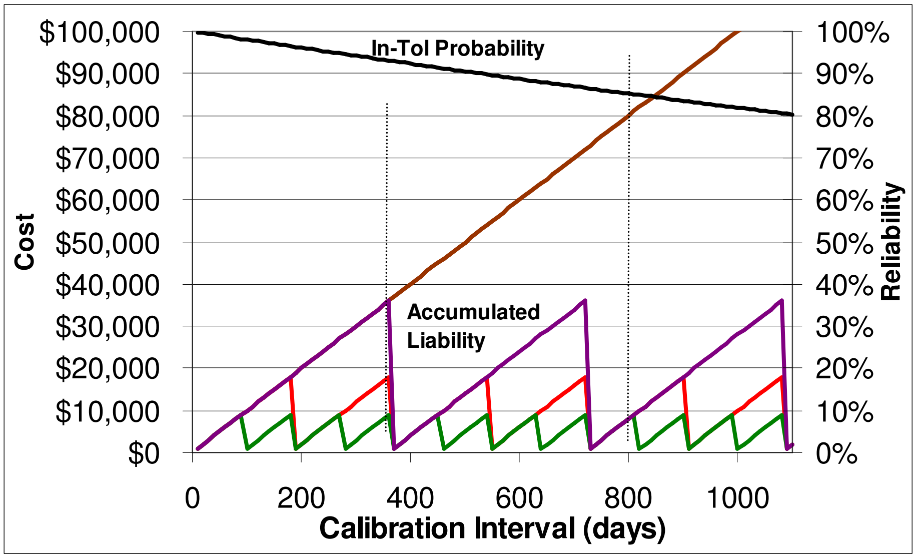

Figure 7 Maximum Accumulated Liability ($100/day Liability Accumulation)

Insurance is often a good idea but it is never a good investment. It is used to protect against maximum catastrophic losses through the payment of premiums which are due even if the loss does not occur. For the example in Figure 7, with the corresponding curves from Figure 4, the additional expected cost can be calculated if the optimum interval of 327 days is not chosen. The choices are summarized in Table 2.

At the optimum interval, the costs are estimated at $4543 and the maximum liability at $32,700. A 6 month calibration interval would reduce the maximum liability exposure almost half to $18,000. Cost would increase $803, about 5% of the reduction in liability. Some laboratories may consider this "insurance" cost very reasonable to limit their maximum exposure. Why not limit the exposure even further? Reducing the maximum liability exposure to $9000, another factor of two, would cost $4219, almost 50% of the liability reduction. This would not be cost effective insurance.

The costs of convenience and ignorance are also summarized in Table 2 by looking at calibration intervals longer than optimum. Small changes in the calibration interval have small consequence costs because the optimum interval is at the inflection point (zero slope) of the cost curve. Changing the calibration interval to from 327 days to 1 year for convenience would cost only $27 annually.

However, we can see the high cost of blindly adopting reliability targets without considering the cost consequences. If we had chosen an in-tolerance reliability target of 80% resulting in a 3 year calibration interval, the expected impact of that decision would be $3300 annually.

Calibration Interval	Pintol	Maximum Accum. Liability	Annualized Cost (S)	Insurance or Extension Cost
90 Days	98.2%	$9,000	$8762	$4219
180 Days	96.5%	$18,000	$5346	$803
327 Days	93.7%	$32,700	$4543	-----
1 Year	93.0%	$36,500	$4570	$27
2 Years	86.4%	$73,000	$5958	$1415
3 Years	80.3%	$109,500	$7845	$3302

Table 2 Summary of Annualized Cost for Non-Optimum Calibration Intervals

CONCLUSION

The development of more sophisticated reliability models that describe the relationship between calibration interval and reliability are a valuable contribution to metrology. This paper contends that combining these reliability models with cost models will result in further improvements in optimizing calibration intervals.

The examples shown in this paper for both the reliability and cost models are very simplified. Further work on the cost models before combining them with the reliability models would be advisable. For example, the cost of an out-of-tolerance was assumed to be linear with time. In practice, responding to an out-of-tolerance standard may result in some fixed cost independent of the number of calibrations or products produced in addition to the incremental costs.