**Load Cell Reliability Introduction**

Over the years, many of us at Morehouse have been asked what value one should use for Reference Standard Stability when a system is new.

You may be thinking: "I need a reliable number for my uncertainty budget. What should I use?" The answer is variable as it depends on several factors.

One of the key factors is figuring out how stable someone needs the load cell system to be that meets their measurement uncertainty requirements. Is 89 % EOPR acceptable with 95 % Confidence, or is 95 % End of Period Reliability (EOPR) the goal?

The other reaction we often receive is, "No one does that because there are too many variables." Load cell reliability will depend on the **complete system** and its use.

The use would include anything that could influence the results.

Force is mechanical things such as using different adapters, different cables, changing thread engagement, overloading the load cell, the meter used, and the number of loading cycles.

So, after being asked numerous times, we decided to tackle the question, "What should I expect for stability with year-to-year annual calibrations?"

We started by finding enough samples to meet the 95 % Confidence Interval criteria, with 95 % End of Period Reliability, which seemed daunting.

**What is required to calculate the Reliability of a Load Cell System?**

$$EOPR = \frac{\text{Number of in-tolerance results}}{\text{Total number of calibrations}}$$

In simplistic terms, End of Period Reliability is defined as the number of calibrations that meet acceptance criteria divided by the total number of calibrations.

Reliability Considerations may include:

- Reliability decreases with time after calibration
- How much testing is required to demonstrate Reliability with confidence?
- *A priori* knowledge of the M&TE

This formula to determine "In-Tolerance" Reliability from historical data is easy to replicate in Excel. The formula is **Sample Size = ln(1-Confidence)/ln(Target Reliability).**

When we use this formula for 95 % EOPR at a 95 % Confidence Interval, we find that we need 59 samples with 0 failures or rejects.

Knowing that Reliability decreases with time after calibration and that anyone wanting a performance of better than 0.05 % will likely need calibration performed annually, we decided that our sampling needed to include load cells on an annual calibration cycle.

Thus, we went on to pull 59 samples with a calibration interval of around 365 days to demonstrate Reliability with the appropriate confidence.

Of the 60 samples pulled, 6 failed the criteria of being better than 0.05 % from 10 % of the range to 100 %.

Upon investigation of the six failures, one load cell was found to have a loose calibration top adapter, which warranted removal from the data set. Two of those points were higher than 0.05 %.

| Reliability Constraints | |
|---|---|
| Reliability Target = | 95.0 % |
| Confidence Target = | 95.0 % |
| Calculated Sample Size = | 59 |

(Used to establish initial sample size)

☐ Correct to "True" EOPR?

| Calibration History Results | |
|---|---|
| Calibrations or Sample Size, n = | 60 |
| Failures/Rejects, c = | 3 |
| Confidence Level = | 95% |
| Failure Rate = | 5.00% |
| Unreliability (worst case) = | 12.42% |
| R(t) = | 87.58% |

Actual Samples 60

Upper Confidence Limit = 98.96%
Lower Confidence Limit = 87.58%

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| UUT Constraints | |
|---|---|
| Assumed EOPR = | 95.00% |
| Use Add. Ref. Std. Samples? | ☐ |
| Max PFA = | 2.00% |

| Reference EOPR with Additional Samples | |
|---|---|
| Samples needed to meet R(t) = | 153 |
| Failures/Rejects, c = | 3 |
| Confidence Level = | 95% |
| Failure Rate = | 1.96% |
| Unreliability (worst case) = | 4.99% |
| Reliability (Sample size adj.) = | 95.01% |

*93 Additional samples needed*

After scrubbing the data, we found that 3 out of 60 failed the criteria of a change of less than 0.05 %.

The loose calibration adapter is a known error source known to make load cells much less reliable.

**Thread Depth Comparison - Shear Web Load Cell**

| 0.25 " Backed Off | Integral Adapter Installed |
|---|---|


| Percent of Full Scale | Percentage Difference In Loading Conditions |
|---|---|
| 10% | 0.184% |
| 50% | 0.174% |
| 100% | 0.138% |

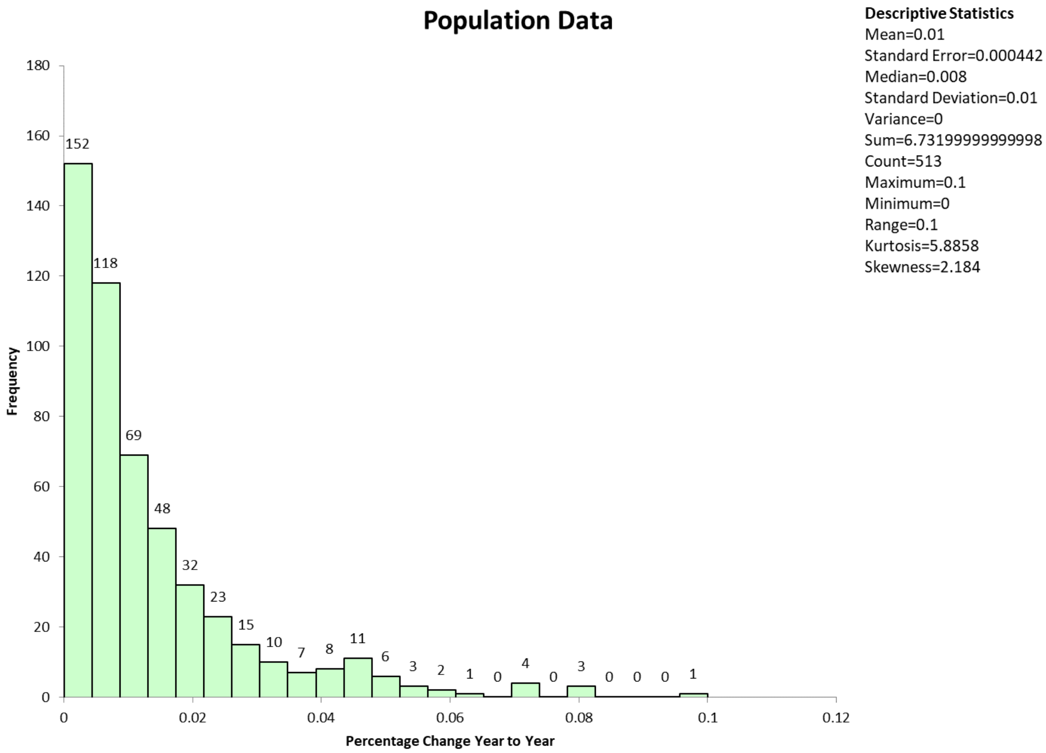
Above is a picture of a Morehouse shear web load cell loaded with the adapter locked in and loaded with 0.8 inches of engagement.

The difference in output is over 0.138 % and enough to demonstrate a priori knowledge that any load cells with loosely threaded adapters could skew the results and should be removed. The adapters are made to be locked in place for a reason.

Another load cell had an entry error of 45 % instead of 0.045 % (oops). Thus, after removing one load cell, we sampled an additional load cell, ending with 60 samples and three failures.

According to the initial calculations, we would need another 93 samples for our load cell reliability target based on a one-year stability of 0.05 % or better.

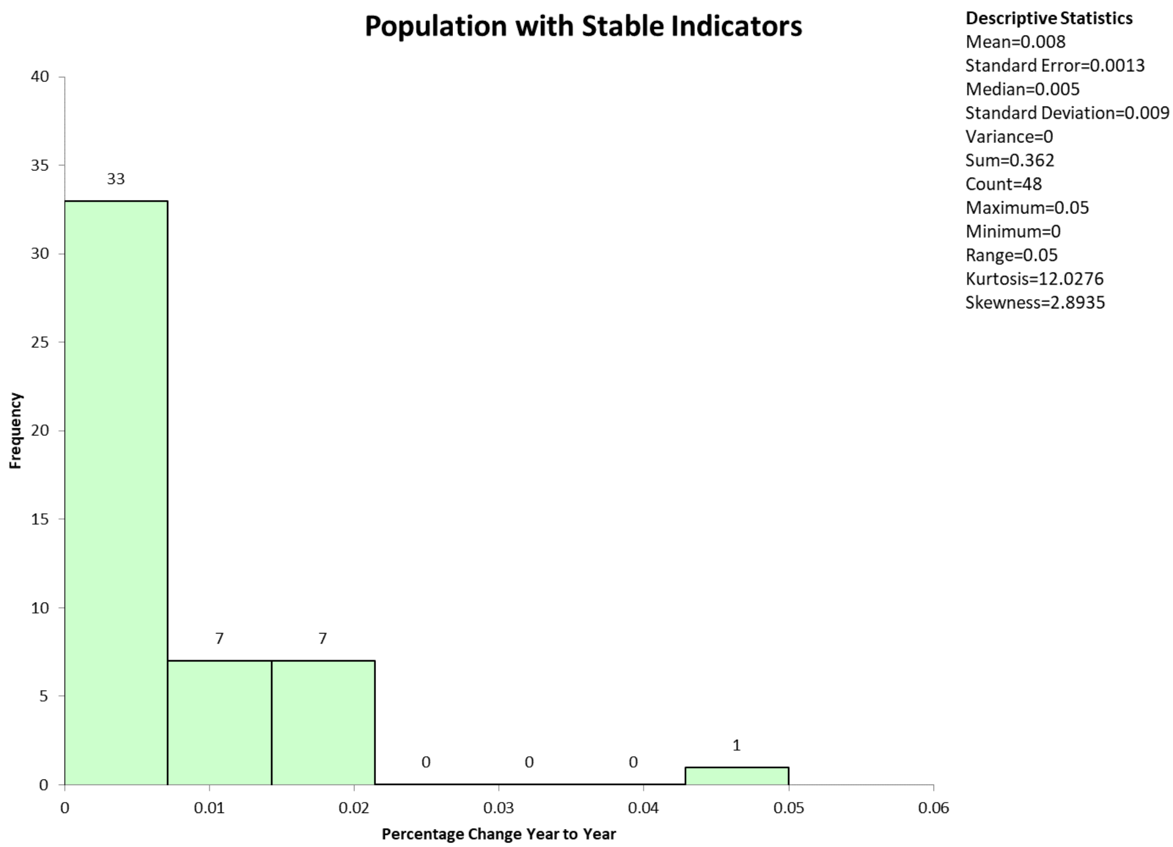
Meaning we would need to continue sampling or raise the stability criteria.




As shown above, we pulled 171 load cells and sampled the stability criteria at 10 %, 50 %, and 100 % test points. Anything below 10 % would have too low of a resolution to use.

For instance, on a 4 mV/V load cell, a change of 0.00005 mV/V would result in a 0.06 % change at the 2 % point. Most indicators used for load cell calibrations are not even stable to ± 0.00002 mV/V, which could account for a shift in stability of 0.025 % at a 2 % point.

On top of that, most indicators significantly contribute to the overall Reliability of the load cell.




We tested the indicator influencing load cell reliability by pulling out any indicator other than our 3458A and DMP 40. With the other indicators pulled out, we were left with 48 samples, and only 1 was over 0.02 %.

| Reliability Constraints | |
|---|---|
| Reliability Target = | 95.0 % |
| Confidence Target = | 95.0 % |
| Calculated Sample Size = | 59 |

(Used to establish initial sample size)

☐ Correct to "True" EOPR?

| Calibration History Results | |
|---|---|
| Calibrations or Sample Size, n = | 513 |
| Failures/Rejects, c = | 14 |
| Confidence Level = | 95% |
| Failure Rate = | 2.73% |
| Unreliability (worst case) = | 4.23% |
| R(t) = | 95.77% |

Actual Samples 513

Upper Confidence Limit = 98.50%

Lower Confidence Limit = 95.77%

With a total of 513 samples from 171 load cells, we had enough data to say with a 95.77 % or better confidence limit that Morehouse load cells from 25 lbf through 1,000,000 capacities paired with a 4215, HADI, Agilent 3458A, HBM DMP 40, or GTM indicator could achieve 0.05 % or better stability for a 1-year calibration cycle when appropriately used from 10 % through 100 % of capacity.

There is more with EOPR as the rules to establish EOPR can be subjective. Rules such as how many first-time calibrations are counted. How many broken instruments should be included? Should we include calibrations with different due dates? What about post-dating and so on?

We did include the one-year after the initial calibration numbers in the data set on new instruments. About 20 % of the population data consisted of a load cell and meter combination back for a second calibration. Including these instruments would tend to skew the data. Load cells will experience a shift within their early years of use.

Many would call this a break-in period. Depending on the load cell and material, the shift could be predictable. For instance, load cells loaded in only one direction usually have a balance shift in the same direction. Typically, the shift will decrease logarithmically with increasing loading cycles.

Sometimes, the shift is due to material hardening with use, gauging, or other factors. Whatever the reason, we typically see this occurring during those first few calibration cycles.

Our initial round included load cells paired with good indicators, and three points at 10 %, 50 %, and 100 % capacity per load cell were sampled. Thus, it would be possible for the 50 % and 100 % test points to skew the data.

What if we did a further analysis on the 10 % point?

**The Load Cell Reliability at the 10 % Test Point**

Of the 14 failures, 9 occurred at the 10 % test point.

| Reliability Constraints | |
|---|---|
| Reliability Target = | 95.0 % |
| Confidence Target = | 95.0 % |
| Calculated Sample Size = | 59 |

(Used to establish initial sample size)

☐ Correct to "True" EOPR?

| Calibration History Results | |
|---|---|
| Calibrations or Sample Size, n = | 171 |
| Failures/Rejects, c = | 9 |
| Confidence Level = | 95% |
| Failure Rate = | 5.26% |
| Unreliability (worst case) = | 9.00% |
| R(t) = | 91.00% |

Actual Samples 171

Upper Confidence Limit = 97.57%
Lower Confidence Limit = 91.00%

The 10 % test point had a failure rate of 5.26 % of the population. At the same time, the failure rate of the 50 % and 100 % test points were both under 2 %. At the 50 % point, there were 3 failures out of 171 samples, resulting in 95 % Confidence that the stability is 95.53 % reliable. At the 100 % point, there were 2 failures out of 171 samples, resulting in 95 % Confidence that the stability is 96.36 % reliable.

If we raised the stability target to 0.06 %, the 95 % reliability target at 95 % confidence at the 10 % point would become 93.95 %. And a stability target of 0.07 % would result in 95.53 % reliability.

If we lowered the target to 0.032 %, the 95 % reliability target at 95 % confidence at the 10 % point would become 74.43 % for the population. At the 50 % point, it would be 91.00 %, and at the 100 % point, it would be 91.72 % reliable.

**89 % End of Period Reliability Rule**

We discussed 95 % Confidence and 95 % EOPR, though the standard rule to control false acceptance is to accept the 89 % EOPR rule as appropriate to limit risk to less than 2 %. The theory is that when a process or system has high Reliability, most error sources are under control. More information can be found in Subclause 5.3 in Z540.3 standard.

The basis is that the calibration process uncertainty should be small enough to detect EOPR confidently. In our case at Morehouse, the calibration process uncertainty did not exceed 0.01 % of applied force, and most of the population was controlled to better than 0.005 %.

Without an extremely good UUT and acceptable reference Standards, providing minuscule PFA or relatively good equipment, it would not be possible to observe a high in-tolerance reliability. This means that if our Measurement Uncertainty was 0.05 %, we could not claim 0.05 % reliability with confidence.

| Reliability Constraints | |
|---|---|
| Reliability Target = | 95.0 % |
| Confidence Target = | 95.0 % |
| Calculated Sample Size = | 59 |

(Used to establish initial sample size)

☐ Correct to "True" EOPR?

| Calibration History Results | |
|---|---|
| Calibrations or Sample Size, n = | 513 |
| Failures/Rejects, c = | 43 |
| Confidence Level = | 95% |
| Failure Rate = | 8.38% |
| Unreliability (worst case) = | 10.68% |
| R(t) = | 89.32% |

95% Confidence the process is at least 89.33% reliable.

Upper Confidence Limit = 93.87%

Lower Confidence Limit = 89.32%

If we were interested in population data for 89 % EOPR, we could meet that number using a load cell reliability target of all data points showing Reliability of better than 0.036 %. From our 513 samples, 43 would fail to be lower than 0.036 % for 89.32 % EOPR at 95 % Confidence.

A number I typically advise people to use for the first year of 0.032 % has an EOPR of 87.61 %. However, I am more confident that this number will increase when a 4215 High Stability model, 4215 plus, or Fluke 8588A, is used as the reference indicator.

**Load Cell Reliability – Conclusion**

All load cells or metals will change with frequent loads applied. Therefore, it's important to determine if a given shift is normal for that load cell or if it is a warning sign of damage. Shifts that trend lower and are not erratic do not indicate a cell going bad.

Shifts that are erratic or get worse with identical loading cycles require troubleshooting. Possible causes include electrical leakage, fatigue, poor gaging, bad material, overload, bad solder joints, and unstable loading conditions.

The first few calibration cycles are typically when the most change occurs.

If someone wants to maintain an overall reliability of 95 % with 95 % confidence of 0.05 % or better, then care must be taken in selecting the overall system.

We showed in our data that maintaining 0.02 % stability with high-end indicators is possible. In our sampling, with 95 % confidence, we were at least 91.66 % reliable when we filtered out the data only to include meters costing USD 15,000.00 or above.

However, there might be other solutions to control the stability of the meter. A load cell simulator is one solution that can be used as a check standard to help control and monitor the indicator stability.

Other Comments on Reliability:

- Calculating Reliability alone may not be enough to ensure confidence in your measurement.
- Calculating Confidence Intervals can give insight into actual Reliability.
- Typically, many labs struggle with getting enough samples. In this case, it may be prudent to seek a calibration provider who can increase the acceptance zone to issue a pass, utilizing reference standards with low measurement uncertainty.
- The system's end-user should look at their requirement for Reliability and evaluate calibration intervals, accordingly, as shortening intervals may be a solution that allows the desired reliability target to be met.