The True Cost of
Measurement Decisions

A Practical Guide to Selecting Force Calibration Equipment,
Load Cells, and Calibration Providers
with Real Cost and Risk Consequences

Henry Zumbrun, President
Morehouse Instrument Company
ISO/IEC 17025 / ANSI/NCSLI Z540.3 Accredited
NVLAP Lab Code 600259 · A2LA Cert. 1398.01

2026 Edition · Version 10 · Cost Basis: $200/hr

Contents

1. Why This Guide Exists

Every force calibration laboratory faces the same question: what combination of machine, load cells, and calibration provider will let us make defensible pass/fail decisions at a cost we can justify?

This guide translates metrology concepts—TUR, Cm, PFA, PFR, CMC, guard bands, and decision rules—into **dollars, hours, and risk.** It is designed for lab managers sizing new equipment and quality managers justifying capital budgets.

Cost baseline: \$200 per hour (\$100 per half hour), reflecting fully burdened labor including overhead and opportunity cost, with 1 000 calibrations per year. Where actual Morehouse CMC data from accredited uncertainty budgets is available, we use it. All cost estimates in this guide are approximate and intended to illustrate relative differences; your actual numbers will vary.

> *The most expensive calibration decision is the one you do not know is wrong. A false accept costs nothing today—and everything when the failure reaches the field.*

2. Start with the End in Mind

1. How good does the measurement need to be? What happens if you are wrong—safety, recalls, regulatory exposure, warranty, scrap, lost uptime?

2. How good can the measurement actually be made? What can your process, equipment, and provider deliver?

2.1 The Backward-Pass Method

Step A — Set risk target and decision rule. Select PFA target (typically ≤ 2 %). Choose: shared risk, guard-banded, Method 6, or subtracting U at 95 %.

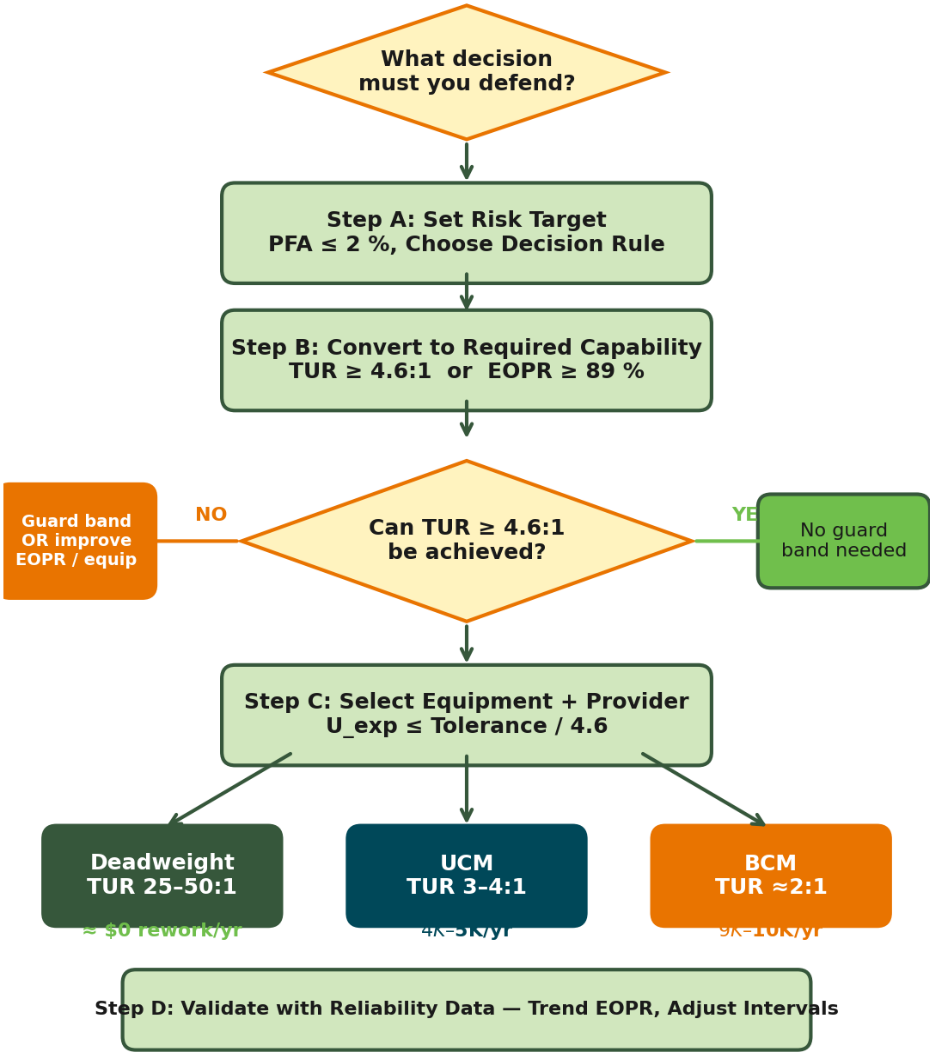
Step B — Convert risk to required capability. With shared risk, TUR ≥ 4.6:1 constrains global PFA to ≤ 2 %. Or: EOPR ≥ 89 % achieves the same.

Step C — Translate to equipment and provider. $U_{exp} \leq$ Tolerance / 4.6 without guard bands.

Step D — Validate with reliability data. Trend in-tolerance reliability. Adjust intervals and guard bands.

Start with the End in Mind

Backward-Pass Equipment Selection



2.2 Sizing Quick Reference

Device Tolerance	Required U (k = 2)	TUR / Cm	Global Risk
0.01 %	0.0022 %	4.6:1	PFA ≤ 2 %
0.05 %	0.0109 %	4.6:1	PFA ≤ 2 %
0.10 %	0.0217 %	4.6:1	PFA ≤ 2 %
0.50 %	0.1087 %	4.6:1	PFA ≤ 2 %

Why 4.6:1? Under ANSI/NCSL Z540.3 and the Dobbert Managed Guard Band (Method 6), a TUR of 4.6:1 is the threshold at which global PFA drops below 2 % with no guard band required. Below 4.6:1, a guard

band must be applied to control risk—and that guard band consumes usable tolerance, increases false rejections, and adds cost. Above 4.6:1, the measurement uncertainty is small enough relative to the tolerance that acceptance limits equal tolerance limits: you get to use every bit of specification range you paid for.

The table above shows the Required U needed to achieve 4.6:1 at each tolerance level. If your calibration process cannot deliver that U, you face a choice: apply guard bands (which increase rework costs), improve your measurement capability (which requires capital investment), or accept elevated risk (which shifts consequences downstream to your customer).

Section 3 quantifies what each of those choices actually costs.

3. The Cost of Measurement Risk

False Accept (PFA): Device called “in tolerance” when out of spec. Consequences: quality escapes, safety incidents, recalls.

False Reject (PFR): Device called “out of tolerance” when actually good. Consequences: rework, unnecessary adjustments, wasted hours at $200/hr.

Specific (Conditional) Vs Global (Unconditional) Risk: The Field Goal Kicker

In American football, a field goal kicker either kicks the ball between the goal posts or does not.

Specific risk is the single kick in front of you right now. The ball either traveled between the goal posts or it didn’t. Pass and points or fail and no points for your team (sorry, Ravens fans). When we make a measurement and record the observed value, it is either between the acceptance limits or it is not. One kick, one result, one decision.

Global (average) risk steps back and looks at all the kicks. Say the Steelers kicker makes 97 % of his field goals from the 35-yard line. This kick is from the 35-yard line, yet it didn’t go in. Based on population data alone, you would say it is likely that it did go in. And the Steelers won the game, hooray!

That is exactly the tension between the two approaches. Global risk uses historical population data to assess the probability of an incorrect decision, such as a false accept or false reject, across a population. Specific risk evaluates the single result in front of you. One tells you how reliable the process is over time. The other tells you what happened right now.

Now shift your focus from the kick to the goal posts themselves. The distance between them represents your tolerance. A kicker with a tight, repeatable trajectory effectively has more room to succeed because their variability is low. In contrast, a kicker with inconsistent performance needs nearly perfect alignment every time. The same principle applies to measurement: as uncertainty decreases, the “usable” portion of the tolerance increases, and confidence in the result improves.

With that perspective in mind, decision rules become the method for determining whether a result truly falls within those goal posts. Most practical decision rules stem from three foundational approaches, each offering a different way to balance risk and confidence.

The question every lab manager needs to answer is: what does that tension between global and specific risk actually cost? The kicker analogy makes the concepts intuitive, but the numbers below make them actionable. Section 3.1 uses the global risk model—the population-level view, like the kicker’s career field goal percentage. Section 3.3 then uses specific risk—the single-kick view, where guard bands tighten the goal posts to ensure each individual result meets the confidence target. Both are legitimate approaches. The difference is how much rework each one generates, and what that rework costs at $200/hr.

3.1 Annual Rework Costs — Global Risk Model (0.1 % Tolerance)

Important: The following table uses a Global Risk model, which calculates PFA and PFR as averages across the entire population of instruments calibrated. Global risk assumes historical population data and can be more optimistic than bench-level (specific risk) calculations. See Section 3.3 for specific risk numbers, which are typically worse.

Machine	TUR	PFR	Est. False Rejects per 1 000 Cal	Rework per Event	Est. Annual Rework
BCM	≈2:1	9–10 %	90–100	$100	$9 000–$10 000
UCM	≈3:1	4–5 %	40–50	$100	$4 000–$5 000
UCM Auto	≈4:1	1–2 %	10–20	$100	$1 000–$2 000
Deadweight	≈50:1	≈0 %	≈0	$100	≈$0

How to read this table: PFR is the percentage of calibrations that falsely reject a good device. Out of 1 000 calibrations, PFR of 9–10 % = 90–100 false rejects. Each triggers approximately 30 minutes of rework at $200/hr = $100 per event. So: 90–100 events × $100 = $9 000–$10 000 per year. These are rough estimates using a Global Risk model (population averages). Specific risk numbers are typically worse—see Section 3.3.

3.2 Cost Escalation at Tighter Tolerances (0.05 %, Global Risk)

TUR	Est. Rework Cost/Decision	Est. Annual (1 000 cal)	Machine Class
1:1	$35	$35 000	Severely under-capable
1.5:1	≈$16	≈$16 000	Below minimum viable
2:1	$9–$10	$9 000–$10 000	BCM range
4:1	$1–$2	$1 000–$2 000	UCM Automated
25:1	≈$0	≈$0	Deadweight

> *At 0.05 % tolerance and 1:1 TUR, estimated hidden rework costs reach $35 000 per year at $200/hr.*

3.3 Specific Risk Model — Bench-Level Measurements

Specific risk evaluates each individual measurement result, not the population average. When using a specific risk decision rule (e.g., subtracting U at 95 % from the acceptance limits), guard bands are applied to each result. This dramatically reduces PFA but increases PFR—especially at low TUR. The costs below reflect this trade-off.

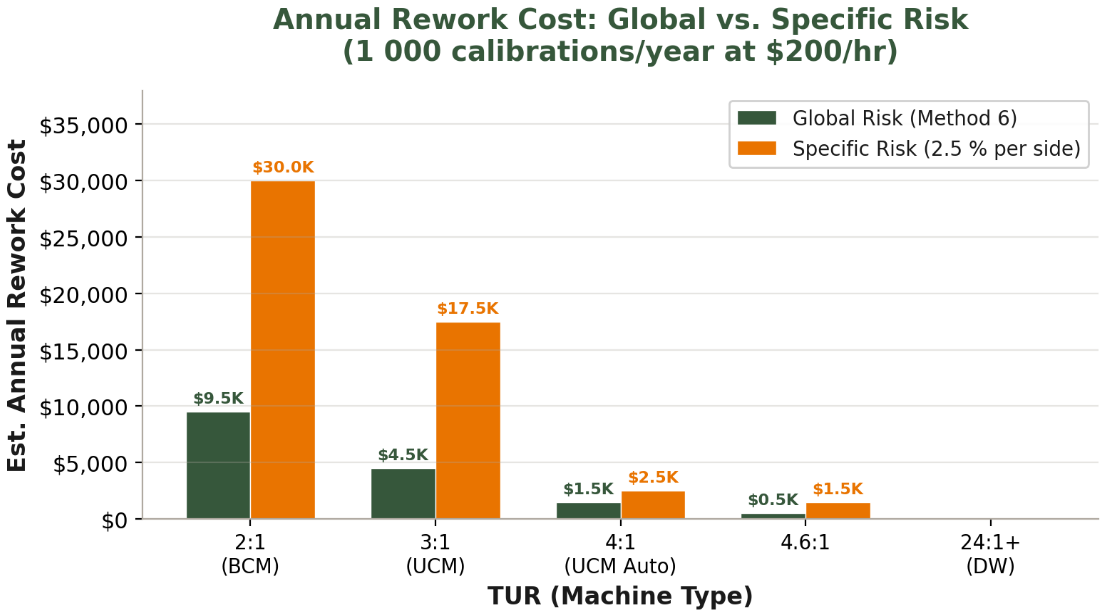
Key difference from Global Risk: At low TUR, specific risk decision rules pull acceptance limits well inside the tolerance to meet the PFA target. This crushes false acceptance to near zero but causes very high false rejection rates. At TUR 2:1 using specific risk, roughly 30 % of rejected items are actually good.

TUR	Specific PFR	Specific PFA	Est. False Rejects per 1 000 Calibrations	Est. Annual Rework Cost
1.2:1	40–70 %	≈0 %	400–700	$40 000–$70 000
2:1	25–35 %	≈0–1 %	250–350	$25 000–$35 000
3:1	15–20 %	≈0–1 %	150–200	$15 000–$20 000
4:1	2–3 %	1–2 %	20–30	$2 000–$3 000
4.6:1	1–2 %	1–2 %	10–20	$1 000–$2 000

How to read this table: PFR is the percentage of calibrations where a good device is incorrectly rejected. Out of 1 000 calibrations, that percentage gives you the number of false rejects. Each false reject triggers approximately 30 minutes of rework (investigation, re-test, documentation) at $200/hr = $100 per event. For example, at TUR 2:1: 25–35 % of 1 000 = 250–350 false rejects × $100 = $25 000–$35 000 per year.

Note: At low TUR, the guard band is so wide that it consumes most of the tolerance, causing massive false rejection. At TUR 2:1, you are throwing away 250–350 good calibrations per year. A lower TUR and higher PFR increases the chance you will wrongly fail a customer's equipment—forcing unnecessary costs, extra analysis, and even potential recalls, all because of a bad measurement decision.

> *Using specific risk: switching from a 2:1 TUR (BCM) to a 3:1 TUR (UCM) cuts false rejections from roughly 300 to 150 out of every 1 000 calibrations. At $100 per rework event ($200/hr), that saves approximately $15 000 per year.*



3.4 The Guard Band Tax on Usable Tolerance

Guard bands protect against false accepts but consume your usable tolerance, increasing false rejects. The size of the guard band depends on which decision rule you use. The two tables below show the same scenario—a 10 000 lbf load cell with ± 0.1 % tolerance (±10 lbf)—under two different decision rules.

3.4.1 Specific Risk Guard Bands (2.5 % PFA per Side, 97.5 % Conformance)

Decision rule: Acceptance Limit = Tolerance Limit – (0.980 × U), where 0.980 = NORM.S.INV(0.975)/2. This controls specific PFA to ≤ 2.5 % at each measurement result. Every row achieves the same PFA target; the cost is how much tolerance is consumed.

TUR	U (lbf)	Guard Band	Tolerance Consumed	Usable Zone	PFA at AL
2.5:1	4.00	3.92 lbf	39 %	±6.08 lbf	2.5 %
3:1	3.33	3.27 lbf	33 %	±6.73 lbf	2.5 %
4:1	2.50	2.45 lbf	25 %	±7.55 lbf	2.5 %
4.6:1	2.17	2.13 lbf	21 %	±7.87 lbf	2.5 %
24:1	0.42	0.41 lbf	4 %	±9.59 lbf	2.5 %

Key insight: Even at TUR 4.6:1, specific risk guard bands still consume 21 % of the tolerance. At TUR 4:1, a full quarter of your tolerance is sacrificed to the guard band. This is the price of point-by-point risk control.

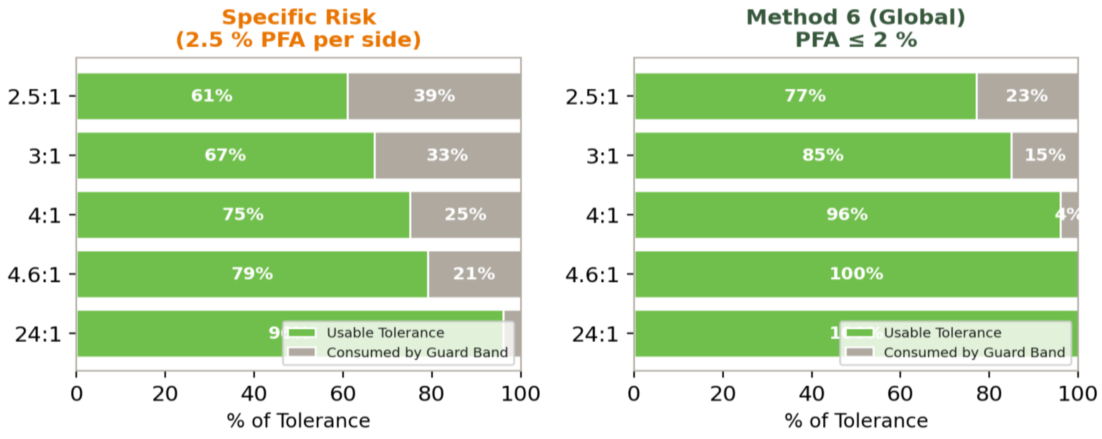
3.4.2 Method 6 Guard Bands (Dobbert Managed, Global PFA ≤ 2 %)

Decision rule: The Dobbert Managed Guard Band (Method 6, ANSI/NCSL Z540.3) uses a dynamic guard band that decreases as TUR increases. At TUR ≥ 4.6:1, the guard band drops to zero and acceptance limits equal tolerance limits. This controls global (unconditional) PFA to ≤ 2 % across the population.

TUR	U (lbf)	Guard Band	Tolerance Consumed	Usable Zone	Global PFA
2.5:1	4.00	≈2.33 lbf	≈23 %	±7.67 lbf	≤ 2 %
3:1	3.33	≈1.48 lbf	≈15 %	±8.52 lbf	≤ 2 %
4:1	2.50	≈0.42 lbf	≈4 %	±9.58 lbf	≤ 2 %
4.6:1	2.17	0 lbf	0 %	±10.00 lbf (full)	≤ 2 %
24:1	0.42	0 lbf	0 %	±10.00 lbf (full)	≤ 2 %

> *The difference is striking. At TUR 4:1, specific risk consumes 25 % of the tolerance while Method 6 consumes only 4 %. At TUR 4.6:1, specific risk still takes 21 % while Method 6 takes nothing. The choice of decision rule has as much cost impact as the choice of machine.*

Guard Band Tax: How Much Tolerance Do You Actually Get to Use?
(±10 lbf tolerance at 10 000 lbf)



4. Machine Comparison: CMC and Cost of Ownership

4.1 Morehouse Deadweight Primary Standards

Actual CMC data from Morehouse accredited uncertainty budgets:

Machine	Capacity	Expanded U (worst case)	Expanded U %
M-8407	6 600 lbf	0.010 lbf at 500 lbf	≈0.002 %
M-4644	12 000 lbf	0.008 lbf at 500 lbf	≈0.0015 %
M-7471	120 000 lbf	0.29 lbf at 20 000 lbf	≈0.0014 %

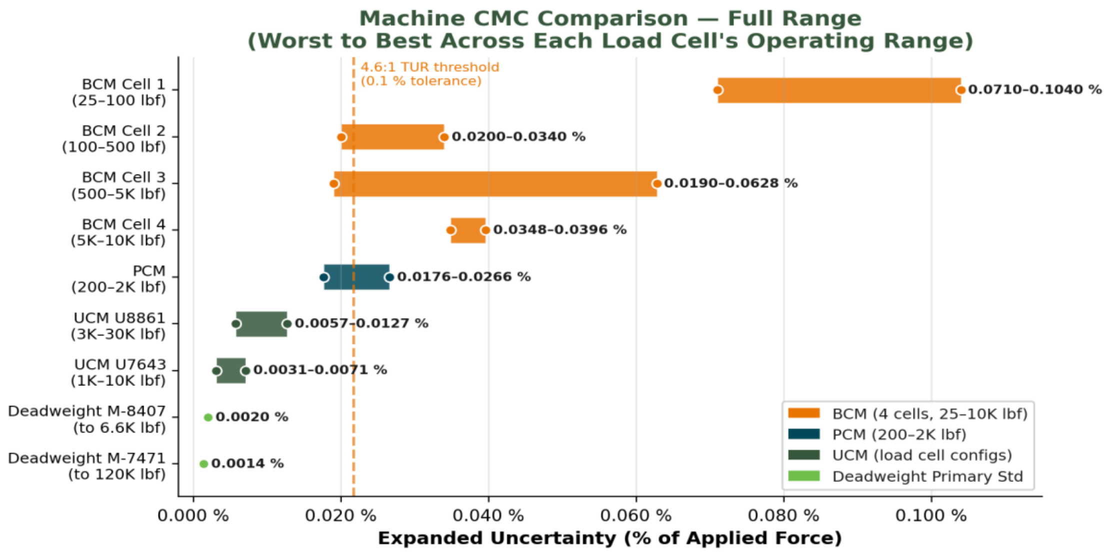
Deadweight machines can achieve TURs of 25:1 to over 50:1. False reject rates approach zero. Calibration intervals stretch into decades. Annual reference maintenance cost is minimal. Most deadweight machines are applied force and the limitations are the weights and the complement of weights, thus it is difficult to achieve all desired force points with one deadweight machine. Most machines can have up to a maximum of 24 weights.

4.2 Morehouse UCM (10 % of Capacity Through Full Scale)

The following CMC data reflects each load cell used from 10 % of its rated capacity through full scale, which is the recommended operating range for maintaining optimal uncertainty and stability:

Configuration	Range (10 %–100 % of Capacity)	Expanded U %
UCM #50751 — ASC Only (1M lbf capacity)	100 000 lbf to 1 000 000 lbf (U: 18.8 lbf to 37.3 lbf)	0.019 % to 0.004 %
UCM w/ Cell U8861 (30K, ASC)	3 000 lbf to 30 000 lbf (U: 0.38 lbf to 2.03 lbf)	0.013 % to 0.007 %
UCM w/ Cell U7643 (10K, ASC)	1 000 lbf to 10 000 lbf (U: 0.071 lbf to 0.37 lbf)	0.007 % to 0.004 %

Note: Morehouse reliability data from 513 samples shows that the 10 % test point had a failure rate of 5.26 %, while 50 % and 100 % test points were both under 2 %. Running cells below 10 % of capacity increases uncertainty and reduces stability. With Morehouse automation and multiple load cells, the UCM can typically achieve CMC between 0.02 %–0.035 %. The data shown above is better than this because we are using high-end load cells and a very high-end indicator (DMP 40) with automation. The Morehouse Automation upgrade typically pushes the measurement uncertainty to the lower range, more towards 0.02 %.



4.3 Morehouse PCM (Portable Calibrating Machine)

The PCM is a portable force calibration machine that uses reference load cells. It is suited for field calibrations and lower-capacity applications. Actual CMC data from the Morehouse 2 000 lbf PCM:

Configuration	Range (10 %–100 % of Capacity)	Expanded U %
PCM w/ 2 000 lbf cell (ASC, 10 %–100 %)	200 lbf to 2 000 lbf (U: 0.053 lbf to 0.353 lbf)	0.027 % to 0.018 %

Note: The PCM typically uses at least two load cell reference standards that must be calibrated annually, adding ongoing costs and downtime. For wider ranges, multiple cells are needed, following the same standard-switching considerations described in Section 6.

4.4 Morehouse BCM (4 Reference Load Cells, 25–10 000 lbf)

The BCM CMC is shown as Expanded U % across each load cell’s range, matching the format of the UCM and PCM tables above. This configuration uses 4 reference load cells:

Configuration	Range	Expanded U %
BCM Cell 1 (≥ 25–100 lbf)	25 lbf to 100 lbf (U: 0.026 lbf to 0.071 lbf)	0.104 %–0.071 %
BCM Cell 2 (> 100–500 lbf)	100 lbf to 500 lbf (U: 0.034 lbf to 0.100 lbf)	0.034 %–0.020 %
BCM Cell 3 (> 500–5 000 lbf)	500 lbf to 5 000 lbf (U: 0.314 lbf to 0.95 lbf)	0.063 %–0.019 %
BCM Cell 4 (> 5 000–10 000 lbf)	5 000 lbf to 10 000 lbf (U: 1.98 lbf to 3.48 lbf)	0.040 %–0.035 %

Key observation: At the low end of each range, the fixed offset in the CMC formula dominates, pushing uncertainty higher as a percentage. At 25 lbf, the BCM reaches 0.104 %—which exceeds many device tolerances. At the low end of the 500–5 000 lbf range, the offset of 0.3 lbf causes a jump to 0.063 %. Compare to the UCM with Cell U7643, which achieves 0.007 % at 1 000 lbf.

4.5 Breakeven Analysis

Using estimated rework savings from Section 3 at $200/hr:

Upgrade Path	Est. Annual Savings	Approx. Price Delta	Est. Payback Period
BCM → UCM	$5 000–$5 500/year	≈$15 000	≈3 years
BCM → UCM Automated	$8 000–$8 500/year	≈$65 000	≈8 years
UCM → Deadweight	$4 000–$5 000/year	≈5× UCM cost	≈10–13 years

Note: These payback calculations consider rework savings only. When you add recovered tolerance (fewer false rejects reaching customers), reduced lead time costs, and lower risk exposure, the effective payback is faster. All figures are rough estimates; actual payback depends on your calibration volume, labor rates, and tolerance requirements.

4.6 The Practical Floor: Minimum Load Cell Capacity and Tare Weight

Every UCM has a yoke tare weight—the mass of the loading assembly that sits on top of the reference load cell before any test force is applied. This tare weight determines the smallest reference load cell that can safely be used in the machine, which in turn determines the lowest force the machine can practically deliver.

The rule: The smallest recommended reference load cell must be large enough that the yoke tare weight does not exceed approximately 15 % of the cell's rated capacity. Morehouse testing has confirmed that taring out up to 15 % of a shear-web load cell's capacity produces the same output as with no tare load. Beyond that, zero shift and overload risk increase. Not all load cells perform the same way—always check the manufacturer's safe overload specification.

The table below shows each UCM model, its yoke tare weight, the minimum recommended reference load cell, and the practical lowest force point at 5 % of that minimum cell's capacity. Below that floor, the lab must consider adding a Morehouse PCM, a deadweight machine, or calibrated weights to cover the low range.

UCM Model	Max Capacity	Yoke Tare	Min Ref Cell	5 % of Min Cell	Practical Floor	Below Floor: Consider
UCM-10K	11 500 lbf	40 lbf	2 500 lbf	125 lbf	125 lbf	PCM, DW, or weights
UCM-30K	30 000 lbf	120 lbf	7 000 lbf	350 lbf	350 lbf	PCM, DW, or weights
UCM-60K	60 000 lbf	220 lbf	12 500 lbf	625 lbf	625 lbf	PCM, DW, or weights

UCM-100K	112 500 lbf	250 lbf	15 000 lbf	750 lbf	750 lbf	PCM, DW, or weights
UCM-200K	225 000 lbf	740 lbf	50 000 lbf	2 500 lbf	2 500 lbf	PCM, DW, or weights
UCM-300K	338 000 lbf	1 340 lbf	100 000 lbf	5 000 lbf	5 000 lbf	PCM, DW, or weights
UCM-600K	675 000 lbf	3 400 lbf	200 000 lbf	10 000 lbf	10 000 lbf	PCM, DW, or weights
UCM-1000K	1 125 000 lbf	6 900 lbf	400 000 lbf	20 000 lbf	20 000 lbf	PCM, DW, or weights

Worked example (UCM-10K): The yoke tare weight is 40 lbf. The minimum recommended reference load cell is 2 500 lbf (40 lbf tare is 1.6 % of 2 500 lbf, well within the 15 % safe zone). At 5 % of that 2 500 lbf cell, the practical floor is 125 lbf. If you need to calibrate devices below 125 lbf, you need a separate system—a Morehouse PCM, a deadweight machine, or calibrated weights—to cover that low range.

Why this matters for cost: A lab that needs to cover 25 lbf to 10 000 lbf on a UCM-10K cannot do it with the UCM alone. The UCM covers 125 lbf to 10 000 lbf; the 25–125 lbf range requires additional equipment. Failing to account for this when sizing a machine purchase leads to capability gaps that only become apparent after the purchase order is signed.

> *Before purchasing any force calibration machine, determine the yoke tare weight, identify the minimum reference load cell, calculate 5 % of that cell's capacity, and compare that floor to the lowest force you need to deliver. If there is a gap, plan for it up front.*

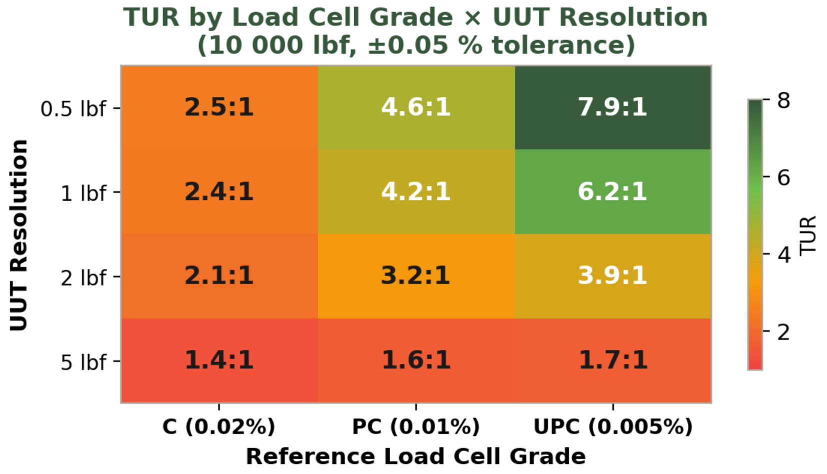
5. Load Cell Selection and the Resolution Lever

5.1 Resolution Is the Lever

Calibrating a 10 000 lbf device, ±0.05 % tolerance (±5.0 lbf), repeatability σ = 0.138 lbf:

Resolution	C (0.02 %)	C TUR	PC (0.01 %)	PC TUR	UPC (0.005 %) / TUR
0.5 lbf	2.04 lbf	2.45:1	1.08 lbf	4.64:1	0.64 lbf / 7.87:1
1 lbf	2.10 lbf	2.38:1	1.19 lbf	4.21:1	0.81 lbf / 6.16:1
2 lbf	2.33 lbf	2.15:1	1.55 lbf	3.22:1	1.29 lbf / 3.88:1
5 lbf	3.52 lbf	1.42:1	3.07 lbf	1.63:1	2.94 lbf / 1.70:1

> *At 0.5 lbf resolution, upgrading from C to UPC improves TUR from 2.45:1 to 7.87:1. At 5 lbf resolution, the same upgrade only moves TUR from 1.42:1 to 1.70:1. Know your denominator before spending money on the numerator.*



6. The Cost of Standard Switching: 5 %, 10 %, and 20 % of Capacity

When a UCM covers a wide range (25 lbf to 10 000 lbf), the minimum loading percentage determines how many reference load cells are needed and how many standard changes occur during each calibration run. Each change adds cycle time, and each cell adds annual calibration cost and downtime.

All figures in this section are rough estimates intended to illustrate the relative cost impact of different minimum loading strategies. Your actual costs will depend on specific cell configurations, operator proficiency, automation level, and calibration provider pricing.

6.1 How Many Reference Standards Do You Need?

Min Loading	Reference Cells Required	# of Cells	Swaps/Run	Coverage Logic
5 %	500 lbf + 10 000 lbf	2	1	500 × 0.05 = 25 lbf; 10K × 0.05 = 500 lbf
10 %	250 lbf + 2 500 lbf + 10 000 lbf	3	2	250 × 0.10 = 25 lbf; 2.5K × 0.10 = 250 lbf; 10K × 0.10 = 1 000 lbf
20 %	100 + 500 + 2 500 + 10 000 lbf	4	3	100 × 0.20 = 20 lbf; 500 × 0.20 = 100 lbf; 2.5K × 0.20 = 500 lbf; 10K × 0.20 = 2 000 lbf

> *Fewer cells covering wider ranges is not just more convenient—it is dramatically cheaper to operate. This is why purchasing the best available load cell upfront can save you a lot of money over time.*

6.2 Estimated Cycle Time Cost of Standard Switching

Each manual standard swap adds approximately 15–30 minutes (adapter changes, warm-up, seating loads, indicator configuration). At $200/hr, the estimated cost per swap is $50–$100. These are rough estimates:

Min Loading	Swaps per Run	Est. Swap Cost per Calibration	Est. Swap Cost per Year (1 000 cal)
5 %	1	$50–$100	$50 000–$100 000
10 %	2	$100–$200	$100 000–$200 000
20 %	3	$150–$300	$150 000–$300 000

6.3 Annual Reference Calibration and Downtime Cost

Each reference load cell requires annual calibration at an estimated $1 500–$2 500 per cell, with 2–3 weeks of downtime per cell assuming Morehouse is your vendor with 7–10 business day turnaround and another 6 business days shipping time. Note: some labs take months to turn equipment around.

Min Loading	# Cells	Est. Annual Cal Cost	Downtime (weeks)	Shipping Risk Events
5 %	2	\$3 000–\$5 000	4–6	2
10 %	3	\$4 500–\$7 500	6–9	3
20 %	4	\$6 000–\$10 000	8–12	4

6.4 Total Estimated Annual Operating Cost Summary of UCM

The rework cost depends on the TUR achieved at each strategy’s worst operating point. More cells operating at higher minimum loading percentages achieve dramatically better TUR, which reduces or eliminates rework. The actual worst-case TUR values below are calculated from Morehouse accredited uncertainty budgets (Cell U7643, 10K lbf).

6.4.1 At 0.1 % Tolerance

Min Loading	Worst TUR	Est. Rework	Est. Swap Cost	Est. Ref Cal	Est. Total Added
5 %	≈3–5:1	\$3 000–\$5 000	\$50 000–\$100 000	\$3 000–\$5 000	\$56 000–\$110 000
10 %	≈14:1	≈\$0	\$100 000–\$200 000	\$4 500–\$7 500	\$104 500–\$207 500
20 %	≈24:1	≈\$0	\$150 000–\$300 000	\$6 000–\$10 000	\$156 000–\$310 000

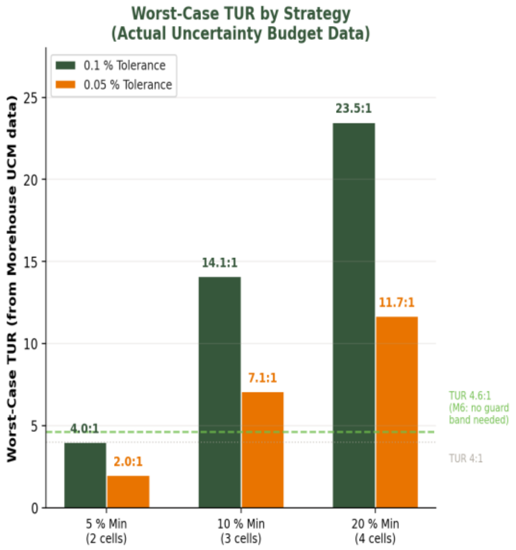
6.4.2 At 0.05 % Tolerance

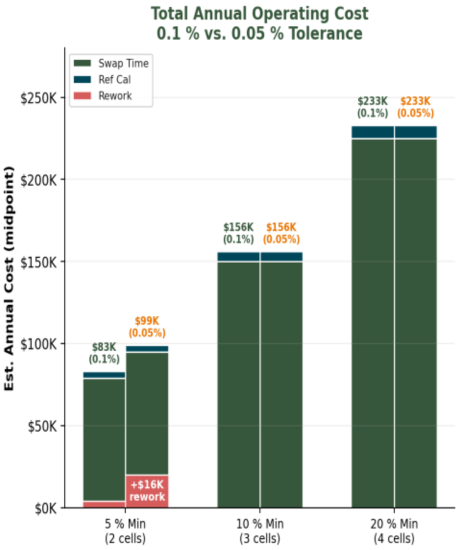
When tolerance tightens to 0.05 %, TUR is halved at every strategy. The 5 % strategy drops below 4:1 into significant rework territory, while the 10 % and 20 % strategies remain well above the guard-band-free threshold.

Min Loading	Worst TUR	Est. Rework	Est. Swap Cost	Est. Ref Cal	Est. Total Added
5 %	≈1.5–2.5:1	\$15 000–\$25 000	\$50 000–\$100 000	\$3 000–\$5 000	\$68 000–\$130 000
10 %	≈7:1	≈\$0	\$100 000–\$200 000	\$4 500–\$7 500	\$104 500–\$207 500
20 %	≈12:1	≈\$0	\$150 000–\$300 000	\$6 000–\$10 000	\$156 000–\$310 000

Key insight: At 0.05 % tolerance, the 5 % min loading strategy’s rework cost jumps from \$3K–\$5K to \$15K–\$25K per year because TUR drops to 1.5–2.5:1. The 10 % and 20 % strategies are unaffected—their TUR stays above 7:1 even at the tighter tolerance. The cost of fewer cells is not just more swaps; it is fundamentally worse measurement capability at the low end.

Compare to Deadweight: The Morehouse Deadweight machine carries near-zero rework cost, zero standard switching cost, and near-zero annual reference calibration cost. The built-in mass stacks do not leave the building.


Worst-Case TUR by Strategy
(Actual Uncertainty Budget Data)
0.1 % Tolerance
0.05 % Tolerance
Worst-Case TUR (from Morehouse UCM data)
0
5
10
15
20
25
4.0:1
2.0:1
14.1:1
7.1:1
23.5:1
11.7:1
TUR 4.6:1
(M6: no guard band needed)
TUR 4:1
5 % Min
(2 cells)
10 % Min
(3 cells)
20 % Min
(4 cells)


Total Annual Operating Cost
0.1 % vs. 0.05 % Tolerance
Swap Time
Ref Cal
Rework
Est. Annual Cost (midpoint)
$0K
$50K
$100K
$150K
$200K
$250K
$83K
(0.1%)
$99K
(0.05%)
+$16K
rework
$156K
(0.1%)
$156K
(0.05%)
$233K
(0.1%)
$233K
(0.05%)
5 % Min
(2 cells)
10 % Min
(3 cells)
20 % Min
(4 cells)

7. Lead Time and Revenue Impact

When a reference standard is out for calibration, the cost extends far beyond the invoice. At $200/hr, three weeks of lost capacity represents significant revenue impact.

Morehouse commits to 7–10 business day turnaround and operates more than five deadweight machines accurate to within 0.002 % of applied force.

Scenario	Morehouse Deadweight	Load-Cell Machine (PCM/UCM)
Ref cal frequency	Decades (with trending)	Annual per cell
Downtime per ref cal	Minimal (on-site validation)	2–3 weeks × multiple cells
Annual cal cost	Near zero	2–4 cells × $1 500–$2 500
Revenue during downtime	Full capacity maintained	Lost or deferred
Shipping damage risk	None (built-in standards)	Real risk per shipment

> *No equipment = delayed or lost revenue. Faster turnaround combined with low uncertainty reduces calibration headaches and lowers total cost.*

8. Decision Rules: A Simplified Guide

8.1 The Three Core Approaches

Simple Acceptance: Highest risk. Only appropriate when TUR > 4.6:1 or consequences are minimal.

Specific Risk (guard-banded): Evaluates each result. Guard bands consume tolerance but provide point-by-point risk control. See Section 3.3 for cost implications.

Global Risk (Method 6): At TUR ≥ 4.6:1, guard band drops to zero and global PFA stays below 2 %. See Section 3.1 for cost implications.

8.2 The Shared Risk Trap

Some labs state a guard band of w = 0 has been applied. This means **no guard band has been applied.** Under shared risk, the consumer accepts up to 50 % PFA. If the UUT carries uncorrected bias, effective PFA can exceed 50 %.

ISO/IEC 17025:2017 Clause 7.1.3 requires the customer agree on the decision rule when conformity statements are made. If you choose not to decide, you still have made a choice—shared risk.

> *Under shared risk, your customer could face much higher risk than intended. The decision rule must be agreed upon during contract review.*

9. Implementation Checklist

Use as purchase order or statement-of-work language:

1. Decision Rule: "Calibrate using a decision rule constraining PFA to ≤ 2 %. If shared risk, ensure TUR ≥ 4.6:1; otherwise apply guard bands."

2. Uncertainty: "Report expanded uncertainty (k = 2). Required U ≤ T / 4.6 unless guard bands are used."

3. Traceability: "Unbroken chain to SI with uncertainties at each stage."

4. Calibration Direction: "If device will be used for descending measurements, calibrate in both ascending and descending modes with separate curves."

5. Reliability: "Provide or accept EOPR data; adjust intervals to maintain target risk."

6. Lead Time: "Commit to a turnaround time. Quantify revenue impact of extended lead times."

7. Standard Coverage: "Specify minimum loading percentage for reference standards. Understand the number of standard changes, cycle time, and annual maintenance cost implications."

Morehouse Instrument Company meets all selection criteria. With primary deadweight standards to 120 000 lbf, dual accreditation (NVLAP 600259, A2LA 1398.01), CMCs 10–50× lower than typical secondary labs, and 7–10 day turnaround.

Appendix A: Glossary of Terms

For quality managers and purchasing agents evaluating force calibration equipment and providers.

CMC: Calibration and Measurement Capability. The smallest uncertainty a lab achieves under normal conditions.

TUR: Test Uncertainty Ratio. Tolerance ÷ (2 × U_{95}). Higher = more confident decisions. Target: ≥ 4:1.

PFA: Probability of False Accept. Device called “in tolerance” when actually out. Target: ≤ 2 %.

PFR: Probability of False Reject. Device called “out of tolerance” when actually good. Creates rework costs.

Guard Band: Inward offset from tolerance that tightens acceptance to control PFA. Increases PFR.

Method 6: Dobbert Managed Guard Band. Controls global PFA to ≤ 2 %. At TUR ≥ 4.6:1, guard band = zero.

EOPR: End-of-Period Reliability. Proportion in tolerance at end of cal interval. ≥ 89 % satisfies PFA ≤ 2 %.

LLF: Lower Limit Factor (ASTM E74). Statistical estimate of calibration equation error.

Global Risk: Risk calculated across the entire population of instruments. Uses historical averages. Can be optimistic.

Specific Risk: Risk evaluated for each individual measurement result. Uses bench-level data. Typically stricter.

Shared Risk: No guard band applied. Consumer accepts full uncertainty risk. PFA can reach 50 %+.

UPC: Ultra-Precision Load Cell. CMC: 0.005–0.02 %. Best for TUR ≥ 4:1 targets.

PC: Precision Load Cell. CMC: 0.01–0.04 %. Often the best value for many labs.

Deadweight Standard: Calibrated mass stacks corrected for gravity and buoyancy. Uncertainty as low as 0.002 %.

Standard Change: Swapping one reference load cell for another during a calibration run. Each adds cycle time.

Minimum Loading: Lowest percentage of a load cell’s capacity at which it can be reliably used. Typically 10–20 %.