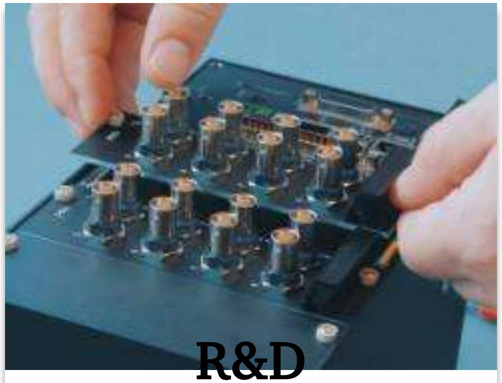
Where WIM Enforcement Meets Metrology

David Alumasa
CAMEA

CAMEA Culture

IN
#BRNOREGION
SINCE 1995



R&D
ORIENTATION
COOPERATION
WITH
UNIVERSITIES

CONTINUOUS
IMPROVEMENT
AND
CUSTOMIZATION

MINIMUM
OUTSOURCING
AND FULL
CONTROL

Experienced WIM Direct Enforcement Systems Supplier

2011	2013	2021	2022	2023
World's 1st Type Approval in CZ	Type Approval in RU	Type Approval in UA	Type Approval in AT and KE	OIML R-134 Type Approval

Extensive Exprerience Worldwide

950+
lanes

WEIGH-IN-MOTION

300+
lanes

WIM DIRECT ENFORCEMENT

600+
lanes

SPEED ENFORCEMENT

1,650+
lanes

ITS WORLDWIDE

We Produce the Key Components

MEASUREMENT UNIT

SMART CAMERA

WEIGHING SENSOR

CAMEA SOFTWARE

Two Metrological Problems

Engineering/Statistical Metrology

- Characterizes measurement performance statistically.
- Evaluates bias (systematic error), standard deviation, repeatability and reproducibility.
- Supports calibration, optimization and long-term stability monitoring.

Legal Metrology

- Defines legally binding requirements for regulated measurement.
- Uses Maximum Permissible Error (MPE), verification and traceability.
- Requires each legally used measurement result to satisfy the applicable decision rules.

OIML R-134: LS-WIM Logic in HS-WIM

Parameter	LS-WIM (OIML R-134 Design)	HS-WIM (Real Road Reality)
Speed Environment	Controlled (<15 km/h)	Free-flow (up to 120+ km/h)
Vehicle Dynamics	Insignificant (quasi-static state)	Violent tire-road oscillations
Pavement Influence	Controlled platform (>30 m)	Uneven highway pavement profiles
Lab Similarity	Highly repeatable (lab-like)	Stochastic, environment-dependent

The R-134 Gap: Unlike controlled low-speed weighing, HS-WIM cannot be validated primarily by laboratory simulation.
The pavement, vehicle dynamics and driving behavior are part of the measurement chain.

The Field Challenge

Slide 1/2

Laboratory tests cannot fully reproduce the dynamic forces of a heavy vehicle traveling at high speed on a real road profile. Therefore, HS-WIM certification and verification must include field tests at different:

- speeds,
- loads,
- vehicle configurations,
- suspension types,
- lateral lane positions,
- temperature and seasonal conditions.

The Field Challenge

Slide 2/2

The aim of these tests is not simply to derive a statistical interval. The aim is to demonstrate that:

1. valid passes meet the relevant MPEs,
2. the system correctly detects and rejects passes outside the approved operational domain,
3. the calibration model is stable under relevant operating conditions,
4. the collision and decision rule sufficiently protect vehicles below the limit.

Introduction to HS-WIM Proof of Concept (PoC)

Real-World Validation

Demonstrating HSWIM technology reliability and accuracy under actual traffic and environmental conditions.

The Path to Type Approval

A PoC serves as the vital first step to verify system performance before entering the official Type Approval process.

Key Evaluation Metrics

- **Weight Accuracy:** meeting strict national standards/regulator requirements (e.g., target maximum permissible error: ±5 % for gross vehicle mass).
- **Vehicle Identification:** integrating and validating automated number plate recognition (ANPR) systems.

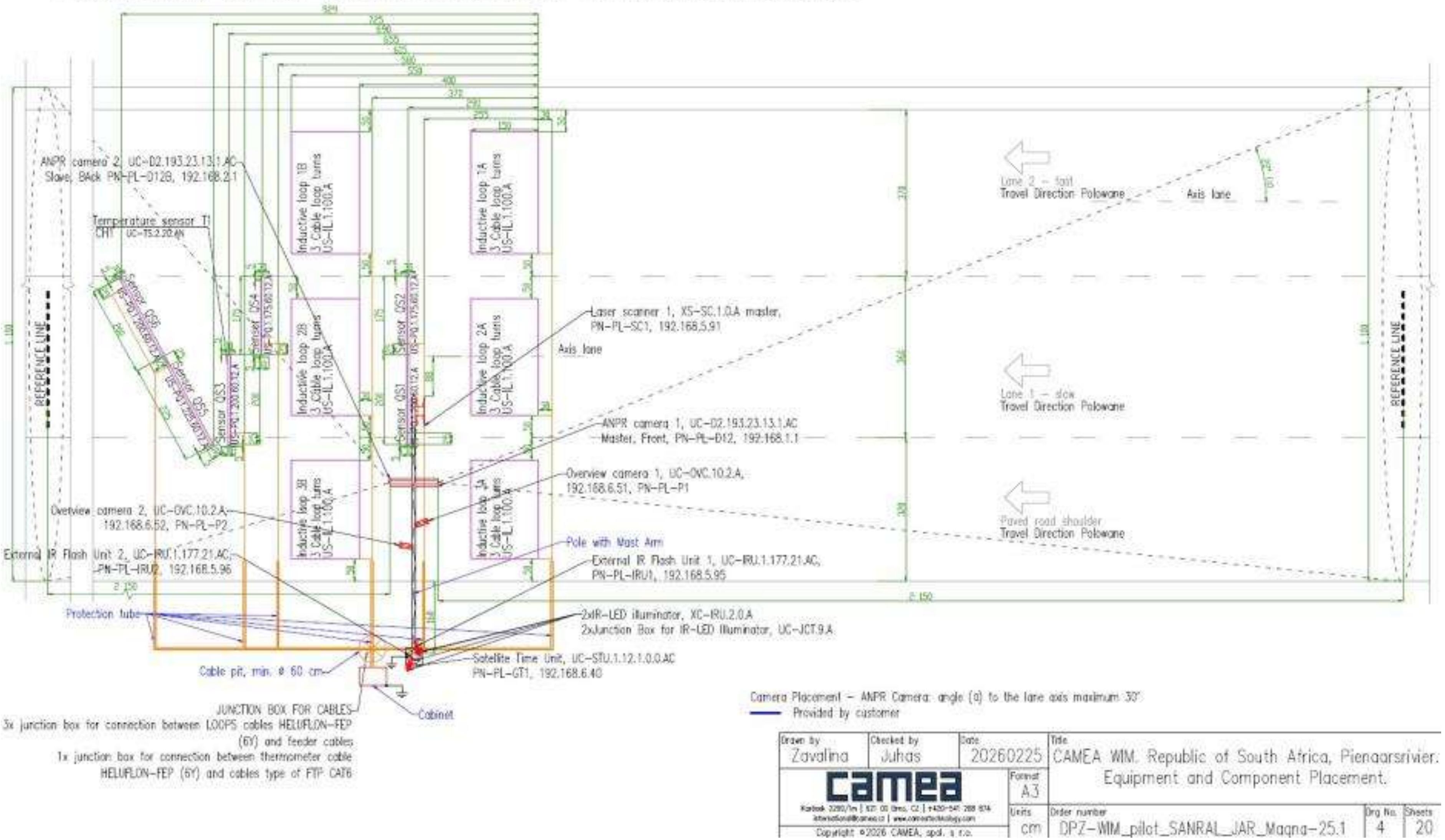
HS-WIM Proof of Concept (PoC) Layout

Road quality must match all specifications according COST323 I Excellent road quality class including all additional requirements mentioned in COST323 document.

One row of sensors must be perfectly straight. The left right position difference must be below 2 cm. A difference of 0 is preferred.

Each sensor which is not interconnected should be grounded separately.

— Sensor expansion joint: length = 300 mm, width = 4–8 mm, distance from the edge of the sensor = 50 mm. Fill the expansion joint with grouting compound.



PoC Methodology: The Mantsole Framework

Case Study

Poc Methodology: Comprehesive Fleet Test

- Load cases: fully loaded (100 % capacity) vs. partially loaded (50 % capacity).
- Various truck configurations:

Poc Methodology: Speed & Pass Matrix

- Testing across the entire operational speed spectrum (e.g., 50 km/h, 70 km/h, and 90 km/h).
- Targeting a robust sample size (e.g., 360 total controlled test runs) to ensure statistical r

Poc Methodology: Ground Truth Verification

- Cross-referencing HSWIM data against certified Static Reference Scales (Weighbridges)

Operational Setup & Market Cooperation

Seamless Infrastructure Integration

Installing WIM sensors in a dedicated test section upstream of existing Traffic Control Centres (TCC) or toll plazas.

Continuous Evaluation

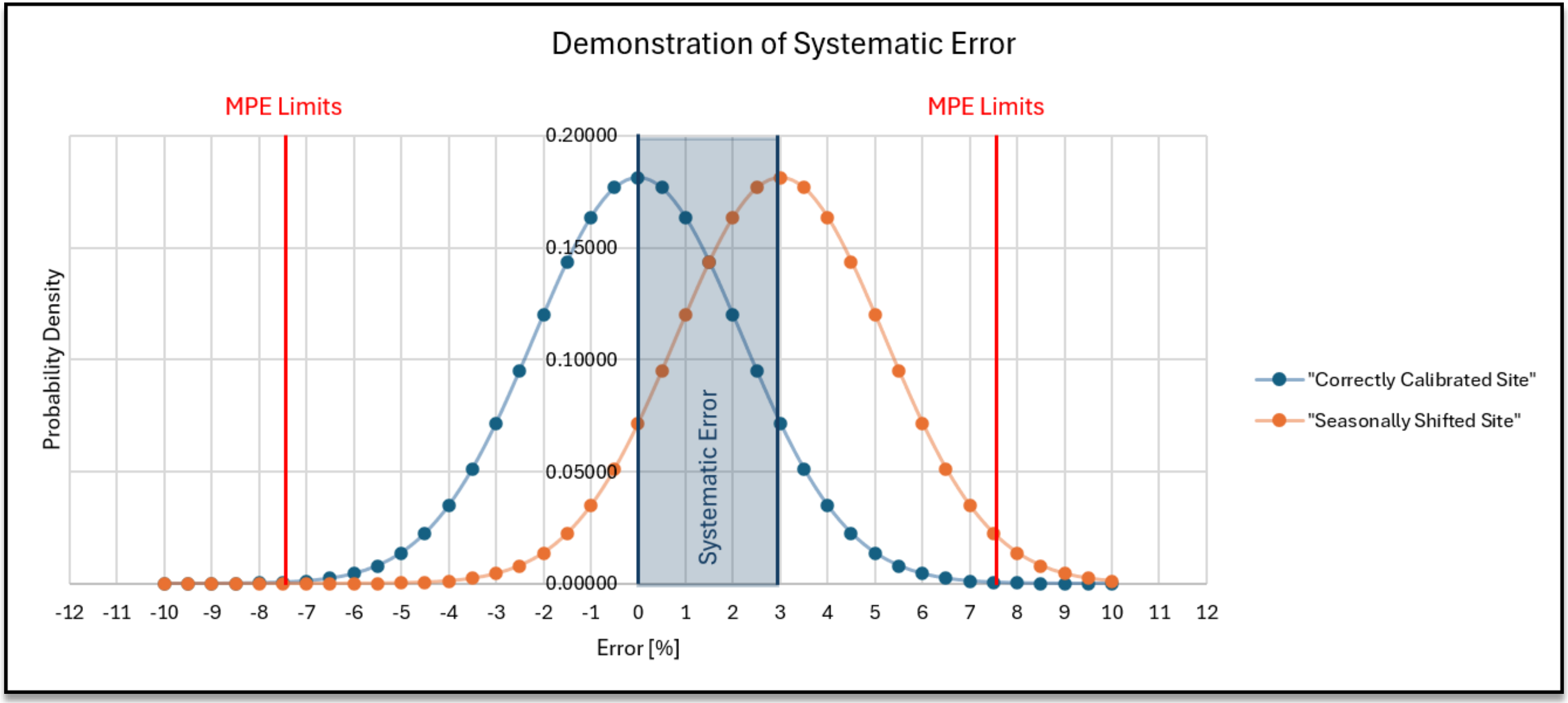
Combining controlled test runs with a 90-day random sample analysis of routine heavy traffic.

Our Goal for Local Partnership

- To align the PoC with your current regional and legislative priorities.
- To understand local market requirements and establish a clear roadmap for future deployment.

Road Selection & Seasonal Calibration

- Road quality is the foundation of every WIM site
- **Seasonal calibration:** Seasonal shift in coefficients (summer vs. winter)
- Site selection criteria are essential for measurement stability



Limits of HS-WIM Technology in Practice

WIMe Performance Ranked by % Excessive Errors

Error Type	Sample	Mean [%]	StDev [%]	5% MPE Exceeded	
				Count	Exceeded by [%]
Technology 1	**346**	**0.8**	**1.7**	**5**	**1**
Technology 2	348	1.3	1.9	6	2
Technology 3	347	-0.2	2.3	10	3
Technology 4	348	-0.9	2.2	14	4
Technology 5	323	2.3	1.8	20	6
Technology 6	348	-2.2	2.9	56	16
Technology 7	339	-2.8	4.0	104	31
Technology 8	344	-4.3	4.2	154	45
Technology 9	343	-5.0	5.8	198	58

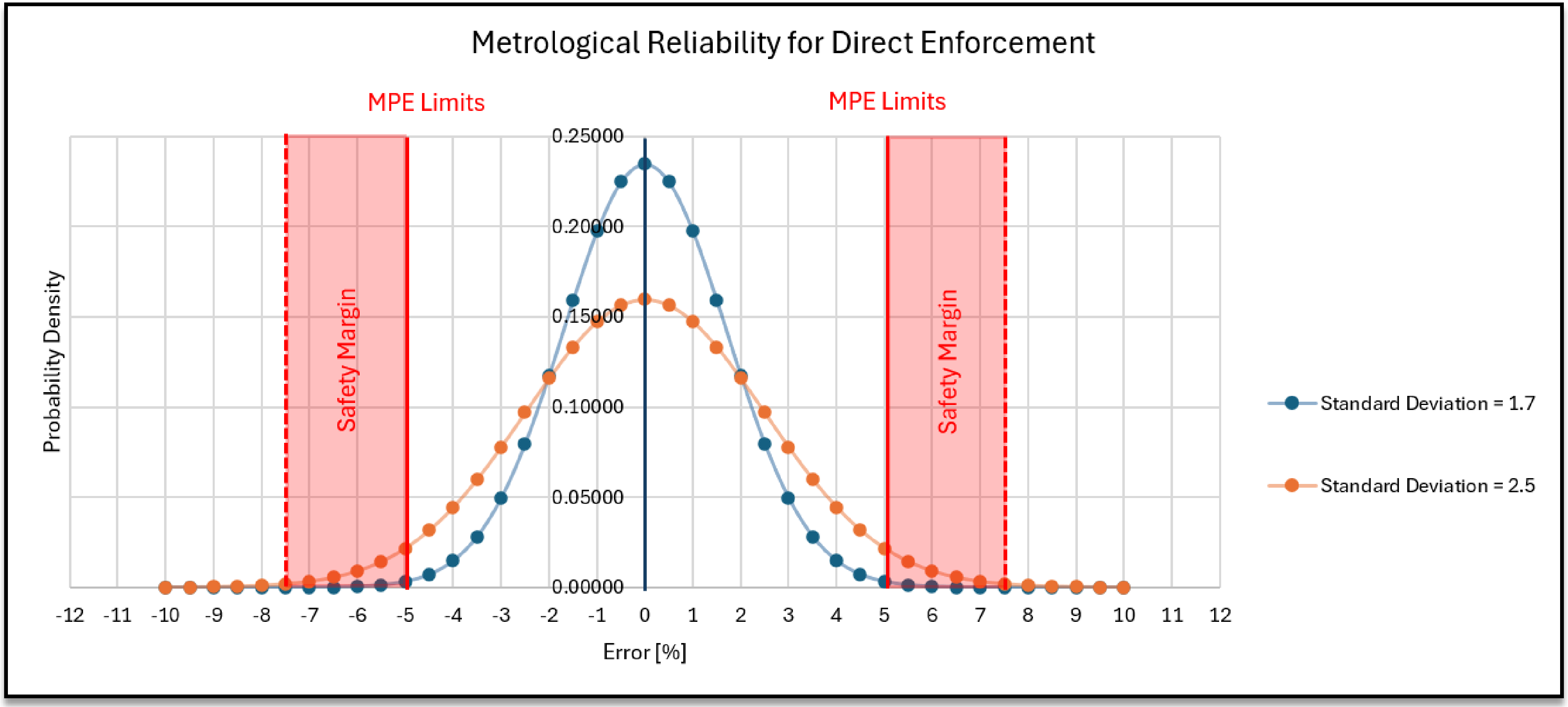
Real PoC Test: Nine WIM technologies tested on same roadway under comparable conditions using the same reference vehicle program. The chart shows the measured performance spread across tested technologies and installations.

If the standard deviation for a particular installation is, for example, 5.8 % and the assessed MPE is 5 %, then even with zero bias, most individual measurements will not be safely within the MPE.

Statistical Probability vs. Legal Certainty

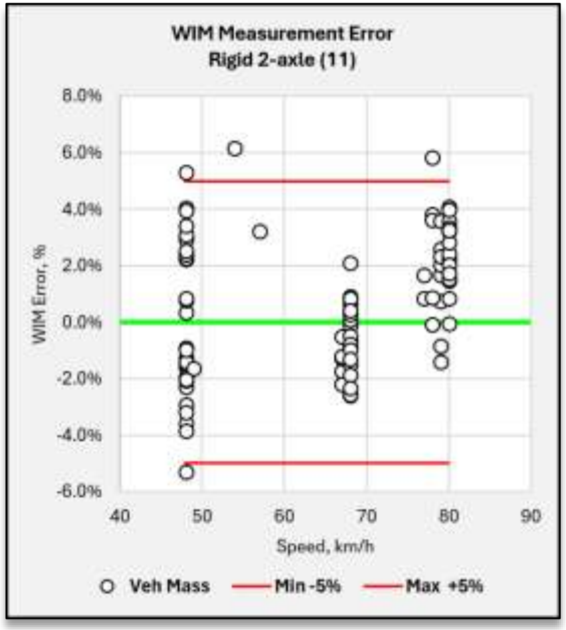
Direct enforcement requires legally defensible risk control based on MPE, validation, monitoring and a decision margin protecting compliant vehicles.

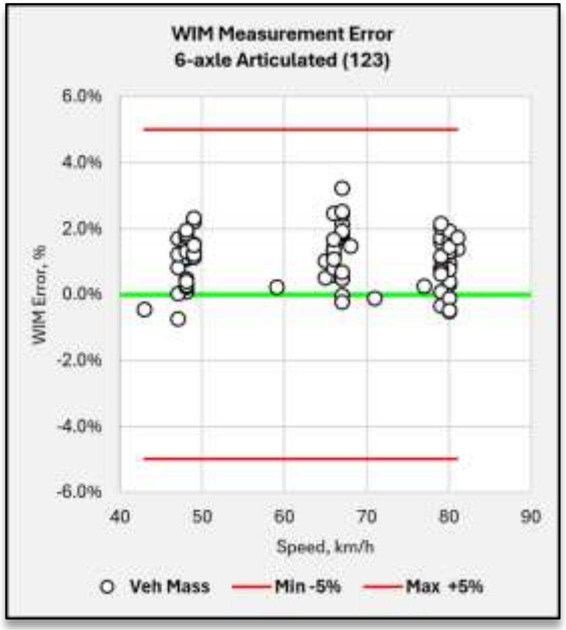
0.33% Violation risk for σ = 1.7
4.55% Violation risk for σ = 2.5

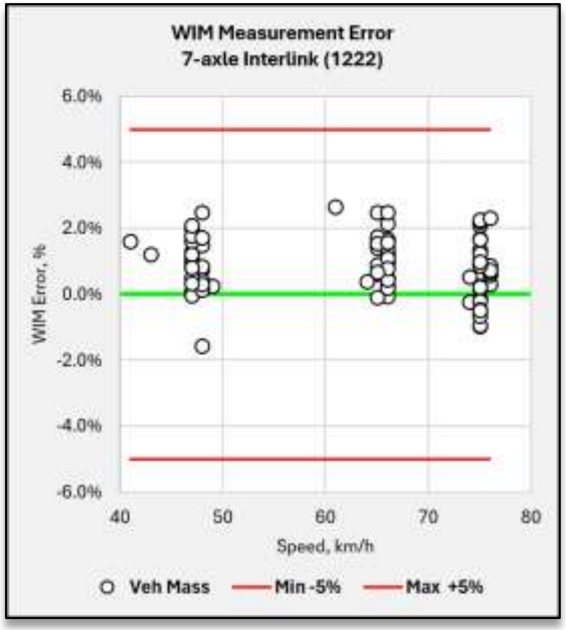


Real On-Site Data
(OIML R-134 Issues)

- Primarily designed for Low-Speed WIM (LS-WIM)
- High-speed 6-axle vehicles are more stable than 2-axle (R 134 states the opposite)
- Testing with unloaded vehicles is irrelevant for HS-WIM Direct Enforcement







ANPR Audit Performance

Proof of Concept verification metrics (May 13, 2026)

Evaluation Parameter	SANRAL Target	Front ANPR camera	Rear ANPR camera	Compliance Status
Trigger Rate	≥ 95.0%	99.1%	98.7%	Compliant
Capture Rate	≥ 92.5%	99.1%	96.6%	Compliant
Correct Read Rate	≥ 90.0%	98.4%	90.7%	Compliant

ANPR Reading Issues

Validation Through Metrological Interlocks

- **Interlocks as safeguards:** Mandatory digital "locks" that invalidate measurements taken under improper conditions.
- **Detection of weighing avoidance:** driving outside the lane, braking/acceleration on sensors, driving in a zig-zag pattern.
- **Proposed OIML parameters:** lateral position, acceleration/deceleration, maneuvers.

Flag Index	Text EN (WEB)	Validation W	Validation V	Validation S	Description
1	Failed to measure wheel position	1	0	0	System failed to measure left or right wheel position. Possible reasons: • Light vehicle or axle (below certified weighing range). • Wheel positioned on or beyond sensor. • Position sensor malfunction. Measurement error can also be caused by heavy vehicles in combination with flexible road surface.
2	Accelerating	1	1	1	Vehicle acceleration exceed the threshold. High acceleration creates additional forces that disturb weight measurements and affect speed measurement accuracy.
3	Decelerating	1	1	1	Vehicle deceleration exceed the threshold. High deceleration creates additional forces that disturb weight measurements and affect speed measurement accuracy.
4	Non-uniform driving	1	1	1	Vehicle speed variation exceeds the threshold. Variation is evaluated using axle speeds. Differences may indicate acceleration, deceleration, or brief driver actions (e.g., braking, gear changes).
5	Chassis vibration	1	0	0	Differences between axle weight measurements from individual sensor rows exceed the threshold. This indicates increased weighing uncertainty. Primary causes: • Vehicle technical condition and load. • Road quality (uneven surface affects suspension and induces oscillations).

Interlock/validation, what should the system generate and under what conditions?

Slide 1/3

The Reality of Weighing Avoidance (The "Cheating" Problem)

- Drivers actively exploit system weak spots to avoid detection.
- Up to 25 % of all vehicles (e.g., 21.9 % of heavy trucks >10 t in KSA) intentionally cheat road sensors.
- Common maneuvers: lane-straddling (driving between lanes) or driving on the road shoulders.
- Standard WIM layouts fail to capture these drivers, rendering standard enforcement ineffective.

Interlock/validation, what should the system generate and under what conditions?

Slide 2/3

The Role of Validation Flags (Metrological Interlock)

- WIM system must generate precise validation flags for every single passage to determine the legality and certainty of the measurement.
- If a vehicle maneuvers outside the calibrated zone, the system must not just discard the data – it must log it as an intentional enforcement violation.

Interlock/validation, what should the system generate and under what conditions?

Slide 3/3

Multi-Sensor Data Fusion for Bulletproof Documentation

- **Sensors:** Must detect exact lateral vehicle position (tire footprint on/off the sensor edge).
- **OVW Cameras:** Visual proof of lane-straddling or shoulder driving.
- **3D scanners:** Volumetric and trajectory tracking to map the exact path of the vehicle over the sensor array.

Does it make sense to weigh empty vehicles?

Slide 1/3

Purpose-Driven Metrology vs. Economic Efficiency

- Unlike commercial scales (e.g., in quarries), direct enforcement has a strictly binary legal purpose: to detect and penalize overloads.
- The critical "target zone" for enforcement begins exclusively at the legal limit (40 t+).
- Wasting track-time on public highways to perform dozens of calibration runs with empty trucks (axle loads of 2 to 3 t) is economically and operationally unjustifiable.

Does it make sense to weigh empty vehicles?

Slide 2/3

Algorithm Optimization (Avoiding Low-End Noise)

- Empty, unladen trucks with stiff suspension suffer from extreme high-frequency dynamic noise (axle hop).
- Forcing the calibration algorithm to adapt its curve to these highly chaotic, low-weight data points risks distorting accuracy in the high-weight zone.
- It is metrologically superior to calibrate the WIM system as a single-range system, optimizing the mathematical model strictly for the **35** to **50 t+** spectrum.

Does it make sense to weigh empty vehicles?

Slide 3/3

Measurement uncertainty at very low vehicle masses has no direct legal consequence for overload enforcement, provided such results are not used to generate overload penalties.

Would it be good to have more accuracy classes for High-Speed WIM?

Slide 1/4

Road Infrastructure as a Metrological Variable

- Vehicle inertia effects (body bounce, axle hop) are directly triggered by road roughness (IRI).
- Driver maneuvers (braking, acceleration, lane changes) introduce unpredictable dynamic forces.
- More accuracy classes allow the system to adapt to the reality of changing pavement conditions over time.

Would it be good to have more accuracy classes for High-Speed WIM?

Slide 2/4

The in-service enforcement class of each site must correspond to its verified current performance

- Systems should be certified to the highest standard (Class A – e.g., ±5 %) to prove hardware and algorithmic integrity under ideal conditions.
- In operation, the system applies the tolerance of a lower class (Class B – e.g., ±10 %).
- This creates a bulletproof "in dubio pro reo" (benefit of the doubt) safety margin, completely eliminating the risk of false-positive fines before a court of law.

Would it be good to have more accuracy classes for High-Speed WIM?

Slide 3/4

Expanding the Direct Enforcement Network

- Current rigid standards limit WIM deployment only to pristine, newly paved highway sections.
- Multi-class certification enables flexible deployment: strict tolerances for perfect roads, wider tolerances for older pavement.

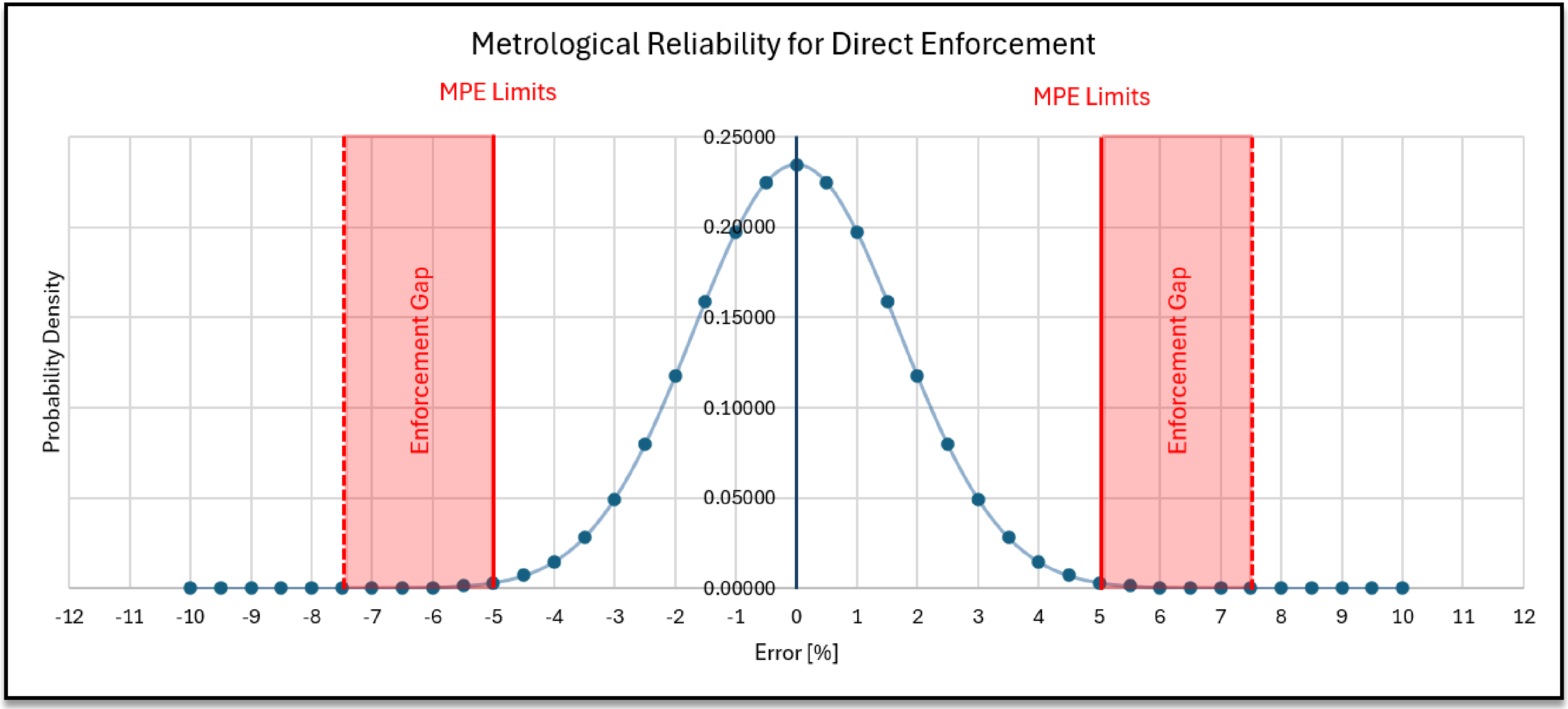
Would it be good to have more accuracy classes for High-Speed WIM?

Slide 4/4

As a result, we can catch the most severely overloaded vehicles even on sub-optimal road infrastructure.

Road Selection & Seasonal Calibration

- **The reality:** If a 5% system measures 5.5% in the field, it loses legal integrity.
- **CAMEA proposal:** Implement a 'safety margin' – if accuracy hits the MPE threshold, the enforcement class must downgrade to



Final Summary (CAMEA Proposals)

1. **Differentiation of Accuracy Classes:** Establish separate accuracy classes tailored for 2-axle vehicles and vehicles with multiple axles.
2. **Exclusion of Empty Vehicles (Trade vs. Direct Enforcement):** Exclude unladen vehicles from testing, calibration, and metrological verification. Empty vehicles exhibit the highest measurement dispersion, are never overloaded, do not damage infrastructure, and are not subject to enforcement fines.
3. **Time-Based Accuracy Degradation:** Allow stations to automatically downgrade to a lower accuracy class over time based on metrological verification. This approach extends the operational lifespan of older stations and maximizes their utility from a single testing cycle.

Key Benefit: Implementing these points will simplify the integration of Direct Enforcement into national legislations and resolve controversial bottlenecks in the certification process.

Acknowledgements

CAMEA

Magna BC