Universal Vehicle Protocols vs. Local Realities:

Systematic Gaps and Safety Risks in AV Deployment across Developing Regions

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The “Reality Gap” in Design

The Training Ground (Ideal)

Standardized, predictable, rule-based.

The Deployment Reality (LMIC)

High entropy, mixed traffic, chaotic.

Research Framework

Research Questions

Q1: Does safety performance significantly degrade in LMIC environments compared to ideal testbeds?

Q2: Which local infrastructure, human, or policy factors have the greatest impact on AV safety and adoption outcomes?

Q3: What design, regulatory, or educational changes are required for more equitable and effective AV deployment in underdeveloped countries?

Scope (PICO)

Population: Autonomous Vehicles (L3–L5)

Intervention: Operation in LMIC/Chaotic roads

Comparator: Operation in Ideal/High-Income roads

Outcome: Safety metrics (Crash/Disengagement rates)

The Human-Machine Mismatch

Universal Protocol

Algorithms assume "universal order"—clear lanes, static signs, and compliant behavior.

Environmental Entropy

LMIC roads present high variability, perceptual noise, and informal human behavior.

Perceptual Breakdown

The mismatch leads to sensor confusion, system disengagement, and safety failures.

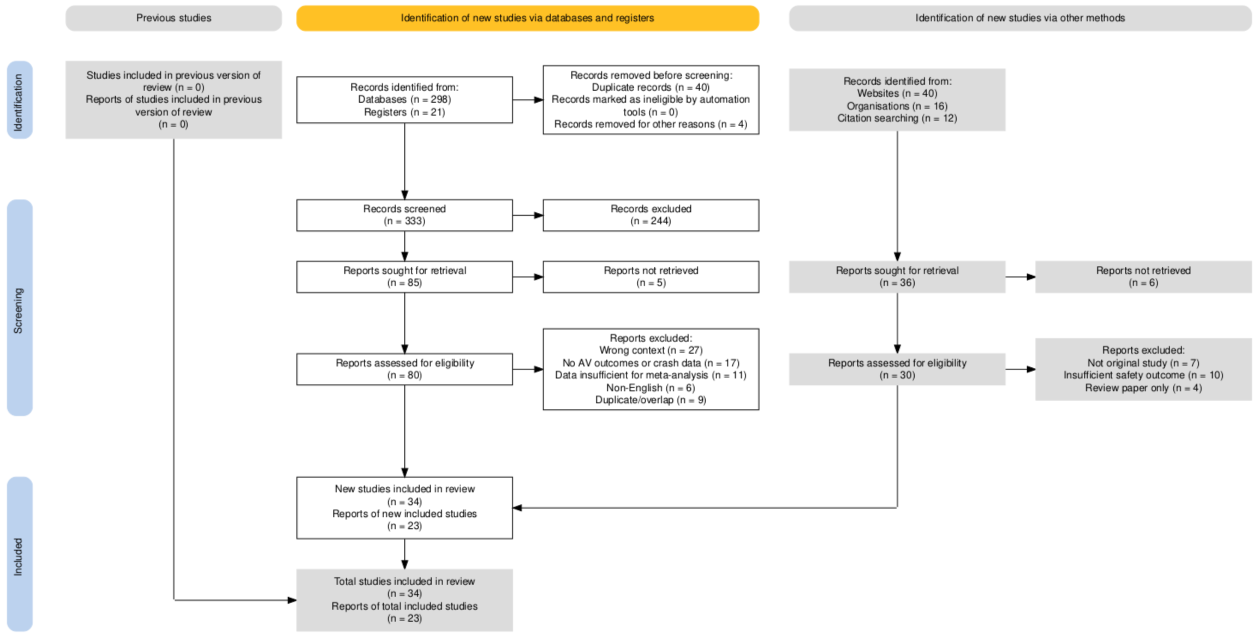
Systematic Review (PRISMA)

Rigorous Filtering: Started with 500+ records from IEEE, Scopus, and TRID.

Quality Control: Studies screened for quantitative safety data in non-ideal environments.

Final Sample: N = 34 high-quality studies included for quantitative synthesis.

Method: Random-Effects Meta-Analysis (REML) with HKSJ adjustments.



Meta-Analysis

Pooled Random-Effects Meta-Analysis:

- Pooled log RR (μ): 0.366
- 95% CI (log): −0.552 to 1.284 (HKSJ)
- τ^2 (REML): 1.399
- I^2: 98.5%
- 95% PI (log): −2.516 to 3.248

- **High Heterogeneity (I2=98.5%):** The vast inconsistency in safety results is not random; it is driven by environmental factors.

- **The "Variance" Drop:** In meta-regression, when controlling for **Road Quality** and **Detection Failures**, the between-study variance (τ2) dropped to nearly **zero** (≈0).

•*Interpretation:* Local infrastructure quality explains almost *all* the performance difference between studies.

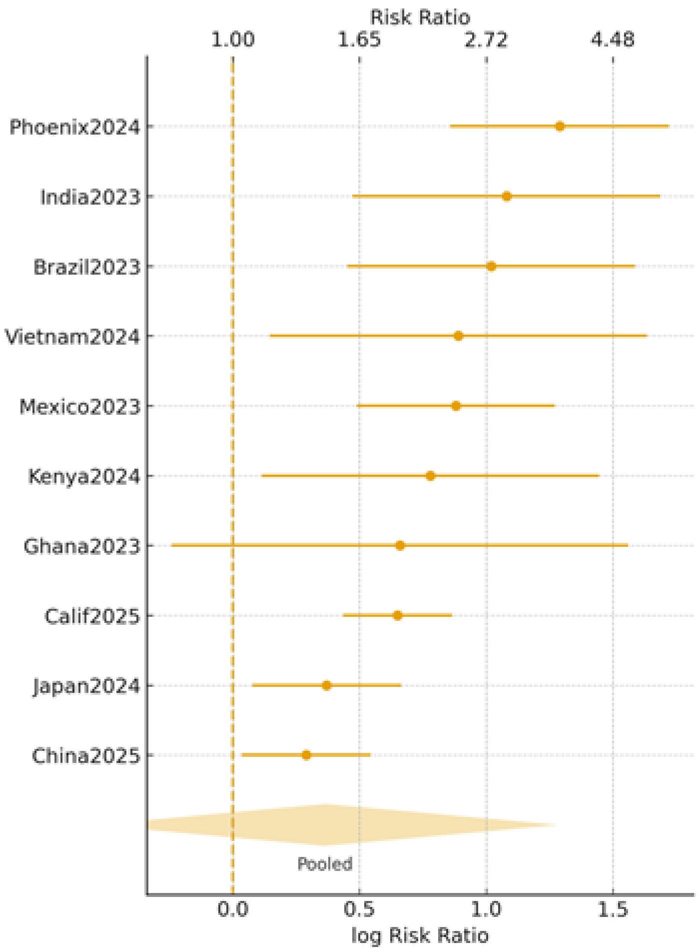
Environment as Moderator

Study Location	Road Quality	Lane Markings	Detection Failure Rate	Risk Outcome
Phoenix, USA	Good	Good	0.00%	Baseline
Mexico	Poor	Patchy	20.00%	High Variance
India	Poor	Very Poor	20.00%	High Risk
Vietnam	Poor	Patchy	30.00%	High Risk

- **Infrastructure as a Predictor:** "Worse" road quality and "Poor" lane markings are statistically associated with higher safety risks and increased intervention rates.

- **The Reality Gap:** Universal protocols perform as intended in "Good" environments (e.g., Phoenix) but degrade significantly when introduced to "Patchy" or "Poor" infrastructure.

Results – The "Context Penalty"

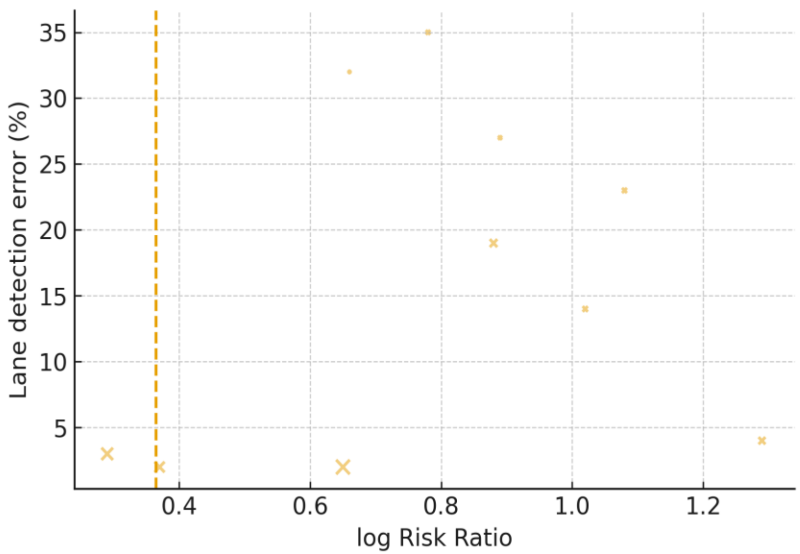


Key Findings

- **Increased Risk:** Pooled Risk Ratio of **1.44** (95% CI: 0.58–3.61) suggests ~44% higher risk in LMIC environments.
- **High Inconsistency:** I^2 = 98.5% indicates massive variability in performance.
- **Wide Prediction Interval:** Safety is not stable. A new deployment could result in vastly different outcomes depending on local context.

Why it Fails: Perceptual Overload

Regression Analysis (Detection Failures)



The Driver of Risk:
- Meta-regression of Log Risk Ratio vs. Detection Failure Rate (%).
- Slope (β) = 0.0435 ($p<0.001$).

The Trend:
- For every 1% increase in sensor detection failures, the safety risk score increases significantly.
- As sensor noise increases (due to environment), safety risk spikes linearly.

Conclusion: Infrastructure degradation directly causes perceptual breakdown.

HF/E Design Implications

For Engineers

Design for Entropy:

- Shift from "Ideal World" training to "Entropy-First" design.
- Develop perception stacks robust to 50% occlusion.
- Systems must handle informal behaviors (e.g., pedestrian jaywalking, un-laned traffic) as standard, not "edge cases."

For Policymakers

Context-Aware Certification:

- Reject "copy-paste" safety ratings from high-income nations.
- Mandate **local validation testing**. (In-situ validation).
- Adopt **Context-Aware Certification**. (A 5-star rating in Phoenix ≠ Safe in Nairobi.)

Safety is Context-Dependent

The "Universal AV" is a myth. To bridge the gap, we must design for the messy, complex human environments of the real world.

Questions?