

Development of a Parallel Level 4 Virtual Electronic Control Unit Verification Platform Based on Cloud Infrastructure

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Background and Motivation

As vehicles evolve toward software-defined architectures, ECU software verification has grown increasingly complex. Traditional HIL verification suffers from three limitations: sequential execution leads to long verification cycles; limited HIL hardware constrains concurrent team access; and each project requires dedicated environment setup. A Level 4 vECU - executing target hardware binaries (Infineon TC39x) without modification - was developed with an automotive OEM, integrating with a plant model to automate verification of 4,632 test cases. However, sequential execution and restricted accessibility across departments remained unresolved.

Key Contribution: Dependency-Based TC Classification (A/B/C)

Limitation of existing parallelization approaches: Prior work assumes test case independence, which does not hold for automotive ECU software where startup sequences, fault states, and diagnostic sessions create inter-TC dependencies. Naive parallelization without systematic dependency handling cannot guarantee correctness of verification results.

This work's solution: Systematic three-tier classification based on dependency characteristics.

- Category A - Fully Independent (76.3%, 3,536 TCs): no prerequisites → distributed across N instances → maximum parallelization
- Category B - Partially Dependent (16.2%, 752 TCs): requires specific system states → grouped by condition, executed on a dedicated isolated instance

- Category C - Sequence Required (7.4%, 344 TCs): strict inter-TC order enforced → sequential execution on a dedicated instance

This classification ensures correctness while enabling maximum speedup for the dominant Category A portion.

Container-Based Cloud Parallel Execution Architecture

All six containers execute simultaneously on cloud-hosted infrastructure: Category A across four instances (Round-Robin), Category B on a state-isolated instance, and Category C on a sequential instance.

Performance Projection

Baseline: 11 Category B TCs, 6.8 min/TC average (slowdown factor 13–15× vs. real-time). Applied uniformly as conservative upper bound across all categories.

- Total sequential baseline: $4,632 \times 6.8 \text{ min} = 524.9 \text{ hours}$ / Category A sequential baseline: $3,536 \times 6.8 \text{ min} = 400.7 \text{ hours}$

- Parallel speedup: $S(m) = 1 / (s + (1-s)/m)$, $s = 0.162$ (Cat B fraction)

At $m=4$, wall clock is driven by Cat A (100.2 h), achieving 80.9% reduction. Rationale for $m=4$: Cat A and Cat B reach near-balance (100.2 h vs. 85.2 h), keeping all instances active with minimal idle time. At $m \geq 5$, Cat B (85.2 h) becomes the bottleneck - adding one container (+17% cost) yields only +2.9% further gain: diminishing returns.

Degree (m)	Cat A (+ m instances)	Cat B	Cat C	Wall Clock (max of A, B, C)	Reduction
m = 1 (Seq.)	400.7 h	85.2 h	39.0 h	400.7 h	23.7 %
m = 2	200.4 h	85.2 h	39.0 h	200.4 h	61.8 %
m = 4	100.2 h	85.2 h	39.0 h	100.2 h	80.9 %
m = 5	80.1 h	85.2 h	39.0 h	85.2 h	83.8 %
m = 6	50.1 h	85.2 h	39.0 h	85.2 h	83.8 %

Sequential baseline: 4,632 TCs × 6.8 min = 524.9 h · Cat B: 752 × 6.8 min = 85.2 h · Cat C: 344 × 6.8 min = 39.0 h
 Sequential fraction $s = \text{Cat B} / \text{Total} = 85.2 / 524.9 = 0.162$. Cat B becomes the system bottleneck at $m \geq 5$.

Accessibility Improvement via Cloud Deployment

The proposed cloud-based platform is expected to significantly reduce the barrier to entry for related development teams. Environment setup time is projected to decrease from 3–5 days to under 30 minutes. Multiple teams can access isolated verification instances simultaneously, eliminating the single-user resource constraint of the conventional on-premises setup.

Conclusion and Future Work

A cloud-based parallel verification platform for Level 4 vECU is proposed, with dependency-based TC classification (A/B/C) as the core contribution enabling correct parallelization. Projected results: 80.9% verification time reduction at $m=4$ (conservative estimate based on Cat B measurements; actual gains expected to be greater); environment setup time reduced from 3–5 days to under 30 minutes. Full-scale validation (~4,600 TCs) and deployment on actual cloud infrastructure are planned.