

Supplementary Materials

Protocol-Realized Compensation and Latent Joint Service Vulnerability in Dynamic Vehicular Ad Hoc Networks

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Table S1 provides the complete component-stability summary. Table S2 summarizes the negative and boundary evidence retained for interpretation.

Table S1. Complete component-stability summary.

Panel A. Original summary fields.

Component	Pairwise Spearman median	3-versus-4 split Spearman median	Split top-five Jaccard median	Interpretation
e	0.9546	0.9945	0.6667	high independent seed reproducibility
rho	0.8702	0.9600	0.6667	high independent seed reproducibility
s	0.9371	0.9759	1.0000	high independent seed reproducibility
c	0.3834	0.6322	0.1111	intermediate independent seed reproducibility
g	0.3255	0.5230	0.1111	intermediate independent seed reproducibility
r	-0.0146	-0.1926	0.0000	low independent seed reproducibility
d	0.2871	0.3347	0.6667	low independent seed reproducibility

Notes. All stability coefficients and Jaccard indices are dimensionless. Components are e, ρ (rho in the data file), s, c, g, r and d. The original summary contains seven components and eleven fields; Panels A and B partition its columns without omitting a component or numerical value. The interpretation labels reproduce the original classifications with spaces replacing underscores.

The analysis domain contains 144 snapshot-node units, seven seeds, twelve snapshots and three dates (1,008 observations). The independent comparisons split the seven seeds into groups of three and four. Jaccard summaries concern the top five nodes. These units are not message-fate census rows or independent city deployments.

Panel A retains the distinct pairwise, independent 3-versus-4 split and top-five Jaccard summary levels; none is a newly calculated pooled or across-date statistic. Values are displayed to four decimal places; the underlying analysis values are retained at full precision in the source workbook.

Table S1. Complete component-stability summary continued

Panel B. Date-specific split-Spearman and top-five Jaccard medians.

Component	2026-05-18 Split Spearman	2026-05-18 Top-five Jaccard	2026-05-20 Split Spearman	2026-05-20 Top-five Jaccard	2026-05-23 Split Spearman	2026-05-23 Top-five Jaccard
e	0.9994	1.0000	0.9791	0.6667	0.9962	0.6667
rho	0.9564	0.6667	0.9899	0.6667	0.9172	1.0000
s	0.9763	1.0000	0.9702	1.0000	0.9988	1.0000
c	0.7668	0.1111	0.1489	0.1111	0.6322	0.2500
g	0.8298	0.4286	0.1295	0.0000	0.5104	0.1111
r	-0.0553	0.2500	-0.1716	0.0000	-0.2833	0.0000
d	0.4577	0.6667	0.3614	0.4286	0.2118	0.6667

Notes. Each date-specific value is the corresponding original within-date summary. Table 2 in the main manuscript reproduces only the three date-specific split-Spearman columns, rounded to four decimal places; it is not a pooled estimate. The separate top-five Jaccard columns and the original summary fields in Panel A are retained here.

The editable workbook retains the complete summary and original decimal precision. Values exceeding fifteen significant digits are stored as text to preserve their precision.

Table S2. Negative and boundary evidence retained for interpretation.

The seven evidence domains below summarize the negative and boundary findings retained for interpretation. The final column identifies the related manuscript sections.

Evidence domain	Analysis / question	Result	Interpretation	Boundary on manuscript claim	Related manuscript section
Net-damage stability	Is net-damage ordering stable across seeds?	The predefined stability criterion was not met.	A common net effect is not a stable ranking endpoint.	A nonzero net effect does not establish a stable node-ranking endpoint.	Sections 3.1–3.2
Compensation modeling	Do compensation models establish robust incremental value?	Compensation contained learnable signal, but robust incremental value was not established across the required comparisons.	Support for service structure is distinct from support for a new model.	Learnable compensation does not by itself establish robust incremental model value.	Section 4.4
Expanded modeling	Do expanded models meet all evaluation criteria?	No single model met all criteria together.	No new ranking-model contribution is claimed.	The evidence does not support a new ranking-model contribution.	Section 4.4
Provider concentration	Does replacement-provider concentration give a unified pair mechanism?	Primary mean-HHI–J2 association: Spearman $\rho = -0.2933$ (100 fixed pairs); 95% date-cluster interval $[-0.4257, 0.0654]$ includes zero.	Provider concentration alone did not give a consistent unified explanation.	Concentration alone is insufficient as a unified explanation of pair loss.	Section 4.4

Table S2. Negative and boundary evidence continued

Evidence domain	Analysis / question	Result	Interpretation	Boundary on manuscript claim	Related manuscript section
Triple descriptors	Do low-dimensional triple descriptors explain the pattern?	No clear mechanism pattern was established.	Retain heterogeneity rather than a single descriptor.	The tested descriptors do not establish a single explanation of triple heterogeneity.	Section 4.4
Exposure–compensation phase	Does the exposure–compensation phase view enrich high pair loss?	In the fixed 70-pair, three-date overlay, high-exposure/high-compensation constituent count was positively associated with repaired J2 (Spearman $\rho = 0.3946$, 95% date-cluster interval [0.0482, 0.4530]).	Positive descriptive association in this three-date overlay; cross-date stability over seven dates is not established.	The phase regions are not causal categories or validated predictors beyond the evaluated overlay.	Section 4.4
Protocol generalization	Is cross-protocol robustness confirmed?	The reported numerical estimates use the AODV routing realization.	Protocol-transferable definitions do not establish protocol-invariant numerical results.	Interpret the numerical estimates as AODV-conditioned; proactive and alternative reactive routing require matched cross-protocol validation.	Section 4.5

Notes. Provider concentration retains its primary negative boundary. The phase association is descriptive for a fixed three-date overlay, not a causal or seven-date-stable predictor. The numerical results remain AODV-conditioned.

Table S3. Fixed-demand communication-radius sensitivity (seven preselected snapshots, 16 flows per snapshot, three primary seeds and 168 fixed pairs).

Metric	R100	R150	R200	Interpretation
Baseline delivery / attempted	12.69%	39.98%	47.18%	Fixed 16-flow demand; R-specific q_0
Exposure-positive single worlds / 375	84	234	158	Positive exposure ($e > 0$)
F2-bearing single worlds / 375	40	118	119	F2 occurrence; no post hoc exclusion
Median node e (three-seed mean)	0.0000	0.0347	0.0013	Exposure magnitude; not an equality criterion

Metric	R100	R150	R200	Interpretation
Median defined node rho	0.2792	0.1219	0.7093	Undefined zero-exposure rho omitted, not set to 0
Median node s (three-seed mean)	0.0000	0.0093	0.0000	Systematic-risk magnitude
F2 messages / valid paths	248 / 248	1158 / 1158	999 / 999	F2 replacement-path completeness
F2 messages with provider occurrence	236	1085	900	Empty replacement segment can still have valid successful path
Dependency-J2 pooled Spearman (168 pairs)	0.4361	0.4638	0.3022	Primary pooled association for the fixed-168-pair panel; distinct from the main 336-pair R150 estimate
Dependency-J2 pooled Kendall	0.4117	0.4135	0.2696	Complementary Kendall rank association
Positive date-wise Spearman / 7	3 / 7	7 / 7	4 / 7	Undefined and nonpositive dates reported separately
Negative date-wise Spearman / 7	0 / 7	0 / 7	1 / 7	Defined negative R200 date: 2026-05-21
Undefined date-wise Spearman / 7	4 / 7	0 / 7	2 / 7	Constant rank inputs; never encoded as zero

The predefined interpretation across this panel is partial range sensitivity: the phenomena persist but their magnitudes and date patterns vary. Undefined date-wise correlations reflect constant rank inputs and were not treated as zero. The R150 fixed-168-pair estimate is not the main 336-pair estimate. J3 was not tested across radii.

Table S4. Illustrative J2 versus J3 comparison (not empirical data).

Feature	J2	J3
Loss universe	Exposure-conditioned F1 losses in pair and single worlds	Complete baseline-success service losses in triple and pair worlds
Subtraction	Pair F1 minus union of constituent single F1	Triple loss minus union of three constituent pair losses
Interpretation	Irreducible pair loss beyond single F1	Residual triple loss beyond constituent pair representation
Illustrative identities	$U_i = \{m_1, m_2\}$; $U_j = \{m_2, m_3\}$; $U_{ij} = \{m_1, m_2, m_3, m_4\}$; J2=1/10 at S0=10	Pair loss union= $\{m_1, m_2, m_3\}$; triple loss= $\{m_1, m_2, m_3, m_5\}$; J3=1/10, $R3 = (1/10)/(4/10 + 10^{-12}) \approx 0.25$

Supplementary sampling and stability protocol note.

The 16-flow demand is generated from taxi/bus endpoints with valid 0/60/120 s positions. Sources rotate through 1 km grid/type/stable-ID order; destination candidates require static 2–4-hop vehicle-graph reachability, are ordered by type/hop/grid and endpoint use/ID with fallback, and the first 16 nested candidates are frozen within each snapshot. Candidate hops are not realized AODV hops; the resulting demand is not a random traffic sample.

Pair snapshots: from complete-input candidates, each of seven dates contributes the largest mean baseline-success snapshot and one nearest the remaining within-date median, with snapshot-ID tie-break. Each of 14 snapshots contributes 24 pairs. Eligible nodes have primary-seed single-world fate evidence and are not protected traffic endpoints. Selection order is A strongest directed dependency (98), B positive bidirectional dependency (9), C high summed single-node F1 vulnerability (56), D weak-dependency deterministic matched control (70), E deterministic hash (70), then fill (33). D uses the within-snapshot ≤ 35 th-percentile dependency-sum pool; matching preferentially preserves node-type combination and otherwise falls back to all types, minimizing standardized differences in V sums ($V=F1/S0$), baseline exposure-count sums and eligible-degree sums on the 150 m candidate graph excluding RSU–RSU links, with deterministic ties. The high/control contrast uses A+B versus D; this is not a one-to-one randomized match for every high pair.

Triple snapshots (eight triples each): 20260517_1500; 20260518_0000; 20260519_1500; 20260520_1700; 20260521_0300; 20260521_1800; 20260522_1800; and 20260523_1700. Candidate nodes have complete three-primary-seed single-world evidence and exclude protected endpoints. The fixed quota design selects A triangles with three positive undirected pair dependencies (17), B two-link directed chains with zero endpoint-pair dependency (14), C zero-pair-dependency triples sharing baseline-exposure/F2 service-flow evidence (12), and D deterministic matched non-mechanistic controls on V, service exposure and degree (21). Quotas, service-activity coverage and stratum feasibility make this a structured non-probability sample; the same 64 triples are not observed on every date.

The study-specific single-node stability acceptance rule requires leave-one-seed Spearman ≥ 0.85 , independent 3-versus-4 split Spearman ≥ 0.70 and top-five Jaccard ≥ 0.60 , each on at least two of three evaluated dates; split Spearman < 0.40 on at least two dates is clearly unsupported. This ranking rule is separate from triple stable-positive J3 (positive in at least two of three primary seeds). The four extended seeds are designated stability/QC evidence and do not enter the primary J2/dependency point estimates.