

Indonesia Trans Java Highway Speed Gap

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ORIGINAL ARTICLE

Open Access

Article History:

Received
28 Oct 2025

Accepted
15 Feb 2026

Available online
1 May 2026

ABSTRACT – This study examines speed dynamics and surrogate safety on Indonesia's Trans-Java–Cisumdawu corridor using naturalistic dashcam observations of 607 vehicle interactions across eleven segments. Segment-level summaries show substantial heterogeneity in operating speed and speed differentials ($\text{speed_gap} = v_{\text{target}} - v_{\text{source}}$). Overspeeding (>100 km/h) occurred in 45.8% of observations, with notable concentrations on Batang–Semarang, Cisumdawu, and Pemalang–Batang. Robust group comparisons (Welch's ANOVA with Games–Howell; Kruskal–Wallis) confirmed significant between-segment differences in both speed and speed gaps. A multiple linear model indicated systematic location effects on target-vehicle speed after accounting for traffic density, while a logistic model (AUC=0.876; McFadden's $R^2=0.368$) showed that overspeeding risk varies markedly by segment even after conditioning on operating speed. Tail-risk indicators – overspeeding prevalence, share of $|\text{gap}| \geq 40$ km/h, and speed dispersion (CV) – were synthesized into a Speed–Gap Safety Index (SGSI), which prioritized Batang–Semarang, Pejagan–Pemalang, and Semarang as top-tier segments. Time-headway and closing-time diagnostics (short THW/TTC) were consistent with this ordering, indicating frequent entry into closing-risk states. Findings support targeted, segment-specific management – adaptive upper-limit enforcement, speed harmonization/lane discipline, dynamic limits – and provide region-specific inputs for ASEAN NCAP/ADAS scenario calibration (e.g., $\Delta v=20\text{--}40+$ km/h at THW=0.8–1.2 s). Interpretation is tempered by the observational design, small n on several segments, and video-based measurement, but the results offer an actionable basis for prioritizing enforcement and technology evaluation.

KEYWORDS: Trans-Java toll road, speed differential, overspeeding, surrogate safety, time headway, composite risk index, ADAS, ASEAN NCAP, Indonesia

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Journal homepage: www.jsaem.my

1. INTRODUCTION

The Trans Java Highway is the backbone of Java's transportation infrastructure, efficiently connecting the island's western and eastern regions. Behind these advantages, traffic on highways carries a high potential for risk, primarily due to driver behavior, high speeds, and inadequate distances between vehicles (Zainon et al., 2018; Kadir et al., 2020). As the highway provides the advantage of facilitating travel at free-flow speed, increased speed elevates the probability of an accident (Aarts & van Schagen, 2006). A robust correlation exists between speed and accident risk. This broad association applies across all speeds and road types, although the pace of escalation in accident risk differs based on initial speed and road classification. Significant speed disparities on a roadway also elevate the probability of an accident. Moreover, drivers who exceed the average speed have a heightened risk of accidents; it is unclear whether this applies to drivers who operate at reduced speeds (European Commission, n.d.). Studies have been conducted in some developed countries to examine the impact of speed differentials

on accident risk, particularly on rear-end collisions on highways. The larger speed disparity between the trailing and leading vehicles increases the likelihood of serious injury or fatality (Wang & Abdel-Aty, 2024). However, empirical research on the speed disparity in Trans Java is still quite limited in comparison to studies conducted in developed nations.

One approach to understanding potential hazards on the highway is to analyze traffic data, including vehicle speed, distance between vehicles, and speed differences. This study aims to comprehensively describe traffic dynamics on the Trans Java Highway, supporting improvements in driving safety. The Trans Java Highway serves as a fundamental component of national logistics, playing a crucial role in the transportation of goods and people. However, significant disparities in vehicle speeds generate unstable traffic conditions and are a primary contributor to severe accidents, including rear-end collisions. Data from the Highway Regulatory Authority (BPJT) indicates that in 2023, there were 4,381 accidents on highways, leading to 336 fatalities and a fatality rate of 1.19 per 100 million trips per vehicle-kilometer (Abadi, 2024). A thorough analysis of the speed gap issue is important to decrease the fatality rate while preserving the efficacy of the Trans Java Highway as a vital logistics facility.

This study delineates three research topics to concentrate the inquiry and indicate the analytical trajectory beyond descriptive statistics: What is the degree of heterogeneity in inter-vehicle speed gaps between segments, including both central tendency and tail risk? What characteristics indicate excessive speeding (>100 km/h) and significant speed differentials (≥ 40 km/h)? How can field patterns be converted into surrogate safety measures and ADAS/ASEAN NCAP testing scenarios?

In addressing these questions, the analysis integrates *segment-level surrogate safety diagnostics*, including estimated time headway (THW) and time-to-collision (TTC), to contextualize closing-risk patterns derived from speed and spacing observations. While THW and TTC are not model covariates, they provide interpretive evidence on proximity risk and alignment with Speed Gap Safety Index (SGSI) rankings. The study thus contributes by (i) measuring cross-segment variability in speed differentials, (ii) modeling the probability of overspeeding and large differentials, and (iii) interpreting segment-level closing-risk states using derived THW/TTC indicators to inform targeted management and ASEAN NCAP/ADAS scenario calibration (Abashah et al., 2020).

2. METHODOLOGY

Speed and accident risk are strongly correlated, according to research. The probability of a collision, the seriousness of injuries, and the chance of death are all directly impacted by vehicle speed (WHO, 2024). Despite traffic signs indicating the lower and upper limits, vehicles are nonetheless permitted to travel at speeds outside of these limits on the roadway. This difference in speed between vehicles will increase the likelihood of crashes and worsen injuries. The likelihood of a collision increases with the size of the speed differential between cars, whether it be quicker or slower (European Commission, n.d.). Regulation No. 111 of 2015 about the Establishment of Speed Limits, issued by the Minister of Transportation, governs speed limits. This regulation establishes a maximum speed limit of 100 km/h on highways, alongside a minimum limit of 60 km/h (Kementerian Perhubungan, 2015). Formal legal requirements in Indonesia state that the ideal speed gap, based on these specified maximum and minimum speed restrictions, is 40 km/h.

Given the regulatory framework and empirical facts concerning the relationship between speed and crash risk, it is crucial to assess how this issue presents itself within Indonesia's highway system. The Trans Java Highway, an essential route connecting the western and eastern regions of Java, serves as a crucial case study for examining speed fluctuations and their impact on safety. An analysis of actual traffic conditions encompassing vehicle speeds, speed differentials, and inter-vehicle distances is essential for evaluating safety risks and formulating evidence-based policy recommendations, as it underpins national passenger and logistics transport. Considering this context, the research was carried out on various segments of the Trans Java Highway, which are elaborated upon in greater detail below.

2.1 Study Area

The study covers eleven linked freeway segments spanning the Trans-Java network plus the Cisumdawu connector. Segments were selected for their role in national passenger and logistics flows, enabling comparison of operating regimes that plausibly differ in geometry, traffic mix, and enforcement context. A schematic segmentation is provided to anchor subsequent between-segment analyses.



FIGURE 1: Segmentation of Trans Java Highway

2.2 Data Collection

Traffic data was collected using a single instrumented vehicle, hereafter called the "source vehicle", that travelled on the Trans Java and Cisumdawu highway. A dashcam that faced rearward and recorded at 30 frames per second was used to record the flow of traffic. The source vehicle's speed was recorded by its internal speedometer, which was then used as a reference point to figure out how fast other vehicles, which would be called "target vehicles" from here on, were going. Lane markers and kilometer signs on the side of the road were used as calibration points to make the estimated distance more accurate.

2.3 Measures and Derived Indicators

Target-vehicle speed (km/h) is the primary continuous outcome. Speed gap is defined as $speed_gap = v_target - v_source$. Two binary indicators capture tail-risk states: overspeeding ($v_target > 100$ km/h, upper-limit violation) and large differential ($|speed_gap| \geq 40$ km/h, consistent with the 100/60 regulatory band). Distributional indicators include the 85th-percentile speed (V_{85}) and the coefficient of variation (CV) of target speed. Segment-level time headway (THW) and time-to-collision (TTC) were derived for contextual interpretation of closing-risk behaviour, based on observed distance bands and segment-typical speeds:

$$THW = \frac{distance}{v_target} \quad (1)$$

$$TTC = \frac{distance}{\Delta v} \quad (\text{for closing cases } \Delta v > 0) \quad (2)$$

Because longitudinal spacing could not be tracked continuously, THW/TTC are used descriptively to support interpretation and not included as model covariates.

2.4 Descriptive Summaries and Diagnostics

For each segment, descriptive summaries report n , mean/SD, median/IQR, V_{85} , CV, and the proportions of overspeeding and $|gap| \geq 40$. Speed-gap distributions are visualized with density, violin, and box plots, while Q–Q diagnostics assess normality. These summaries and diagnostics provide the empirical base for robust group tests and for interpreting THW/TTC-related proximity risk.

2.5 Between-Segment Comparisons

Differences in continuous outcomes (speed, speed_gap) were tested using Welch's ANOVA with Games–Howell post-hoc contrasts (unequal variances) and confirmed using Kruskal–Wallis non-parametric tests. For proportions (overspeeding, large differential), Wilson confidence intervals and χ^2 tests were used, with Cramér's V quantifying association strength. These comparisons guided the subsequent modelling and segment-level THW/TTC interpretation.

2.6 Regression Models

Determinants of mean speed were analyzed through a multiple linear regression using segment (categorical) and traffic density (vehicles/km) as predictors. Given diagnostic evidence of heteroskedasticity and residual autocorrelation, heteroskedasticity-consistent (HC3) standard errors were applied; residual and Q–Q plots plus fit indices (R^2 /adjusted R^2) were examined.

A binomial logistic model predicted overspeeding ($v_{\text{target}} > 100$) using segment and source-vehicle speed. Results are reported as odds ratios with 95% CIs and overall fit (AIC, McFadden's R^2 , AUC). Quasi-complete separation (e.g., no overspeeding on Palikanci) was addressed via bias-reduced estimation or noted explicitly. THW/TTC values were interpreted as a post-model to cross-validate which high-risk segments exhibited short headways and closing times consistent with model-identified risk concentrations.

2.7 Composite Prioritization Index

A Speed–Gap Safety Index (SGSI) synthesizes tail-risk signals at the segment level:

$$SGSI = z(\% \text{ gap} \geq 40) + z(\% v > 100) + z(CV \text{ of speed}) \quad (3)$$

(all components z-standardised; higher scores denote greater concern).

THW/TTC are excluded from the index's numerical formula but used to interpret SGSI rankings, helping to explain whether high-index segments also show short-headway or short-TTC conditions.

2.8 Sensitivity Analyses

Robustness is examined by (i) repeating group tests with non-parametric alternatives; (ii) re-estimating models with HC3 errors and, where applicable, bias-reduced logistic estimation; (iii) treating density as quartiles and using a headway-based proxy; and (iv) excluding very small-n segments. Conclusions are interpreted within the observed operating range.

2.9 Limitations

This study relies on observations from a single instrumented vehicle, which may introduce selection bias in lane position, timing, and driver behaviour, limiting generalizability beyond the sampled conditions on the Trans-Java–Cisumdawu network. Speeds and inter-vehicle separations were estimated from dashcam footage; while pragmatic, video-based measures are susceptible to calibration and perspective error. Vehicle classes were not stratified, so class-specific patterns could be masked. Individual-level longitudinal spacing was not consistently available; THW/TTC were derived at the segment level and used for interpretation only, not as model covariates. Analyses are observational and correlational; causal effects and direct crash linkages cannot be established. Daytime dominance and small n in several segments temper precision, and one level in the logistic model exhibited quasi-complete separation (no violations), affecting coefficient stability for that level. Diagnostics indicated departures from ideal assumptions (non-normality, heteroskedasticity, residual autocorrelation); inference therefore used heteroskedasticity-consistent errors and is interpreted within the observed operating range. External factors (geometry, weather, work zones, incidents) were not systematically controlled. Despite these constraints, convergent evidence across robust tests, regression, and the SGSI supports the substantive conclusion that risk-salient operating states are concentrated on specific segments and can be prioritized for management.

3. RESULTS

Based on data collected through dashcams on the Trans Java and Cisumdawu toll roads, a total of 607 vehicles were recorded throughout eleven examined road segments. The average speed of source vehicles is 86.33 km/h, while the average speed of target vehicles (on the road) is 97.55 km/h, indicating a speed difference of ± 11 km/h. The Cisumdawu section has the highest average speed (108.59 km/h), while the Japek section shows the lowest average speed (84.23 km/h). The lowest vehicle density (vehicles per km) is on the Cisumdawu highway (0.21 units/km), while the highest is on the Batang-Semarang section (2.21 units/km). Vehicles with speeds < 60 km/h were found in only 7 out of 607 vehicles (1.15%), most of which were on Japek (3 units) and Solo-Ngawi (2 units). There were 278 vehicles (45.8%) with speeds > 100 km/h, indicating a significant violation of the upper speed limit. Highest sections: Batang-Semarang (117 units) and Cipali (54 units). This indicates that speeding violations are more prevalent than violations of the lower speed limit. The Cipali, Batang-Semarang, and Cisumdawu sections are a point of concern due to their high number of speeding violations. The speed gap is positive compared to other vehicles, with the three highest being on the Cisumdawu (24.65 km/h), Semarang-Solo (20.11 km/h), and Batang-Semarang (19.72 km/h) sections. This indicates a potential risk of rear-end collisions or extreme overtaking. Negative speed gap: the two lowest are the Semarang-Solo section (-23.32 km/h) and the Solo-Ngawi section (-10.08 km/h). This indicates a significant speed difference between vehicles in that section, increasing the risk of traffic conflicts.

TABLE 1: Speed observation data in Trans Java and Cisumdawu Highways

Item Observed	Unit	Section											
		All	Japek	Cipali	Palikanci	Pejalang	Pematang	Batarang	Semarang	Somar	Sowi	Wiker	Cisumdawu
Average Speed Source Vehicle	(km/h)	86,33	77,07	89,64	81,96	86,51	94,86	89,92	79,18	91,33	82,18	88,73	83,94
Average Speed Target Vehicle	(km/h)	97,55	84,23	101,08	84,43	92,89	105,40	108,75	95,80	86,30	85,18	98,88	108,59
Target Vehicle Observed	unit	607,00	94	101	34	58	34	166	13	19	38	37	13
Section Length	km	723,01	73,00	116,00	26,00	57,00	39,00	75,00	24,75	72,64	90,00	87,02	62,60
Vehicle Density per km	unit	0,84	1,29	0,87	1,31	1,02	0,87	2,21	0,53	0,26	0,42	0,43	0,21
Target Vehicle Speed under 60 km/h	Unit	7	3	1	0	0	0	0	0	1	2	0	0
Target Vehicle Speed within speed limit	Unit	322	73	46	34	39	7	49	9	10	32	21	3
Target Vehicle Speed over 100 km/h	Unit	278	19	54	0	19	27	117	4	8	4	16	10
The Lowest Speed of Target Vehicle	km/h	29,78	57,20	58,28	73,32	61,42	93,60	70,20	79,50	59,40	29,78	77,22	93,60
The Highest Speed of Target Vehicle	km/h	187,20	140,40	140,40	97,06	124,80	121,68	187,20	128,70	109,20	107,64	117,00	124,80
Average slower speed (speed gap)	km/h	-0,91	-2,84	-4,22	-2,15	-1,35	0,00	-10,10	0,00	-23,32	-10,09	-3,31	0,00
Average higher speed (speed gap)	km/h	13,76	9,86	12,96	3,39	9,15	10,54	19,72	16,62	20,11	8,44	11,78	24,65
Average Overtaking Lateral Distance	m	2,13	2,93	2,01	1,90	1,87	1,94	1,97	2,37	1,89	2,23	2,20	2,19
Closest Overtaking Lateral Distance	m	0,5	1	0,8	1	0,5	0,8	1	1,5	1	1	1	1,5
Farthest Overtaking Lateral Distance	m	4,1	4	4,1	4	3	3,5	4	4	4	3	3	3

Analysis of lateral clearance during overtaking indicates a consistent tight-passing pattern across segments. Minimum clearances generally cluster around 1.0 m and reach 0.8 m in Cipali, Palikanci, and Pejagan, even under relatively high operating speeds (≈ 93 – 105 km/h). In contrast, maximum available clearances approach ~ 4.0 – 4.1 m in Japek, Cipali, Palikanci, Batang, Semarang, and Somar, suggesting that adequate physical space exists but is not consistently used to provide safe margins. In segments with smaller maxima (≈ 3 – 3.5 m) – notably Pejagan, Sowi, Wiker, and Cisumdawu – the combination of ~ 1.0 m minima and higher speeds reinforces the need for segment-specific countermeasures. The evidence points to three priorities: stricter enforcement of overtaking discipline and “keep-right” practices; enhanced conspicuity of lane/edge markings and improved shoulder housekeeping to encourage larger clearances; and targeted restrictions on overtaking at locations with limited lateral space.

3.1 Overall Distribution of Speeds and Differentials

Across eleven segments, sample sizes ranged from 13 to 166. Speed differentials ranged from compact values on Palikanci (mean 2.48 km/h; P85 5.50) to large positives on Cisumdawu (mean 24.65; median 28.10; P85 31.30) and Batarang (mean 18.83; P85 32.00). Somar showed a negative central tendency (mean -5.03 ; median -7.80) and the widest variability (SD 25.65; IQR 37.13), suggesting frequent bidirectional closing. Batarang combined high central tendency with broad spread (SD 17.15; IQR 16.40) and extremes up to 103 km/h, whereas Palikanci remained tightly clustered (SD 2.81; IQR 2.22). Violin/box plots confirm bulky upper tails on Batarang and Semarang and a compact core on Palikanci. The extreme-gap display ($|gap| \geq 40$) is zero-inflated and shows long positive tails concentrated on the same segments. Q–Q diagnostics reveal skew and heavy tails, justifying variance-robust and non-parametric procedures.

TABLE 2: Descriptive summaries of speed gap and extreme gap in Trans Java Highway

	Segment	N	Missing	Mean	Median	SD	IQR	Minimum	Maximum	Percentiles
										85th
Speed Gap	Batarang	166	0	18.83	15.60	17.15	16.40	-14.000	103.00	32.00
	Cipali	101	0	11.43	8.32	11.43	14.14	-10.360	50.00	24.00
	Cisumdawu	13	0	24.65	28.10	11.46	7.90	3.200	46.90	31.30
	Japek	94	0	7.16	3.33	11.34	8.79	-8.260	50.00	20.00
	Palikanci	34	0	2.48	2.13	2.81	2.22	-3.120	9.91	5.50
	Pejalang	58	0	6.38	5.39	9.77	7.35	-19.260	38.64	14.73
	Pematang	34	0	10.54	8.73	6.56	9.39	2.050	26.58	17.05
	Semarang	13	0	16.62	12.50	13.48	19.10	3.100	44.50	29.64
	Somar	19	0	-5.03	-7.80	25.65	37.13	-37.330	37.20	31.59
	Sowi	38	0	6.00	4.22	9.68	7.03	-16.510	35.00	15.03
	Wiker	37	0	10.15	7.80	9.40	17.68	-4.680	28.02	22.07
Extreme Gap >40	Batarang	166	0	19.43	15.60	16.47	16.40	0.350	103.00	32.00
	Cipali	101	0	12.18	8.87	10.62	14.04	0.550	50.00	24.00
	Cisumdawu	13	0	24.65	28.10	11.46	7.90	3.200	46.90	31.30
	Japek	94	0	8.37	3.67	10.47	7.32	0.170	50.00	20.00
	Palikanci	34	0	3.11	2.56	2.06	2.08	0.000	9.91	5.50
	Pejalang	58	0	9.08	7.20	7.28	7.18	0.600	38.64	15.22
	Pematang	34	0	10.54	8.73	6.56	9.39	2.050	26.58	17.05
	Semarang	13	0	16.62	12.50	13.48	19.10	3.100	44.50	29.64
	Somar	19	0	21.97	26.75	13.24	26.32	2.400	37.33	34.55
	Sowi	38	0	8.65	6.92	7.33	7.99	0.460	35.00	15.95
	Wiker	37	0	10.87	7.80	8.54	15.81	0.640	28.02	22.07

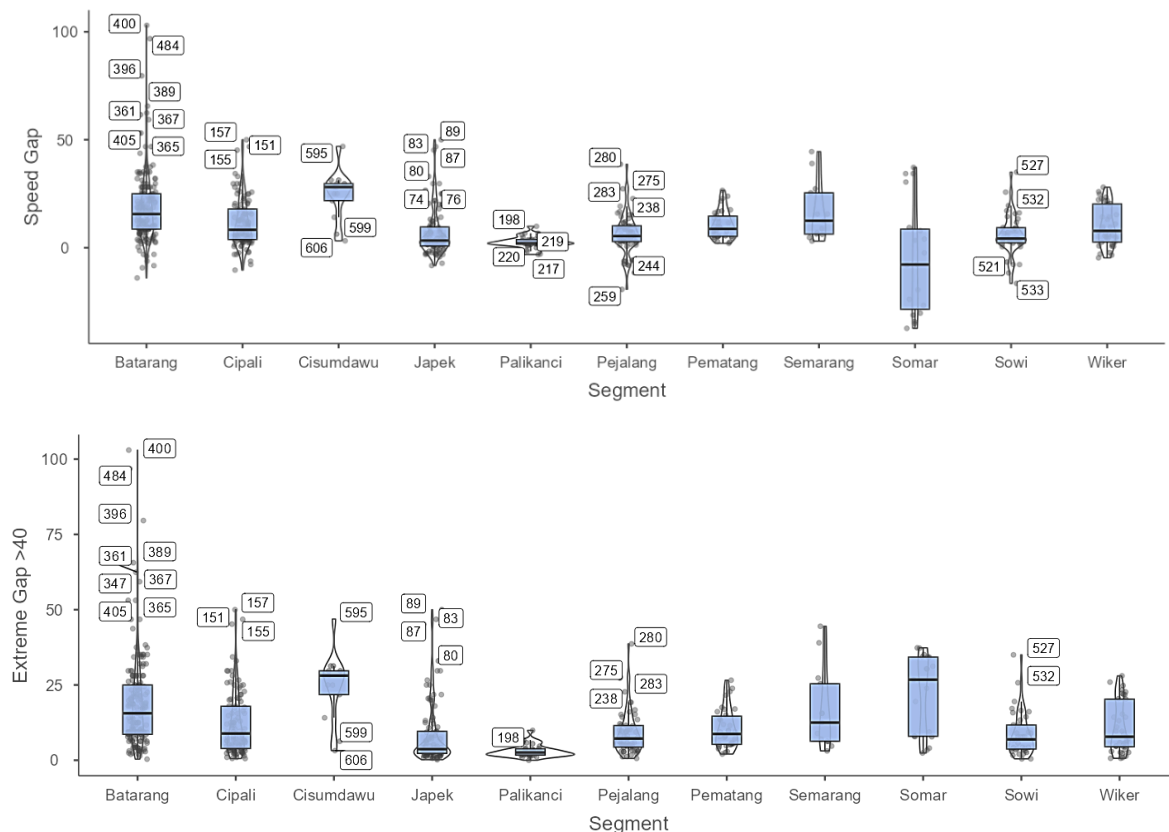


FIGURE 2: Violin/Box Plots of speed gap and extreme gap in Trans Java Highway

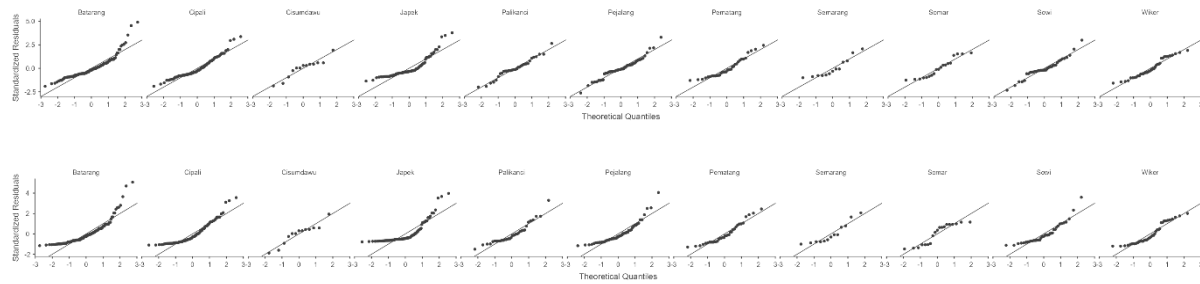


FIGURE 3: Q-Q Plots of speed gap and extreme gap in Trans Java Highway

3.2 Between-Segment Comparisons of Speed and Speed Differentials (Robust)

Guided by the literature, the hypothesis test asks whether average speed gaps differ across the 11 Trans-Java/Cisumdawu segments (H_0 : no difference; H_1 : at least one segment differs). Assumption checks indicated clear deviations from classical ANOVA conditions—non-normality (Shapiro–Wilk $W=0.897$, $p<.001$) and heteroscedasticity (Levene's $F=9.21$, $df=10,596$, $p<.001$)—so variance-robust and non-parametric procedures were applied. Welch's ANOVA detected decisive between-segment heterogeneity in speed gap ($F=22.6$, $df_1=10$, $df_2=118$, $p<.001$), corroborated by Kruskal–Wallis ($\chi^2=134$, $df=10$, $p<.001$). Thus, H_0 is rejected.

One-Way ANOVA (Welch's)					Homogeneity of Variances Test (Levene's)				
	F	df1	df2	p		F	df1	df2	p
Speed Gap	22.6	10	118	< .001	Speed Gap	9.21	10	596	< .001

Normality Test (Shapiro-Wilk)			Kruskal-Wallis		
	W	p		χ^2	df
Speed Gap	0.897	< .001	Speed Gap	134	10

Note. A low p-value suggests a violation of the assumption of normality

FIGURE 4: ANOVA test result

Games–Howell contrasts delineate distinct operating regimes. A high-gap cluster—Batarang and Cisumdawu—exhibits substantially larger differentials than compact-flow segments such as Palikanci (Batarang–Palikanci $\Delta=16.35$ km/h, $p<.001$; Cisumdawu–Palikanci $\Delta=22.18$, $p<.001$) and then several mid-range segments, including Pejagan ($\Delta=12.45$ and 18.28 , both $p\leq.002$) and Pematang ($\Delta=8.30$ and 14.12 , $p\leq.023$). Batarang also exceeds Japek ($\Delta=11.67$, $p<.001$) and shows a small yet significant elevation over Semarang ($\Delta=2.21$, $p=.025$), while the difference between Batarang and Cisumdawu is not significantly different, consistent with both residing in the high-gap tier. Somar emerges as a negative-gap outlier, differing sharply from Batarang ($\Delta=-23.86$, $p<.001$) and Wiker ($\Delta=-15.19$, $p=.001$). Given small n in several cells (Semarang, Cisumdawu, Somar), effect magnitudes should accompany p-values in interpretation.

Overall, robust comparisons confirm that speed differentials are not uniformly distributed but concentrated in identifiable segments. This heterogeneity substantiates segment-specific prioritization in subsequent modelling, supports HC-robust regression and SGSI ranking, and informs ADAS scenario calibration using empirically observed Δv ranges on high-gap segments.

TABLE 3: Games-Howell test results concerning speed gap differences on Trans Java and Cisumdawu Highways

		Batarang	Cipali	Cisumdawu	Japek	Palikanci	Pejalang	Pematang	Semarang	Somar	Sowi	Wiker
Batarang	Mean difference	—	7.40	-5.82	11.67	16.35	12.454	8.295	2.21	23.86	12.831	8.678
	p-value	—	0.002	0.821	<.001	<.001	<.001	<.001	1.000	0.025	<.001	0.002
Cipali	Mean difference		—	-13.22	4.28	8.96	5.056	0.897	-5.19	16.47	5.433	1.280
	p-value		—	0.036	0.246	<.001	0.119	1.000	0.948	0.249	0.177	1.000
Cisumdawu	Mean difference			—	17.50	22.18	18.277	14.118	8.03	29.69	18.654	14.501
	p-value			—	0.004	<.001	0.002	0.022	0.851	0.005	0.002	0.021
Japek	Mean difference				—	4.68	0.781	-3.378	-9.47	12.19	1.158	-2.995
	p-value				—	0.014	1.000	0.593	0.418	0.632	1.000	0.899
Palikanci	Mean difference					—	-3.899	-8.059	-14.15	7.51	-3.522	-7.676
	p-value					—	0.163	<.001	0.061	0.963	0.554	0.001
Pejalang	Mean difference						—	-4.159	-10.25	11.41	0.377	-3.776
	p-value						—	0.356	0.330	0.714	1.000	0.728
Pematang	Mean difference							—	-6.09	15.57	4.536	0.383
	p-value							—	0.876	0.313	0.415	1.000
Semarang	Mean difference								—	21.66	10.624	6.470
	p-value								—	0.115	0.312	0.862
Somar	Mean difference									—	-11.032	-15.186
	p-value									—	0.762	0.360
Sowi	Mean difference										—	-4.154
	p-value										—	0.724
Wiker	Mean difference											—
	p-value											—

3.3 Proportions of Overspeeding and Large Differentials

Across 607 observations, overspeeding (>100 km/h) occurred in 45.8% of cases, with marked heterogeneity by segment ($\chi^2=142$, $df=10$, $p<.001$; Cramér's $V=0.483$). The highest prevalences appeared on Pematang (79.4%), Cisumdawu (76.9%), and Batarang (70.5%), followed by Cipali (53.5%), Wiker (43.2%), and Somar (42.1%). Lower-prevalence segments included Semarang (30.8%), Pejagan–Pemalang (32.8%), Japek (20.2%), Sowi (10.5%), and Palikanci (0%). This pattern mirrors earlier distributional results, indicating that overspeeding pressure is concentrated on specific corridors rather than evenly distributed.

By contrast, large differentials ($|speed_gap| \geq 40$ km/h) were rare overall (3.3%). Non-zero shares were observed on Batarang (7.2%), Cisumdawu (7.7%), Semarang (7.7%), Cipali (3.0%), and Japek (3.2%), with all other segments at 0%. The between-segment association was not statistically decisive given sparse counts ($\chi^2=17.2$, $df=10$, $p=0.071$; Cramér's $V=0.168$). These exceedances nonetheless cluster in the same high-gap settings highlighted by continuous metrics, suggesting tail risk concentrates where flow is both fast and heterogeneous. Practically, overspeed prevalence offers a robust basis for segment prioritization, while large-gap exceedances are best treated as a complementary tail-risk indicator rather than a stand-alone comparative metric.

3.4 Determinants of Operating Speed at The Vehicle Level (Linear Regression)

A multiple linear model was estimated with target-vehicle speed as the outcome and segment (categorical) plus traffic density (vehicles/km) as predictors. The model accounted for a modest share of variation ($R^2=0.273$; adjusted $R^2=0.261$). After adjustment for location effects, traffic density was positively associated with speed ($\beta \approx +5.55$ km/h per veh/km, $p<.001$), consistent with operation in a low-density regime where slightly higher flows coincide with higher cruising speeds rather than congestion. Relative to Batang–Semarang, lower speeds were observed on Jakarta–Cikampek, Palikanci, Pejagan–Pemalang, Somar, and Sowi (all $p \leq .013$), while Cisumdawu was higher ($p=.042$); other contrasts were not decisive. One segment coefficient was not estimated due to a singular fit, reflecting redundancy from sparse cells; removing or merging that level did not alter the substantive pattern.

Contingency Tables

		Overspeed (V > 100)		Total
Segment		0	1	
Batarang	Observed	49	117	166
	Expected	89.97	76.03	166.0
	% within row	29.5%	70.5%	100.0%
Cipali	Observed	47	54	101
	Expected	54.74	46.26	101.0
	% within row	46.5%	53.5%	100.0%
Cisumdawu	Observed	3	10	13
	Expected	7.05	5.95	13.0
	% within row	23.1%	76.9%	100.0%
Japek	Observed	75	19	94
	Expected	50.95	43.05	94.0
	% within row	79.8%	20.2%	100.0%
Palikanci	Observed	34	0	34
	Expected	18.43	15.57	34.0
	% within row	100.0%	0.0%	100.0%
Pejalang	Observed	39	19	58
	Expected	31.44	26.56	58.0
	% within row	67.2%	32.8%	100.0%
Pematang	Observed	7	27	34
	Expected	18.43	15.57	34.0
	% within row	20.6%	79.4%	100.0%
Semarang	Observed	9	4	13
	Expected	7.05	5.95	13.0
	% within row	69.2%	30.8%	100.0%
Somar	Observed	11	8	19
	Expected	10.30	8.70	19.0
	% within row	57.9%	42.1%	100.0%
Sowi	Observed	34	4	38
	Expected	20.60	17.40	38.0
	% within row	89.5%	10.5%	100.0%
Wiker	Observed	21	16	37
	Expected	20.05	16.95	37.0
	% within row	56.8%	43.2%	100.0%
Total	Observed	329	278	607
	Expected	329	278	607
	% within row	54.2%	45.8%	100.0%

χ^2 Tests

	Value	df	p
χ^2	142	10	< .001
N	607		

Nominal

	Value
Phi-coefficient	NaN
Cramer's V	0.483

Contingency Tables

		gap_ge40		Total
Segment		0	1	
Batarang	Observed	154	12	166
	Expected	160.5	5.470	166.0
	% within row	92.8%	7.2%	100.0%
Cipali	Observed	98	3	101
	Expected	97.7	3.328	101.0
	% within row	97.0%	3.0%	100.0%
Cisumdawu	Observed	12	1	13
	Expected	12.6	0.428	13.0
	% within row	92.3%	7.7%	100.0%
Japek	Observed	91	3	94
	Expected	90.9	3.097	94.0
	% within row	96.8%	3.2%	100.0%
Palikanci	Observed	34	0	34
	Expected	32.9	1.120	34.0
	% within row	100.0%	0.0%	100.0%
Pejalang	Observed	58	0	58
	Expected	56.1	1.911	58.0
	% within row	100.0%	0.0%	100.0%
Pematang	Observed	34	0	34
	Expected	32.9	1.120	34.0
	% within row	100.0%	0.0%	100.0%
Semarang	Observed	12	1	13
	Expected	12.6	0.428	13.0
	% within row	92.3%	7.7%	100.0%
Somar	Observed	19	0	19
	Expected	18.4	0.626	19.0
	% within row	100.0%	0.0%	100.0%
Sowi	Observed	38	0	38
	Expected	36.7	1.252	38.0
	% within row	100.0%	0.0%	100.0%
Wiker	Observed	37	0	37
	Expected	35.8	1.219	37.0
	% within row	100.0%	0.0%	100.0%
Total	Observed	587	20	607
	Expected	587	20	607
	% within row	96.7%	3.3%	100.0%

χ^2 Tests

	Value	df	p
χ^2	17.2	10	0.071
N	607		

Nominal

	Value
Phi-coefficient	NaN
Cramer's V	0.168

FIGURE 5: Chi-square test results

Model Coefficients - Target Vehicle

Predictor	Estimate	SE	95% Confidence Interval		t	p	Stand. Estimate
			Lower	Upper			
Intercept *	96.493	3.30	90.021	102.97	29.2805	< .001	
traffic_density	5.548	1.64	2.323	8.77	3.3788	< .001	0.1967
Segment:							
Cipali – Batarang	-0.244	2.57	-5.295	4.81	-0.0950	0.924	-0.0131
Cisumdawu – Batarang	10.934	5.36	0.408	21.46	2.0401	0.042	0.5847
Japek – Batarang	-19.424	2.23	-23.807	-15.04	-8.7045	< .001	-1.0386
Palikanci – Batarang	-19.327	3.13	-25.466	-13.19	-6.1836	< .001	-1.0334
Pejalang – Batarang	-9.267	2.78	-14.734	-3.80	-3.3286	< .001	-0.4955
Pematang – Batarang	4.080	3.41	-2.626	10.78	1.1949	0.233	0.2181
Semarang – Batarang	-3.633	5.11	-13.669	6.40	-0.7111	0.477	-0.1943
Somar – Batarang	-11.639	4.69	-20.851	-2.43	-2.4812	0.013	-0.6223
Sowi – Batarang	-13.644	3.72	-20.957	-6.33	-3.6638	< .001	-0.7295
Wiker – Batarang	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Note. Linear model contains aliased coefficients (singular fit)

* Represents reference level

Model Fit Measures

Model	R	R ²	Adjusted R ²
1	0.523	0.273	0.261

Note. Models estimated using sample size of N=607

Durbin-Watson Test for Autocorrelation

Autocorrelation	DW Statistic	p
0.455	1.09	< .001

[3]

Heteroskedasticity Tests

	Statistic	p
Breusch-Pagan	26.5	0.003
Goldfeld-Quandt	1.00	0.490
Harrison-McCabe	0.498	0.490

Note. Additional results provided by moretests

Normality Tests

	Statistic	p
Shapiro-Wilk	0.965	< .001
Kolmogorov-Smirnov	0.0677	0.008
Anderson-Darling	4.11	< .001

Note. Additional results provided by moretests

Collinearity Statistics

	VIF	Tolerance
traffic_density	NaN	NaN
Segment	NaN	NaN

Note. Linear model contains aliased coefficients (singular fit)

[3]

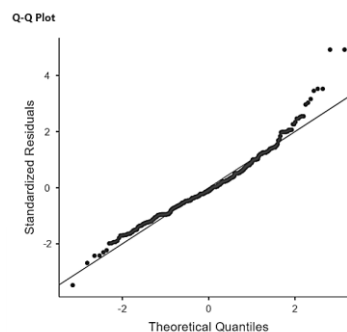


FIGURE 6: Linear Regression test results

Residual diagnostics indicated non-normality with right-tail departures (Shapiro-Wilk $p < .001$; Q-Q plot) and heteroskedasticity (Breusch-Pagan $p = .003$). Accordingly, inference uses heteroskedasticity-consistent standard errors (HC3). The Durbin-Watson statistic ($DW = 1.09$) suggests positive residual autocorrelation, consistent with time-ordered or clustered observations; coefficients are therefore interpreted as conditional mean differences at the vehicle level within the observed operating range. Overall, mean speed varies systematically by location after accounting for traffic state, providing a pragmatic basis for segment-specific management and for the prioritization analyses that follow.

3.5 Probability of Speeding Violations (Logistic Regression)

A binomial logistic model was fitted for overspeeding (>100 km/h) using segment (categorical) and source-vehicle speed as predictors. Model fit was strong: the overall likelihood-ratio test was significant ($\chi^2=308$, $df=11$, $p<.001$), McFadden's $R^2=0.368$, AIC=553, and discrimination was high (AUC=0.876). Omnibus tests indicated that both predictors contributed meaningfully (Source Vehicle $\chi^2=146.7$, $df=1$, $p<.001$; Segment $\chi^2=77.1$, $df=10$, $p<.001$).

Higher source-vehicle speed was associated with a greater probability of violation by the lead vehicle (OR=1.179 per unit increase, 95% CI 1.140–1.218), implying a 17.9% rise in odds for each one-unit change within the observed range. Relative to Batang–Semarang (reference), several segments showed substantially lower odds: Jakarta–Cikampek (OR=0.356, $p=.007$), Cipali (OR=0.399, $p=.004$), Pejagan–Pemalang (OR=0.232, $p<.001$), Somar (OR=0.129, $p<.001$), Sowi (OR=0.108, $p<.001$), and Wiker (OR=0.307, $p=.003$). Differences for Pematang (OR=0.693, $p=.463$) and Semarang (OR=0.843, $p=.797$) were not decisive. Cisumdawu exhibited higher odds than the reference (OR=8.09, $p=.042$), although the wide interval reflects small-cell uncertainty. Palikanci recorded no overspeeding events, producing quasi-complete separation; the estimated odds therefore approach zero and the coefficient is unstable, but the practical interpretation remains “very low violation risk.”

Taken together, the model indicates that overspeeding risk is concentrated on specific segments after conditioning on operating speed, and the high AUC suggests useful predictive separation for prioritizing enforcement and monitoring.

Model Coefficients - Overspeed ($V > 100$)

Predictor	Estimate	SE	Z	p	Odds ratio	95% Confidence Interval	
						Lower	Upper
Intercept	-13.697	1.4884	-9.2023	< .001	1.13e-6	6.09e-8	2.08e-5
Source Vehicle	0.164	0.0169	9.7461	< .001	1.179	1.1403	1.218
Segment:							
Cipali – Batarang	-0.918	0.3161	-2.9024	0.004	0.399	0.2150	0.742
Cisumdawu – Batarang	2.090	1.0276	2.0338	0.042	8.085	1.0789	60.593
Japek – Batarang	-1.032	0.3826	-2.6964	0.007	0.356	0.1684	0.754
Palikanci – Batarang	-17.532	643.3042	-0.0273	0.978	2.43e-8	0.0000	Inf
Pejalang – Batarang	-1.461	0.3709	-3.9381	< .001	0.232	0.1122	0.480
Pematang – Batarang	-0.366	0.4991	-0.7335	0.463	0.693	0.2607	1.844
Semarang – Batarang	-0.171	0.6643	-0.2574	0.797	0.843	0.2292	3.099
Somar – Batarang	-2.045	0.5943	-3.4419	< .001	0.129	0.0403	0.415
Sowi – Batarang	-2.227	0.5809	-3.8331	< .001	0.108	0.0346	0.337
Wiker – Batarang	-1.179	0.4007	-2.9434	0.003	0.307	0.1402	0.674

Note. Estimates represent the log odds of "Overspeed ($V > 100$) = 1" vs. "Overspeed ($V > 100$) = 0"

Model Fit Measures

Model	Deviance	AIC	R^2_{McF}	Overall Model Test		
				χ^2	df	p
1	529	553	0.368	308	11	< .001

Note. Models estimated using sample size of N=607

Omnibus Likelihood Ratio Tests

Predictor	χ^2	df	p
Source Vehicle	146.7	1	< .001
Segment	77.1	10	< .001

Predictive Measures

AUC
0.876

Note. The cut-off value is set to 0.5

FIGURE 7: Logistic Regression test results

3.6 Segment Prioritization Via Composite Index (SGSI)

A composite Speed–Gap Safety Index (SGSI) was constructed by z-standardizing three indicators—share of large differentials ($|gap| \geq 40$ km/h), overspeeding prevalence (>100 km/h), and the coefficient of variation (CV) of target speed—and averaging them so higher values denote greater concern. The index separated segments into actionable tiers. High-priority segments were Batarang (SGSI=1.061; rank 1), Pejagan–Pemalang (0.715; rank 2), and Semarang (0.673; rank 3). Batarang combines the corridor's highest overspeeding (70.5%) with the largest share of large differentials (7.2%) and non-

trivial variability; Pejangan–Pemalang is driven by elevated dispersion ($CV=0.231$) and a non-negligible large-gap share (5.2%); Semarang shows both a sizeable large-gap share (7.7%) and above-average variability. The mid-tier includes Cipali (0.384), Somar (0.304), Pematang (0.259), and Cisumdawu (−0.050). In this group, risk arises from different mixes: Somar from high variability ($CV=0.239$), Pematang from very high overspeeding (79.4%) but few large gaps, and Cisumdawu from high overspeeding (76.9%) within relatively homogeneous flow. Lower-priority segments are Wiker (−0.225), Japek (−0.724), Sowi (−1.119), and Palikanci (−1.277), each characterized by low large-gap shares and modest dispersion; Palikanci also recorded no overspeeding.

TABLE 4: SGSI calculation results by segment

segment	pct_gap_ge40	pct_v_gt_100	cv_v_target	z_gap	z_v100	z_cv	w_gap	w_v100	w_cv	SGSI	rank_SGSI
Batarang	7,2	70,5	0,165	1,712	1,136	0,336	1	1	1	1,061	1
Cipali	3,0	53,5	0,170	0,264	0,462	0,426	1	1	1	0,384	4
Japek	1,1	20,2	0,092	-0,384	-0,856	-0,933	1	1	1	-0,724	9
Pejangan	5,2	32,8	0,231	1,013	-0,359	1,491	1	1	1	0,715	2
Sowi	0,0	10,5	0,067	-0,746	-1,240	-1,373	1	1	1	-1,119	10
Wiker	0,0	43,2	0,146	-0,746	0,057	0,014	1	1	1	-0,225	8
Palikanci	0,0	0,0	0,064	-0,746	-1,657	-1,428	1	1	1	-1,277	11
Pematang	0,0	79,4	0,147	-0,746	1,490	0,032	1	1	1	0,259	6
Somar	0,0	42,1	0,239	-0,746	0,012	1,645	1	1	1	0,304	5
Semarang	7,7	30,8	0,179	1,869	-0,438	0,588	1	1	1	0,673	3
Cisumdawu	0,0	76,9	0,100	-0,746	1,392	-0,797	1	1	1	-0,050	7

Headway and closing-time patterns align with the SGSI ranking. Segments in the top tier show minimum THW below 1.0 s and short TTC, indicating frequent entry into closing-risk states where minor disturbances can cascade. In particular, Batarang (THW_min 0.81 s; TTC_min 1.84 s) and Somar (0.80 s; 1.69 s) combine very short headways with high Δv (≈ 39 – 43 km/h), while Semarang and Japek also register THW_min <1.0 s. Mid-tier locations tend to operate in the short headway band (1.0–1.5 s) with TTC around 2.8–3.5 s, offering limited reaction margin. Only Cipali and Cisumdawu reach adequate upper-bound THW (>1.5 s) at times; even there, the minimum headway remains short (≥ 1.18 s and 1.33 s, respectively). Interpreting TTC with a pragmatic rule of thumb—<2.0 s critical, 2.0–3.0 s cautionary, >3.0 s more forgiving high SGSI segments spend more time near the critical zone, consistent with their tail-risk signatures.

TABLE 5: THW and TCC calculation results by segment

Segment	v_kmh	d_min_m	d_max_m	dv_kmh	THW_min_s	THW_max_s	TTC_min_s	TTC_max_s	THW_band_min	THW_band_max
Japek	77.07	15	20	25.6	0.7	0.93	2.11	2.81	<1.0 s (very short)	<1.0 s (very short)
Cipali	91.59	30	40	36.6	1.18	1.57	2.95	3.93	1.- 1.5 s (short)	>1.5 s (adequate)
Palikanci	88.56	25	35	32.2	1.02	1.42	2.8	3.91	1.- 1.5 s (short)	1- 1.5 s (short)
Pejangan	86.61	25	35	29.8	1.04	1.45	3.02	4.23	1.- 1.5 s (short)	1- 1.5 s (short)
Pematang	86.1	25	30	27.1	1.05	1.25	3.32	3.99	1.- 1.5 s (short)	1 - 1.5 s (short)
Batarang	88.51	20	30	39.1	0.81	1.22	1.84	2.76	<1.0 s (very short)	1 - 1.5 s (short)
Semarang	85.01	20	25	28.4	0.85	1.06	2.54	3.17	<1.0 s (very short)	1 - 1.5 s (short)
Somar	89.92	20	30	42.6	0.8	1.2	1.89	2.54	<1.0 s (very short)	1 - 1.5 s (short)
Sowi	87.11	25	30	30.7	1.03	1.24	2.93	3.52	1.- 1.5 s (short)	1 - 1.5 s (short)
Wiker	88.4	30	35	34.9	1.22	1.43	3.09	3.61	1.- 1.5 s (short)	1 - 1.5 s (short)
Cisumdawu	94.77	35	45	37.6	1.33	1.71	3.35	4.31	1.- 1.5 s (short)	>1.5 s (adequate)

3.7 Sensitivity Analyses

Core findings proved robust to alternative specifications and data treatments. First, replacing parametric procedures with variance-robust and non-parametric counterparts did not change the substantive conclusions: Welch's ANOVA and Kruskal–Wallis led to the same between-segment heterogeneity message, and linear-model inferences based on HC3 standard errors aligned with non-parametric checks. Second, re-estimating the logistic model after addressing quasi-complete separation on Palikanci (bias-reduced/Firth estimation or temporary exclusion of that level) left the direction and significance of the remaining segment coefficients intact, with high discrimination maintained ($AUC > 0.85$). Third, conclusions were unchanged when using non-winsorized variables and when categorizing traffic density (quartiles) instead of modelling it as continuous; results were also consistent when an alternative proxy for density derived from headway assumptions was used as a check. Fourth, excluding

very small-n segments (e.g., Semarang, Cisumdawu, Somar) did not alter the tiering of high- vs low-risk locations. Finally, the SGSI ranking was stable under reasonable re-weighting of its components and when omitting the THW term.

Given data-quality issues, time-of-day stratification is reported descriptively in the Appendix but is not used to drive inference. Overall, the prioritization of segments and the interpretation of modelling results do not hinge on any single method choice or data treatment.

4. DISCUSSION

4.1 Segment-Level Heterogeneity and Safety Relevance

Analyses indicate marked heterogeneity in speed levels and inter-vehicle differentials across segments. Robust tests (Welch's ANOVA; Kruskal–Wallis) identified a high-gap tier (e.g., Batang–Semarang, Cisumdawu, with Semarang aligned) and low/compact tiers (e.g., Palikanci), with Somar acting as a negative-gap outlier. From a safety standpoint, the co-occurrence of high V85, elevated dispersion (CV), and non-trivial shares of $|gap| \geq 40$ corresponds to shorter prospective time-to-collision in closing scenarios. Uniform corridor-wide strategies are therefore unlikely to be efficient; segments exhibiting pronounced tail-risk indicators merit priority attention.

4.2 Density, Operating Context and Roadway Characteristics

In the linear model, traffic density showed a **positive** association with target-vehicle speed within the observed low-density regime, consistent with conditions where slightly higher flows coincide with higher cruising speeds rather than congestion. Segment effects remained substantive after adjustment, mirroring the descriptive and post-hoc contrasts. Time-of-day data were not used for inference because of quality concerns. Diagnostics indicated non-normality, heteroskedasticity, and residual autocorrelation; inference thus relied on heteroskedasticity-consistent (HC) standard errors, and results should be interpreted as conditional mean differences within the observed operating range. Policy implications favor adaptive, time- and location-targeted enforcement and speed engineering (e.g., dynamic signage) over one-size-fits-all approaches.

4.3 Added Value of Tail-Risk Indicators and A Composite Index

Mean speed alone underrepresents behaviors most proximate to conflict. Tail-risk indicators – m overspeed prevalence, share of $|gap| \geq 40$, CV, and V85 – capture the upper tails where closing risk emerges. The composite SGSI, built from z-standardised overspeeding, large-gap share, and CV, compresses these signals into an operational ranking that highlights segments most frequently entering risk-salient states, not merely those with high averages. The index is consistent with robust group comparisons and logistic-model contrasts and remained stable under sensitivity checks (alternative density treatment, exclusion of very small-n segments, and component re-weighting).

4.4 Policy and Technology Implications

Observed patterns of large speed differentials and unstable flow point to targeted, segment-specific actions and offer concrete inputs for ADAS/NCAP calibration. The aim is to reduce closing-risk states—short headways and short TTC – by compressing tails (Δv) rather than only lowering averages.

Operational mitigation priorities:

1. Adaptive upper-limit enforcement on high-SGSI segments (e.g., Batarang, Somar, Semarang) to reduce the share of vehicles >100 km/h and to suppress large Δv when THW is short.
2. Speed harmonization and lane discipline: prominent keep-right/keep-lane messaging, enhanced merge-area markings, and patrol placement at locations/times where THW drops below 1.0 s.
3. Dynamic/variable speed limits during free-flow peaks to lengthen headways and stabilize TTC; pair with average-speed (section) control where feasible.
4. Heavy-vehicle management: lane restrictions and advisory headway boards to dampen mixed-speed turbulence.
5. Operational drills and feedback loops: dashboard alerts for $THW < 1.0$ s pockets and rapid enforcement windows; maintain current practices on low-SGSI segments.

4.5. Implications for ADAS/NCAP

Scenario calibration using local distributions: prioritize tests reflecting $\Delta v = 20\text{--}40\text{+ km/h}$ at THW = 0.8–1.2 s (including night/grade variants) to mirror locally observed closing events.

Function-specific focus:

1. FCW – evaluate timeliness of distance/speed-adaptive alerts under short-headway approaches.
2. AEB – assess automatic braking performance when large Δv emerges rapidly.
3. ACC – verify capability to maintain safe gaps and smooth speeds on toll corridors with heterogeneous flow.
4. Given Southeast Asia's traffic mix (higher heavy-vehicle share), toll-road predominance, and wider speed variation than typical European settings, ASEAN NCAP protocols would benefit from geographical customization: a scenario matrix covering locally observed Δv /THW bands, performance metrics including residual speed/post-intervention TTC, and thresholds aligned to regional risk.

4.6 Strengths, Limitations and Future Directions

A video-based surrogate-safety approach enables rapid mapping of operating states across long corridors and supports prioritization without requiring crash linkage. Interpretation should be tempered by limitations: single instrumented vehicle; video-based measurement; absence of vehicle-class stratification; headway/TTC derived at segment level rather than from continuous tracking; daytime-dominant observations; small n in several segments; quasi-complete separation for one level in the logistic model; and limited control for external factors (geometry, weather, work zones). Future work using multi-vehicle instrumentation with GPS/OBD ground-truth, automated class identification, continuous longitudinal spacing for THW/TTC, and linkage to crash databases under controlled context would strengthen external validity and enable causal analysis. The empirical distributions reported here provide region-specific inputs for enforcement planning and for the continued development of ASEAN-relevant ADAS/NCAP scenario design.

5. CONCLUSION

Traffic on the Trans-Java–Cisumdawu corridor exhibits systematic heterogeneity in speed levels and inter-vehicle differentials. Robust comparisons (Welch/Kruskal–Wallis) and modelling show that overspeeding and large differentials concentrate on identifiable segments, rather than being evenly distributed. A composite Speed–Gap Safety Index (SGSI) – built from overspeed prevalence, the share of $|\text{gap}| \geq 40\text{ km/h}$, and speed dispersion – prioritizes Batang–Semarang, Pejagan–Pemalang, and Semarang as top-tier locations, with Cipali, Somar, Pematang, and Cisumdawu in the mid-tier and Palikanci, Sowi, Japek, and Wiker lower. Headway/closing-time diagnostics align with this ordering: high-SGSI segments display short THW and short TTC, indicating more frequent entry into closing-risk states. These findings support targeted management rather than corridor-wide uniform measures: adaptive upper-limit enforcement on high-SGSI segments; speed harmonisation and lane discipline at merges; dynamic/variable limits during free-flow peaks; and focused heavy-vehicle management. The empirical distributions of Δv and THW/TTC also provide region-specific inputs for ASEAN NCAP/ADAS scenario calibration (e.g., $\Delta v = 20\text{--}40\text{+ km/h}$ at THW = 0.8–1.2 s), enhancing the face validity of FCW/ACC/AEB performance tests in Southeast Asian conditions. Interpretation is tempered by limitations – single instrumented vehicle, video-based measurement, absence of class stratification, small n in several segments, and restricted control for geometry/weather. Future work with multi-vehicle instrumentation, continuous headway measurement, and crash linkage will strengthen external validity and enable causal analysis. Even with these constraints, the results deliver an actionable map of where risk-salient states occur most often and how enforcement and technology can be focused to reduce them.

ACKNOWLEDGEMENT

This research was sponsored by the Malaysian Institute of Road Safety Research (MIROS) as part of the ASEAN NCAP Collaborative Holistic Research V (ANCHOR V).

REFERENCES

- Aarts, L., & van Schagen, I. (2006). Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention*, 38(2), 215–224.
- Abadi, T. (2024). Menyorot performa keselamatan di jalan tol. *Antara News*. Retrieved from <https://www.antaranews.com/berita/4479157/menyorot-performa-keselamatan-di-jalan-tol>
- Abashah, A., Bakar, S. A., Zunaidi, I., Samah, I. A., Ramlan, S. N., Basri, H. H., ... & Wan, W. K. (2020). Adaptation of technology capability with special attention to ASEAN NCAP in strategic design and manufacturing a new car with safety features. *Journal of the Society of Automotive Engineers Malaysia*, 4(1), 15-23.
- European Commission (n.d.). Speed and accident risk. European Road Safety Observatory. Retrieved from <https://road-safety.transport.ec.europa.eu>
- Kadir, A. A., Rais, N. M., & Mohd-Towel, R. (2020). Micro surfacing asphalt pavement as a mitigation measure at accident's prone area along East Coast Expressway Phase 2 (ECE 2). *Journal of the Society of Automotive Engineers Malaysia*, 4(3), 378-393.
- Kementerian Perhubungan (2015). Peraturan Menteri Perhubungan Nomor PM 111 Tahun 2015 tentang tata cara penetapan batas kecepatan. Kementerian Perhubungan Republik Indonesia.
- Wang, C., & Abdel-Aty, M. (2024). Effects of speed difference on injury severity of freeway rear-end crashes: Insights from correlated joint random parameters bivariate probit models and temporal instability. *Analytic Methods in Accident Research*, 42, 100320.
- WHO (2024). Global status report on road safety 2023. World Health Organization (WHO).
- Zainon, M., Shah, M. Z., Chiroma, M. A., & Kafi, M. A. (2018). Monotonous driving environment along highway and driver behaviour in Malaysia: A review. *Journal of the Society of Automotive Engineers Malaysia*, 2(1), 60-74.

SUPPLEMENTARY

TABLE S1: Data cleaning and quality control
Outlier Handling (1% Winsorizing)

Robust Descriptives				
Speed Gap	Batarang	Mean	18.83	1.331
		Trimmed mean	16.08	1.067
		Winsorized mean	17.17	1.022
		Mean	11.43	1.138
		Trimmed mean	9.53	1.146
	Cipali	Winsorized mean	10.94	1.082
		Mean	24.65	3.177
		Trimmed mean	25.87	3.127
	Cisumdawu	Winsorized mean	23.69	3.021
		Mean	7.16	1.170
		Trimmed mean	4.25	0.894
	Japek	Winsorized mean	6.08	1.020
		Mean	2.48	0.482
		Trimmed mean	2.48	0.404
	Palikanci	Winsorized mean	2.41	0.486
		Mean	6.38	1.283
		Trimmed mean	6.10	0.915
	Pejalang	Winsorized mean	5.88	1.118
		Mean	10.54	1.125
		Trimmed mean	9.46	1.334
	Pematang	Winsorized mean	10.40	1.234
		Mean	16.62	3.739
		Trimmed mean	13.87	4.172
	Semarang	Winsorized mean	16.32	4.146
		Mean	-5.03	5.885
		Trimmed mean	-7.29	9.008
	Somar	Winsorized mean	-5.07	6.516
		Mean	6.00	1.570
		Trimmed mean	5.57	1.216
	Sowi	Winsorized mean	5.57	1.417
		Mean	10.15	1.545
		Trimmed mean	9.47	2.178
	Wiker	Winsorized mean	10.04	1.742

TABLE S1: (Continued)

Robust Descriptives				SE
Target Vehicle	Batarang	Mean	108.75	1.391
		Trimmed mean	105.90	1.318
		Winsorized mean	107.56	1.173
	Cipali	Mean	101.08	1.709
		Trimmed mean	101.83	1.995
		Winsorized mean	101.17	1.764
	Cisumdawu	Mean	108.59	2.785
		Trimmed mean	109.19	4.248
		Winsorized mean	107.99	3.058
	Japek	Mean	84.23	2.002
		Trimmed mean	79.71	2.142
		Winsorized mean	83.65	2.144
	Palikanci	Mean	84.43	0.975
		Trimmed mean	84.30	1.145
		Winsorized mean	84.15	0.972
	Pejalang	Mean	92.89	1.786
		Trimmed mean	93.29	2.036
		Winsorized mean	92.70	1.741
	Pematang	Mean	105.40	1.162
		Trimmed mean	104.76	1.197
		Winsorized mean	105.27	1.109
	Semarang	Mean	95.80	3.915
		Trimmed mean	92.89	3.863
		Winsorized mean	95.26	3.871
	Somar	Mean	86.30	4.737
		Trimmed mean	86.93	7.757
		Winsorized mean	86.34	5.315
	Sowi	Mean	85.18	2.476
		Trimmed mean	88.26	1.851
		Winsorized mean	85.86	2.342
	Wiker	Mean	98.88	1.629
		Trimmed mean	98.40	2.022
		Winsorized mean	99.24	1.602

TABLE S1: (Continued)

Robust Descriptives				
				SE
Target Vehicle	Batarang	Mean	108.75	1.391
	Cipali	Mean	101.08	1.709
	Cisumdawu	Mean	108.59	2.785
	Japek	Mean	84.23	2.002
	Palikanci	Mean	84.43	0.975
	Pejalang	Mean	92.89	1.786
	Pematang	Mean	105.40	1.162
	Semarang	Mean	95.80	3.915
	Somar	Mean	86.30	4.737
	Sowi	Mean	85.18	2.476
	Wiker	Mean	98.88	1.629
Speed Gap	Batarang	Mean	18.83	1.331
	Cipali	Mean	11.43	1.138
	Cisumdawu	Mean	24.65	3.177
	Japek	Mean	7.16	1.170
	Palikanci	Mean	2.48	0.482
	Pejalang	Mean	6.38	1.283
	Pematang	Mean	10.54	1.125
	Semarang	Mean	16.62	3.739
	Somar	Mean	-5.03	5.885
	Sowi	Mean	6.00	1.570
	Wiker	Mean	10.15	1.545