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MICROSIMULATION ANALYSIS OF THE EFFECTS OF HEAVY VEHICLE PROPORTION ON SPEED AND DELAY ON NATIONAL ROAD IN ASTANAJAPURA, CIREBON REGENCY

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Abstract

The proportion of heavy vehicles is one of the factors that can influence the operational performance of arterial road segments, particularly on corridors serving regional movements under heterogeneous traffic conditions. This study analyzes the sensitivity of average speed and average simulated delay to variations in heavy-vehicle (HV) proportion on National Road 1 in Astanajapura, Cirebon Regency, using PTV VISSIM microsimulation. Model inputs were obtained from geometric surveys, traffic counts, and speed observations during the selected peak hour. The baseline model was evaluated using the GEH statistic for traffic volume and MAPE for average speed, resulting in GEH values of 0.084 and 0.188 and MAPE values of 4.451% and 4.761% for Directions 1 and 2, respectively. The observed baseline HV proportions were 1.50% in Direction 1 and 1.84% in Direction 2. Five hypothetical scenarios were then evaluated at HV proportions of 5%, 10%, 15%, 20%, and 25%, while total traffic demand, road geometry, and calibrated driving-behavior settings were maintained across scenarios. The simulated results showed decreasing average speed and increasing average delay as the HV proportion increased. In Direction 2 toward Cirebon City, average speed decreased from 31.97 km/h under the baseline condition to 23.05 km/h at 25% HV, while average delay increased from 2.04 to 8.14 s/veh. Descriptive linear trend analysis, using the actual direction-specific baseline HV proportions together with the five hypothetical scenarios, indicated a stronger simulated response in Direction 2. These findings indicate that the operational performance of the modeled arterial segment is sensitive to changes in vehicle composition, particularly under the higher-volume traffic condition.

Keywords: heavy vehicles, traffic microsimulation, average speed, vehicle delay, national arterial roads.

1. INTRODUCTION

The operational performance of urban arterial road sections is influenced not only by traffic volume but also by the vehicle composition of the traffic flow. In the context of heterogeneous traffic, the proportion of heavy vehicles (HV) is an increasingly relevant variable because their dynamic characteristics differ significantly from those of light vehicles. Differences in vehicle length, acceleration–deceleration, and following distance requirements mean that heavy vehicles have the potential to reduce effective capacity, disrupt platoon progression, and increase the likelihood of queues forming, particularly in corridors affected by intersections and lateral obstructions. The literature from the past decade shows a consistent trend that an increase in the HV proportion is associated with a decrease in average speed and an increase in delay under the same demand conditions [1]–[3].

From the perspective of fundamental traffic flow relationships, changes in vehicle composition can shift the speed–flow–density relationship, such that at a given flow rate, the system tends to operate at lower speeds as the proportion of heavy vehicles increases [1]. Furthermore, the impact of HV proportion is

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reflected not only in average speed values but also in travel stability. Reliability approaches indicate that vehicle heterogeneity, including the significant presence of trucks and buses, increases travel time variability and worsens the consistency of service levels [4]. On urban arterial roads dominated by signalized intersections or direct access to land uses, changes in traffic flow structure due to HV proportion also have implications for intersection capacity and accumulated delay patterns along the corridor [3], [5].

Although the operational effects of heavy vehicles have been widely discussed, quantitative evidence on how arterial-segment performance responds progressively to different heavy-vehicle proportions remains highly context-dependent. Previous studies have frequently focused on intersections or networks at the aggregate level, so segment-level responses have not always been examined systematically [2], [3]. In addition, many operational evaluations rely on comparisons between an existing condition and a single alternative scenario, without tracing the gradual response of traffic performance across several heavy-vehicle proportion levels. Consequently, the incremental changes in average speed and delay under progressively increasing HV proportions remain relevant to investigate, particularly under heterogeneous arterial traffic conditions. Understanding these response patterns is important for identifying the sensitivity of arterial-road performance as the proportion of heavy vehicles increases.

The microsimulation approach offers an adequate analytical framework to address these needs. Microsimulation models allow for the explicit representation of vehicle classes, driving behavior parameters, and vehicle-to-vehicle interactions at the micro level, which aggregate into macro indicators such as average speed and delay. Several VISSIM-based studies have shown that changes in vehicle composition can be analyzed through controlled scenarios to assess performance responses to variations in design and traffic management [6]–[8]. However, the credibility of this approach heavily depends on the model calibration and validation process to ensure that simulation outputs adequately represent real-world conditions.

In a national context, the practice of calibrating and validating microsimulations for operational performance analysis has been demonstrated in VISSIM-based studies that integrate speed and delay with statistical validation procedures. Aryahito et al. [9] utilized VISSIM to evaluate operational performance through these indicators within the framework of traffic condition analysis and management scenarios. Meanwhile, Pradana et al. [10] emphasize the importance of validation using GEH statistics as a basis for the consistency between simulation results and field volume data before the model is used for further evaluation. This approach underscores that scenario-based experiments are meaningful only if the base model has been quantitatively verified.

Based on this research gap, this study evaluates the sensitivity of arterial-road operational performance to progressive changes in heavy-vehicle proportion using a calibrated and validated PTV VISSIM microsimulation model. The analysis focuses on average speed and average simulated delay under the observed baseline composition and hypothetical HV-proportion scenarios of 5%, 10%, 15%, 20%, and 25%. Total traffic demand, road geometry, and calibrated driving-behavior settings are maintained across the scenarios so that the analysis focuses on the operational response associated with changes in vehicle composition [1]–[3], [10].

The specific contribution of this study lies in its multi-level, scenario-based sensitivity analysis of heavy-vehicle proportion on a heterogeneous national arterial road segment under controlled demand and geometric conditions. Rather than comparing only an existing condition with a single alternative, the study traces the response pattern of speed and delay across several HV-proportion levels and compares two travel directions with different baseline traffic volumes. The resulting regression models are used descriptively to summarize these scenario-response trends rather than to infer causal relationships from observational data.

2. RESEARCH METHOD

This study employs a quantitative approach based on microsimulation to analyze the impact of variations in the proportion of heavy vehicles on the operational performance of arterial road sections. The study

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site is located on National Road 1 (Jl. Pantura) in Kanci, Astanajapura Subdistrict, Cirebon Regency, West Java. This section is part of a national arterial corridor serving both regional traffic and local activities. Traffic characteristics on this segment are mixed, with the presence of heavy vehicles remaining relevant for analysis even though their proportion was not dominant during the survey. This segment was selected because changes in vehicle composition have the potential to affect traffic flow dynamics, particularly in terms of speed and delay indicators.

The modeled section represents a four-lane, two-way divided arterial road (4/2 D), with two lanes in each direction. Each directional carriageway is approximately 7.0 m wide, separated by an approximately 1.4 m median. The outer shoulders are approximately 2.7 m on the Central Java side and 2.5 m on the Cirebon City side. The network geometry in VISSIM was coded to represent the geometric configuration observed in the field. A map of the location and boundaries of the analysis segment is presented in Figure 1.

Source: Google Earth, 2026

Figure 1. Study Location

2.1. Data Collection and Model Input Preparation

Field data collection included road-geometry measurements, classified traffic counts, vehicle-speed observations, and observations of road operational conditions. Traffic counts were conducted separately for each direction and vehicle class during the survey periods. Vehicle-speed observations were used to characterize the existing operating condition and to provide a benchmark for model validation.

Surveys were conducted on four days representing both weekday and weekend conditions: December 30, 2025; January 3, 2026; January 18, 2026; and January 19, 2026. The analysis period used for microsimulation was selected from the surveyed periods based on the highest observed traffic demand. The selected peak hour occurred on Tuesday, December 30, 2025, from 07:00 to 08:00 WIB, with traffic volumes of 2,266 veh/h in Direction 1 and 3,431 veh/h in Direction 2. This period was used as the baseline demand condition for calibration, validation, and subsequent HV-proportion scenario analysis.

For the purpose of this study, heavy vehicles (HV) were operationally defined as the combined category of large buses (BB) and large trucks (TB). Medium-sized vehicles (KS) were retained as a separate vehicle class and were not included in the HV proportion used as the scenario variable. This classification follows the vehicle categories adopted in the field survey and microsimulation input structure. Therefore, the reported HV percentages refer specifically to the combined share of BB and TB rather than to all vehicles larger than passenger cars.

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2.2. Development and Calibration of the Microsimulation Model

The microsimulation model was developed using PTV VISSIM by coding the study network into links and connectors according to the observed geometric characteristics. Vehicle classes were represented separately to account for differences in operational characteristics among the vehicle types observed in the field.

Calibration was conducted iteratively by reviewing the driving-behavior configuration, particularly car-following and lane-changing interactions, together with vehicle-specific characteristics related to vehicle dimensions and acceleration–deceleration behavior. The objective was to obtain a baseline model that reproduced the observed traffic operation with acceptable agreement in terms of realized traffic flow and average speed [11]–[14].

The same calibrated model configuration was maintained across the baseline and all HV-proportion scenarios. Therefore, the scenario analysis was conducted under controlled geometry, total traffic demand, and driving-behavior settings, while vehicle composition was varied. This design allows the differences among scenario outputs to be interpreted primarily as sensitivity responses to changes in vehicle composition [15]–[17].

2.3. Model Validation

Model assessment was conducted using the Geoffrey E. Havers (GEH) statistic as a traffic-flow consistency measure and Mean Absolute Percentage Error (MAPE) as an indicator of average-speed agreement between the observed and simulated conditions.

The GEH statistic was calculated as:

$$GEH = \sqrt{\frac{2(S-O)^2}{S+O}} \quad (1)$$

where S is the simulated traffic volume and O is the observed traffic volume. The GEH statistic was used as a traffic-flow consistency check between the observed demand and the traffic volume realized in the baseline simulation. Because the observed traffic volumes were used as model-demand inputs, the GEH results were not treated as independent validation of driving behavior. A GEH value below 5 was adopted as the criterion for assessing traffic-volume consistency [16], [18], [19]. Operational agreement was therefore assessed primarily through the comparison between observed and simulated average speeds.

The agreement between observed and simulated speeds was evaluated using Mean Absolute Percentage Error (MAPE), calculated as:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{O_i-S_i}{O_i}\right| \quad (2)$$

where Oi and Si represent the observed and simulated speeds, respectively, and n denotes the number of paired observations included in the calculation. Lower MAPE values indicate smaller relative deviations between simulated and observed speeds. In this study, MAPE was used as a complementary error measure rather than as an independent universal validation threshold. The resulting MAPE values were interpreted together with the GEH results to assess whether the baseline model adequately represented the observed traffic conditions before it was applied to the heavy-vehicle composition scenarios.

The speed assessment in this study was conducted at the aggregate directional level by comparing the observed and simulated average speeds. Therefore, the resulting MAPE values evaluate agreement in mean operating speed and do not represent validation of the complete vehicle-speed distribution. Future

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studies should extend the validation using larger documented speed samples and distributional measures such as standard deviation, percentile speeds, and observed-versus-simulated speed distributions.

2.4. Scenario Design and Sensitivity Analysis

After the model was validated, scenario experiments were conducted on variations in the proportion of heavy vehicles while maintaining the geometry, total volume, and driving behavior parameters under constant conditions. Changes were made only to the vehicle composition through the vehicle composition/relative flow settings in VISSIM. This approach was used so that performance changes between scenarios could be attributed primarily to changes in the proportion of heavy vehicles, rather than changes in volume or network configuration.

The analyzed scenarios consisted of the observed baseline condition and five hypothetical heavy-vehicle proportion scenarios of 5%, 10%, 15%, 20%, and 25%. Heavy vehicles (HV) were defined as the combined proportion of large buses (BB) and large trucks (TB). Accordingly, the non-HV group consisted of motorcycles, passenger cars, medium-sized vehicles, and non-motorized vehicles.

For each scenario, the aggregate HV proportion was increased to the specified target, while the shares of the non-HV vehicle classes were proportionally reduced so that the total vehicle composition remained 100% and the total traffic volume remained unchanged. Thus, the scenarios represent a substitution in vehicle composition rather than an increase in total traffic demand.

The analysis treats large buses and large trucks as one aggregate HV category. Therefore, the scenario experiment evaluates sensitivity to changes in the total HV share rather than the separate effects of bus and truck proportions. Total traffic demand, road geometry, and calibrated driving-behavior settings were kept constant across scenarios. This multi-level scenario design is used to assess the sensitivity of road segment performance to changes in the composition of heavy vehicles [20]–[22].

Table 1. Heavy-Vehicle Proportion Scenarios

Scenario	Direction 1 HV	Direction 2 HV	Interpretation
Baseline	1.50%	1.84%	Observed composition
S1	5%	5%	Hypothetical scenario
S2	10%	10%	Hypothetical scenario
S3	15%	15%	Hypothetical scenario
S4	20%	20%	Hypothetical scenario
S5	25%	25%	Hypothetical scenario

The performance indicators analyzed were average speed and average delay. Both indicators were extracted from the VISSIM outputs for each HV scenario and each direction of travel. The simulation results were compared descriptively using tables and graphs, followed by simple linear regression to summarize the direction and magnitude of the response trend across the tested HV proportions. Regression analysis was conducted separately for Direction 1 and Direction 2 because the two directions had different traffic volumes and baseline operating conditions. Because the regression was fitted to deliberately constructed simulation scenarios rather than to independently observed samples, it was used as a descriptive measure of scenario sensitivity and not as evidence of a causal statistical relationship. Average delay refers to the delay indicator extracted from the VISSIM model and reported in seconds per vehicle for each direction and scenario. The same delay measure was applied consistently to the baseline and all HV-proportion scenarios.

2.5. Research Stages

In general, the research stages began with the determination of the study location, field data collection, preparation of model inputs, development of the microsimulation model, calibration and validation,

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development of scenarios for varying the proportion of heavy vehicles, and sensitivity analysis regarding average speed and delay. This sequence of research stages is summarized in Figure 2.

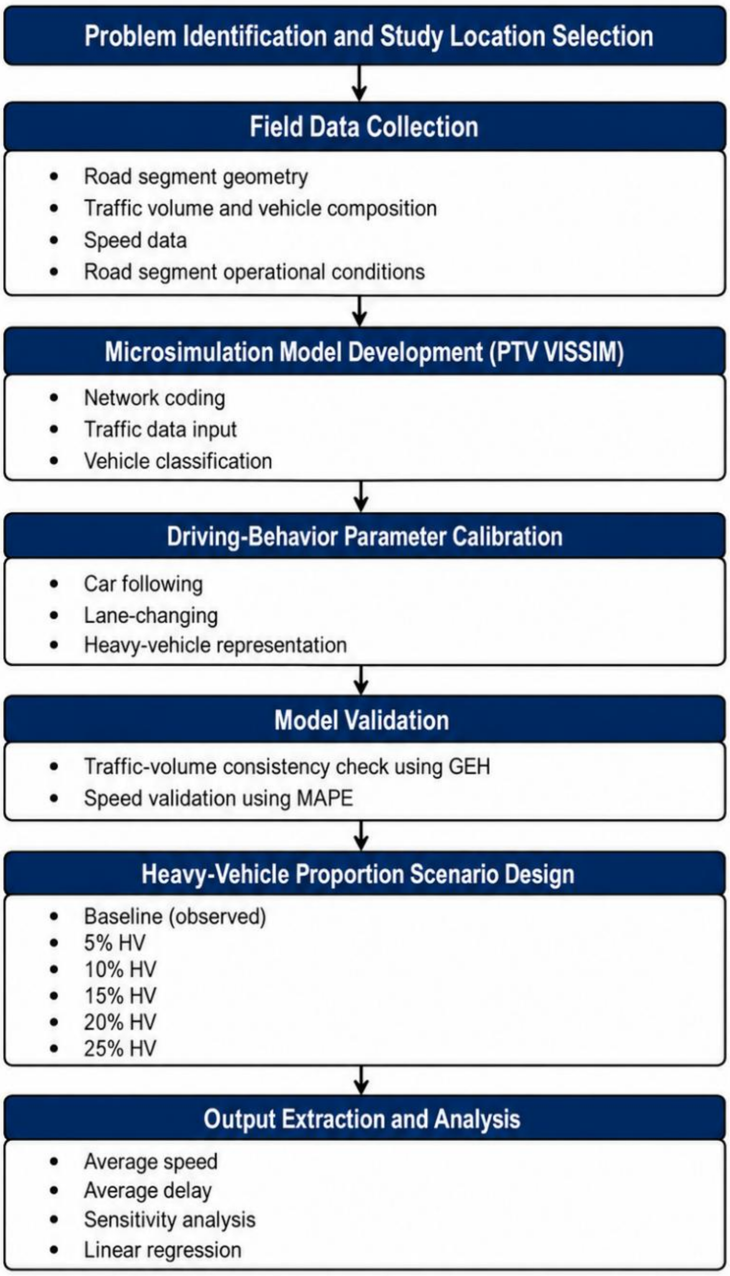

Figure 2. Research Process Stages

3. RESULTS AND DISCUSSION

3.1. Geometric and Traffic Characteristics of the Study Section

The study section is located on National Road 1 (Pantura) in the Astanajapura area, Cirebon Regency. This corridor is part of the primary arterial network serving both regional traffic and local activities around the section. Traffic characteristics on the study segment are mixed, dominated by motorcycles and passenger cars, with heavy vehicles present in a relatively small proportion at the time of the survey.

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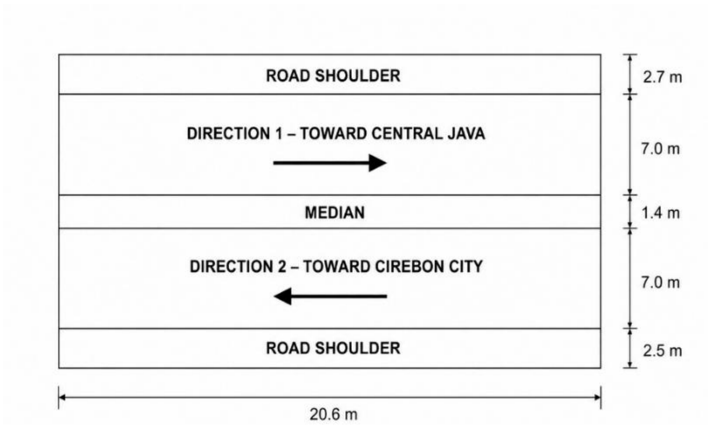

Figure 3. Geometric Configuration of the National Road 1 Study Section in Astanajapura

Geometrically, the study segment has a four-lane, two-way configuration with a median, or a 4/2 D type. Each direction consists of two lanes with a total width of approximately 7 meters, while the median is approximately 1.4 meters wide. This road section is also equipped with road shoulders on the outer sides, with a width of approximately 2.7 meters on the Central Java side and 2.5 meters on the Cirebon City side. The geometric scheme of the study section used as the basis for the microsimulation model is presented in Figure 3.

The traffic survey was conducted over four days, consisting of two weekdays (December 30, 2025, and January 19, 2026) and two weekends (January 3, 2026, and January 18, 2026). Based on the survey results, the peak hour occurred on Tuesday, December 30, 2025, from 07:00–08:00 WIB. This period was used as the basis for traffic volume input into the microsimulation model. During the peak hour, the total traffic volume was recorded at 2,266 vehicles per hour for Direction 1 toward Central Java and 3,431 vehicles per hour for Direction 2 toward Cirebon City. The distribution of traffic volume and vehicle composition is shown in Table 2.

Table 2. Peak Hour Traffic Volume and Composition

Vehicle Type	**Direction 1 (Toward Central Java)**		**Direction 2 (Toward Cirebon)**	
	Volume (veh/h)	**Percentage (%)**	Volume (veh/h)	**Percentage (%)**
Motorcycles (SM)	1,724	76.08%	2,685	78.26%
Passenger Cars (MP)	308	13.59%	444	12.94%
Medium-Sized Vehicles (KS)	191	8.43%	231	6.73%
Large Buses (BB)	8	0.35%	8	0.23%
Large Trucks (TB)	26	1.15%	55	1.60%
Non-Motorized Vehicles (KTB)	9	0.40%	8	0.23%
Total	**2,266**	**100.00%**	**3,431**	100.00%

Based on Table 2, traffic flow in both directions is dominated by motorcycles. In Direction 1, the proportion of motorcycles reached 76.08%, while in Direction 2 it was 78.26%. Passenger cars constitute the second-largest vehicle group, accounting for 13.59% in Direction 1 and 12.94% in Direction 2. This pattern indicates that traffic flow in the study segment remains dominated by light vehicles and motorcycles, even though the section is part of a national arterial corridor.

The proportion of heavy vehicles defined as a combination of large buses and large trucks, was recorded at 1.5% in Direction 1 and 1.84% in Direction 2. These figures indicate that heavy vehicles were not a

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dominant component of traffic flow at the time of the survey. However, their presence remains important to analyze because heavy vehicles have operational characteristics that differ from those of light vehicles, particularly in terms of vehicle dimensions, acceleration–deceleration, maneuvering space requirements, and following distance. In heterogeneous traffic, the influence of heavy vehicles is determined not only by their proportion but also by their interaction with other vehicles, the geometric conditions of the road segment, and the level of traffic density [12], [20].

In addition to vehicle volume and composition, the survey also recorded vehicle speeds during peak hours. These data were used to describe initial operational conditions and served as a benchmark in the microsimulation model validation process. The survey results on vehicle speeds are presented in Table 3.

Table 3. Vehicle Speed Data During Peak Hours

Vehicle Type	Speed in Direction 1 (km/h)		Speed in Direction 2 (km/h)	
	Min	Max	Min	Max
SM	25.62	59.70	19.87	59.48
MP	29.81	59.98	25.41	59.68
KS	29.69	59.31	22.35	44.50
BB	22.45	59.17	29.73	59.84
TB	25.45	44.57	9.47	44.73
KTB	7.50	22.42	7.80	19.97
Average	37.14		33.57	

Table 3 summarizes the observed speed ranges by vehicle class and the aggregate average speed used for baseline model assessment in each direction. The available dataset reported the directional average speeds of 37.14 km/h for Direction 1 and 33.57 km/h for Direction 2. Because the present analysis uses these directional averages as the operational benchmark, the speed-validation results should be interpreted as agreement at the aggregate directional level rather than as validation of the full observed speed distribution.

When viewed by vehicle type, non-motorized vehicles have the lowest speed range in both directions. Heavy trucks also exhibit low minimum speeds, particularly in Direction 2, at 9.47 km/h. This condition indicates that vehicles with slower movement characteristics can influence traffic flow dynamics, even though the proportion of heavy vehicles in the survey conditions was not dominant. The vehicle composition during peak hours was then visualized to clarify the traffic flow structure in each direction. The visualization of the vehicle composition is shown in Figure 4.

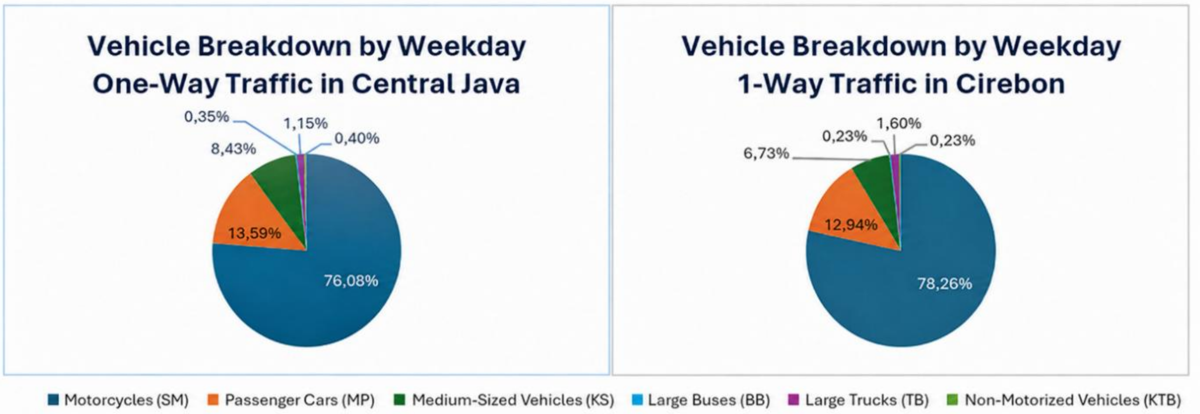

Figure 4. Peak Hour Vehicle Composition

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The geometric, volume, composition, and traffic speed data were used as the basis for developing the VISSIM microsimulation model. Each vehicle class was modeled separately so that differences in movement characteristics between vehicle types could be represented in the simulation. The survey results were used as the baseline scenario, while changes in the proportion of heavy vehicles were used to assess the sensitivity of the road segment's performance to average speed and delay.

3.2. Operational Performance of Existing Conditions

After the microsimulation model was developed based on the geometric characteristics and traffic composition from the survey, the next step was to evaluate operational performance under existing conditions. The baseline scenario used actual heavy vehicle proportions of 1.5% for direction 1 and 1.84% for direction 2, with no changes to vehicle composition. A view of the study section model in the VISSIM software is presented in Figure 5.

Figure 5. PTV VISSIM Microsimulation Model of the Study Section

Baseline-model assessment was conducted using GEH as a traffic-flow consistency measure and MAPE as an indicator of average-speed agreement. GEH was used to compare the observed traffic demand with the traffic volume realized in the simulation, while MAPE was used to assess the relative deviation between observed and simulated average speeds. The use of validation indicators is necessary to ensure that the baseline model not only represents the number of vehicles but also closely approximates actual field operational conditions. In microsimulation studies, GEH is widely used to check the consistency of traffic volume, while error measures such as MAPE can help identify deviations between observed data and model results [16], [18], [19]. The model validation results are presented in Table 4.

Table 4. Microsimulation Model Validation Results

Validation Indicator	Direction	Observed Data	Simulation Result	Validation Value	Interpretation
Traffic volume (veh/h)	Direction 1 / Central Java	2,266	2,270	GEH = 0.084	GEH < 5; acceptable
Traffic volume (veh/h)	Direction 2 / Cirebon City	3,431	3,420	GEH = 0.188	GEH < 5; acceptable
Average speed (km/h)	Direction 1 / Central Java	37.14	38.79	MAPE = 4.451%	Low relative error
Average speed (km/h)	Direction 2 / Cirebon City	33.57	31.97	MAPE = 4.761%	Low relative error

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The baseline-model assessment showed close consistency between the observed and simulated traffic volumes. The GEH values were 0.084 for Direction 1 and 0.188 for Direction 2, both below the adopted consistency criterion of 5. The MAPE values for average speed were 4.451% and 4.761%, respectively, indicating relatively small deviations between the simulated and observed directional average speeds. Considering the traffic-flow consistency and speed-agreement results together, the calibrated baseline model was considered adequate for the subsequent controlled sensitivity analysis of heavy-vehicle proportions. The results of the operational performance of the existing conditions are presented in Table 5.

Table 5. Operational Performance of Existing Conditions

Performance Indicators	Direction 1 / Central Java	Direction 2 / Cirebon City
Average speed (km/h)	38.79	31.97
Average delay (s/veh)	0.49	2.04

Under the baseline condition, the simulated average speed was 38.79 km/h in Direction 1 and 31.97 km/h in Direction 2. The corresponding average delays were 0.49 s/veh and 2.04 s/veh, respectively. Direction 2 therefore exhibited lower average speed and higher delay than Direction 1, consistent with its higher traffic volume. These baseline performance values were used as the reference for evaluating changes under the heavy-vehicle proportion scenarios.

3.3. Effect of Heavy-Vehicle Proportion on Average Speed

To identify the sensitivity of the section's performance to changes in vehicle composition, simulations were conducted for scenarios involving absolute variations in the proportion of heavy vehicles. The analyzed scenarios include the existing conditions, followed by increases in the proportion of heavy vehicles to 5%, 10%, 15%, 20%, and 25%. In all scenarios, total traffic volume, road geometry, and driving behavior parameters were kept constant. Changes were made only to the vehicle composition via the vehicle composition/relative flow settings, so that differences in simulation results could be attributed primarily to changes in the proportion of heavy vehicles. Simulation results show that increasing the proportion of heavy vehicles is associated with a decrease in average speed in both directions under the controlled simulation scenarios. Table 6 presents the simulated average speeds and their absolute differences from the baseline condition.

Table 6. Average Speed under Heavy-Vehicle Proportion Scenarios

HV Proportion	Average Speed D1 (km/h)	Average Speed D2 (km/h)	Change from Baseline D1 (km/h)	Change from Baseline D2 (km/h)
Baseline	38.79	31.97	–	–
5%	38.66	30.83	−0.13	−1.14
10%	38.38	28.80	−0.41	−3.17
15%	37.79	26.75	**−1.00**	−5.22
20%	37.39	25.57	**−1.40**	−6.40
25%	36.63	23.05	**−2.16**	−8.92

In Direction 1, the average speed decreased from 38.79 km/h under the baseline condition to 36.63 km/h in the 25% HV scenario, corresponding to a reduction of 2.16 km/h. In Direction 2, the average speed decreased from 31.97 km/h to 23.05 km/h, corresponding to a larger reduction of 8.92 km/h. These results indicate that the simulated performance of Direction 2 was more sensitive to increases in the proportion of heavy vehicles. The relationship between the proportion of heavy vehicles and average speed is visualized in Figure 6.

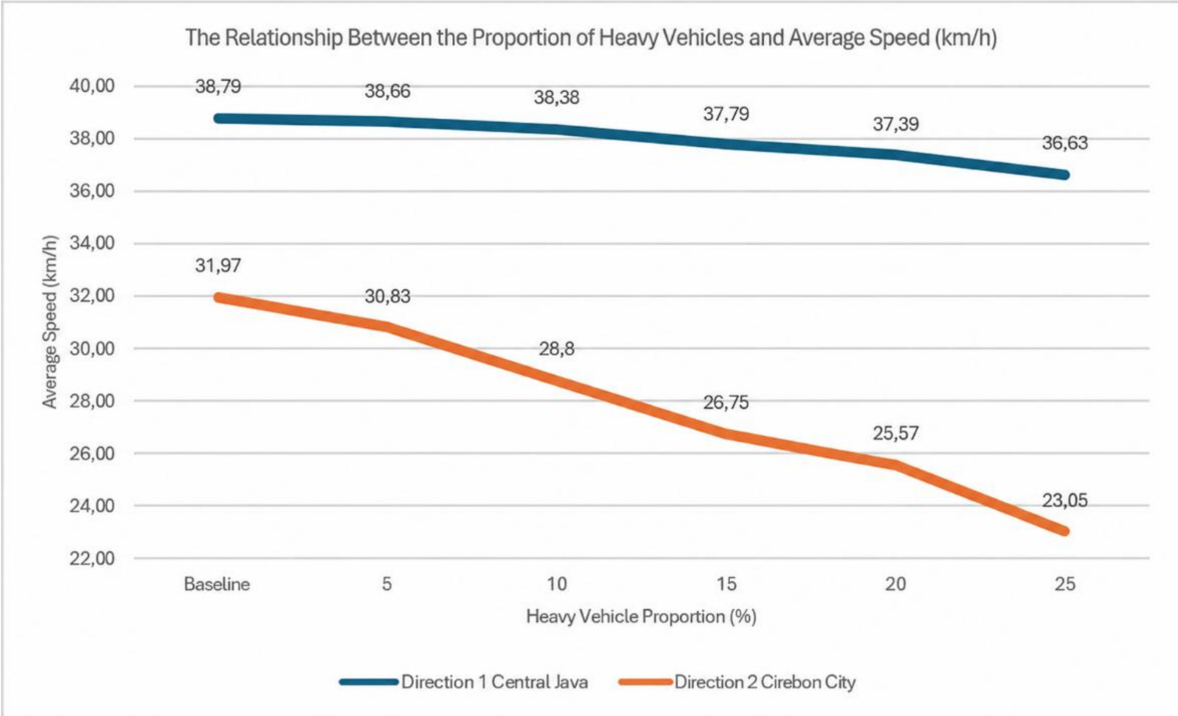

Figure 6. Relationship Between the Proportion of Heavy Vehicles and Average Speed

Figure 6 shows a pattern of decreasing speed in both directions. In Direction 1, the decrease in speed occurs gradually and is relatively gentle. Conversely, in Direction 2, an increase in the proportion of heavy vehicles results in a sharper decrease in speed. This condition can be attributed to the higher traffic volume in Direction 2, making it easier for additional heavy vehicles to affect the stability of traffic flow and the maneuvering space of other vehicles. To analyze this relationship, a simple linear regression was performed between the proportion of heavy vehicles and the average speed in each direction of travel. The regression results are summarized in Table 7.

Table 7. Linear Trend Between Heavy-Vehicle Proportion and Average Speed

Direction of Travel	**Regression Equation**	R^2	**Interpretation of Coefficients**
Direction 1 / Central Java	V = 39.105 − 0.091HV	0.966	Each 1-percentage-point increase in HV corresponds to a speed decrease of 0.091 km/h
Direction 2 / Cirebon City	V = 32.650 − 0.376HV	0.994	Each 1-percentage-point increase in HV corresponds to a speed decrease of 0.376 km/h

The fitted linear trends indicate a negative association between the proportion of heavy vehicles and average speed across the controlled simulation scenarios. For Direction 1, the fitted equation was V=39.105−0.091HV, with R^2=0.966. For Direction 2, the fitted equation was V=32.650−0.376HV, with

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R^2=0.994. These R^2 values indicate that the simulated speed responses closely followed a linear trend over the tested HV proportions.

The fitted slopes indicate different levels of sensitivity between the two directions. Within the tested scenarios, each one-percentage-point increase in HV corresponded to an average speed reduction of approximately 0.091 km/h in Direction 1 and 0.376 km/h in Direction 2. The larger absolute slope in Direction 2 indicates a stronger simulated speed response to increasing HV proportions.

These regression results are interpreted as descriptive summaries of the controlled scenario-response pattern. They are not intended to establish a causal statistical relationship from observational data, because the HV proportions were deliberately specified as simulation scenarios while traffic demand, road geometry, and other model settings were held constant [20], [22], [23]. Operationally, this reduction can be explained by the characteristics of heavy vehicles, which have larger dimensions, lower acceleration capabilities, and require longer following distances compared to light vehicles [12]. On the study section, this effect is more pronounced in the Cirebon City direction due to its higher traffic volume, making it easier for additional heavy vehicles to affect traffic flow stability and the maneuvering space of other vehicles.

3.4. Effect of Heavy-Vehicle Proportion on Average Delay

In addition to average speed, delay was also analyzed to assess the effect of variations in the proportion of heavy vehicles on the operational performance of the section. Delay represents the additional time experienced by vehicles due to traffic interactions, deceleration, and limited maneuvering space while on the simulated segment. In this scenario, changes in delay were observed while maintaining the total volume and road geometry as in the baseline conditions. To illustrate traffic conditions under the scenario with the highest proportion of heavy vehicles, the queue visualization from the microsimulation is shown in Figure 7.

Simulation results show that an increase in the proportion of heavy vehicles is followed by an increase in average delay in both directions of travel. Average delay was evaluated under the observed baseline condition and the five hypothetical HV-proportion scenarios. The baseline HV proportions were 1.50% in Direction 1 and 1.84% in Direction 2, whereas the hypothetical scenarios used common target HV proportions of 5%, 10%, 15%, 20%, and 25% for both directions. Total traffic volume, road geometry, and other controlled model settings were maintained across the scenarios. The resulting average delays and their absolute differences from the baseline condition are presented in Table 8.

Figure 7. Queue Visualization on the Pantura Kanci–Astanajapura Section under the 25% HV Scenario

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Table 8. Average Delay under Heavy-Vehicle Proportion Scenarios

Scenario	HV Proportion D1	HV Proportion D2	Average Delay D1 (s/veh)	Average Delay D2 (s/veh)	Change from Baseline D1 (s/veh)	Change from Baseline D2 (s/veh)
Baseline	**1.50%**	**1.84%**	0.49	2.04	–	–
S1	5%	5%	0.51	2.67	0.02	0.63
S2	10%	10%	0.62	3.70	0.13	1.66
S3	15%	15%	0.73	5.05	0.24	3.01
S4	20%	20%	0.82	5.86	0.33	3.82
S5	25%	25%	0.99	8.14	0.50	6.10

In Direction 1, average delay increased from 0.49 s/veh under the observed baseline condition to 0.99 s/veh in the 25% HV scenario, corresponding to an increase of 0.50 s/veh. In Direction 2, average delay increased from 2.04 to 8.14 s/veh, corresponding to a substantially larger increase of 6.10 s/veh. These scenario outputs indicate that the simulated delay response in Direction 2 was more sensitive to increases in the HV proportion. The relationship between the proportion of heavy vehicles and average delay is shown in Figure 8.

Figure 8 shows that delay increases as the proportion of heavy vehicles increases. In Direction 1, the increase in delay is relatively small and gradual. In Direction 2, the increase in delay is more pronounced, particularly in scenarios with a higher proportion of heavy vehicles. This pattern indicates that directions with higher traffic volumes tend to be more sensitive to changes in the composition of heavy vehicles.

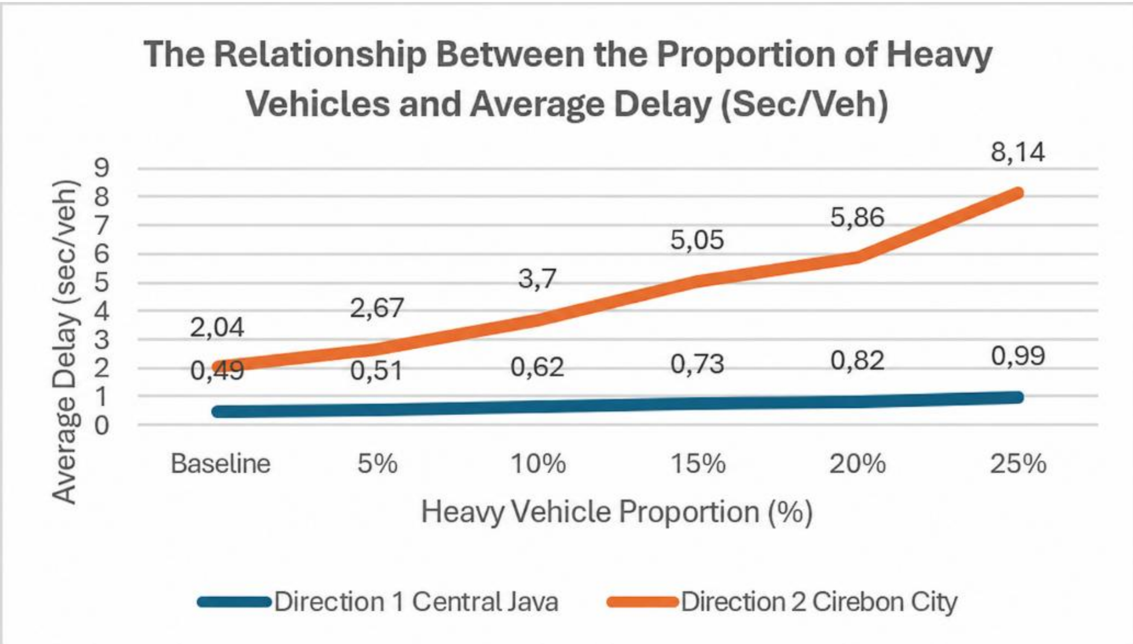

Figure 8. Relationship Between Heavy-Vehicle Proportion and Average Delay

The increase in delay due to a higher proportion of heavy vehicles can be explained by their greater space requirements, lower acceleration, and slower flow recovery time following a deceleration. In mixed traffic flows, interactions between heavy vehicles, light vehicles, and motorcycles can amplify

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headway variations and disrupt platoon smoothness, thereby increasing average delay. This pattern aligns with previous microsimulation studies showing that the impact of heavy vehicles on delay tends to be stronger under dense traffic conditions or near the operational disruption threshold [20], [22], [23]. To reinforce the trend analysis, a simple linear regression was performed between the proportion of heavy vehicles and average delay for each direction of travel. The regression results are summarized in Table 9.

Table 9. Linear Trend Between Heavy-Vehicle Proportion and Average Delay

Direction of Traffic	Regression Equation	R^2	Interpretation of Coefficients
Direction 1 / Central Java	D = 0.422 + 0.021HV	0.978	Each 1-percentage-point increase in HV corresponds to a delay increase of 0.021 s/veh
Direction 2 / Cirebon City	D = 1.365 + 0.251HV	0.976	Each 1-percentage-point increase in HV corresponds to a delay increase of 0.251 s/veh

The fitted linear trends indicate a positive association between the proportion of heavy vehicles and average delay across the controlled simulation scenarios. For Direction 1, the fitted equation was $D=0.422+0.021HV$, with $R^2=0.978$. For Direction 2, the fitted equation was $D=1.365+0.251HV$, with $R^2=0.976$. The high R^2 values indicate that the simulated delay responses were closely represented by linear trends across the tested HV proportions.

The fitted slope for Direction 1 indicates an increase in average delay of approximately 0.021 s/veh for each one-percentage-point increase in HV within the tested scenarios, whereas the corresponding increase for Direction 2 was approximately 0.251 s/veh. The substantially larger slope in Direction 2 indicates a stronger simulated delay response to increasing heavy-vehicle proportions.

As with the speed analysis, the regression is used descriptively to characterize scenario sensitivity. It should not be interpreted as causal statistical inference from observational data because the HV proportions were predetermined inputs in a controlled microsimulation experiment.

Although the fitted linear trend provides a useful summary of the scenario responses, the simulated delay pattern should be interpreted with caution. In Direction 2, the increase in delay becomes more pronounced at higher HV proportions, particularly in the 25% scenario. This suggests that the operational response may become increasingly nonlinear as the traffic condition approaches a more constrained state. Therefore, the linear regression is used primarily as a compact indicator of overall sensitivity across the tested scenarios rather than as evidence that the relationship is universally linear.

3.5. Operational and Managerial Implications

Simulation results show that an increase in the proportion of heavy vehicles reduces average speed and increases delays in both directions of travel. This impact is stronger in the Cirebon City direction, which has higher traffic volume compared to the Central Java direction. These findings provide several implications for the management of arterial sections with mixed traffic.

First, vehicle composition must be considered in route performance evaluations. Analysis based solely on total volume is insufficient to describe actual operational conditions on the ground, as traffic flows with the same volume can yield different performance when vehicle composition changes. On routes

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serving both regional movements and local activities, changes in the proportion of heavy vehicles can affect speed stability and delay even if their proportion was not dominant during the survey period.

Second, temporal management of heavy-vehicle movements may be considered as a potential traffic-management option during periods of high traffic demand. However, the present simulation results alone are not sufficient to support a definitive restriction on heavy-vehicle operating hours. Any implementation of such a strategy would require additional evaluation of freight demand, alternative routes, off-peak operating conditions, logistics costs, and broader socioeconomic implications. Therefore, the potential role of heavy-vehicle management may warrant further operational assessment, particularly in the direction with higher traffic volume.

Third, the geometric conditions of the road section must be considered as they can amplify the impact of heavy vehicles on traffic performance. On a four-lane, two-way section with a median, the presence of two lanes per direction provides better maneuverability compared to a two-lane, two-way section without a median. However, as traffic volume increases, heavy vehicles can still affect traffic flow due to their greater space requirements and lower acceleration capabilities. Therefore, operational regulation of heavy vehicles remains relevant, especially in the direction with higher volume.

Fourth, the regression results indicate that the Cirebon City direction exhibits higher sensitivity to increases in the proportion of heavy vehicles. The stronger simulated response observed in Direction 2 suggests that this direction may warrant greater attention in future operational assessments, particularly during periods of high traffic demand or increased freight activity. However, any direction-specific management intervention should be evaluated using additional traffic, freight, and implementation considerations beyond the present composition-sensitivity analysis.

Practically, the findings can provide preliminary operational information for road managers when evaluating potential changes in vehicle composition. The microsimulation results demonstrate how speed and delay respond under the tested HV scenarios and may therefore support the screening of possible management alternatives. Detailed policy formulation, however, requires additional assessment of traffic demand patterns, freight operations, alternative routes, economic impacts, and implementation feasibility.

A limitation of the present study is that the analysis focuses on comparative responses among controlled heavy-vehicle composition scenarios using the calibrated baseline model. The study does not quantify output variability associated with alternative random seeds or multiple stochastic replications. Accordingly, the reported speed and delay values should be interpreted primarily as scenario-based sensitivity indicators for the modeled road segment rather than as probabilistic estimates of traffic performance. Future studies may extend the analysis using multiple simulation replications and explicit reporting of run-specific stochastic settings.

4. CONCLUSION

This study analyzes the impact of variations in the proportion of heavy vehicles on the operational performance of National Road 1 in Astanajapura, Cirebon Regency, using the PTV VISSIM microsimulation approach. The base model was constructed using survey data on geometry, volume, vehicle composition, and speeds during peak hours. The baseline-model assessment showed close consistency between observed and simulated traffic volumes and relatively small deviations in average speed. The GEH values were 0.084 and 0.188 for Directions 1 and 2, respectively, while the corresponding MAPE values were 4.451% and 4.761%. These results were considered adequate for applying the baseline model to the subsequent controlled sensitivity analysis.

Simulation results indicate that an increase in the proportion of heavy vehicles consistently reduces average speed and increases delay. In the Central Java direction, speed decreases from 38.79 km/h under existing conditions to 36.63 km/h in the 25% HV scenario, while delay increases from 0.49 s/veh to 0.99 s/veh. In the Cirebon City direction, the changes observed were more significant: speed decreased from 31.97 km/h to 23.05 km/h, while delay increased from 2.04 s/veh to 8.14 s/veh.

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Descriptive linear trend analysis further summarized the sensitivity of the simulated responses. The fitted speed slopes were −0.091 km/h and −0.376 km/h per percentage point of HV for Directions 1 and 2, respectively, while the corresponding delay slopes were 0.021 and 0.251 s/veh per percentage point of HV. These coefficients indicate that Direction 2 exhibited a stronger simulated response to increasing HV proportions. The regression results are interpreted as scenario-based sensitivity indicators rather than causal statistical estimates.

Within the tested simulation scenarios, the Cirebon City direction exhibited a stronger operational response to increasing heavy-vehicle proportions than the Central Java direction, as indicated by the larger reductions in average speed and increases in average delay. This difference in sensitivity is related to the higher traffic volume in the Cirebon City direction, meaning that additional heavy vehicles more easily affect flow stability, speed, and delay. Therefore, evaluating the performance of arterial road sections requires not only considering total traffic volume but also incorporating vehicle composition as an analytical variable. The results of this study can provide preliminary operational information for road managers when evaluating potential heavy-vehicle management alternatives, particularly under higher traffic-demand conditions.

The findings should be interpreted within the scope of the controlled microsimulation scenarios examined in this study. Total traffic demand, road geometry, and calibrated driving-behavior settings were maintained constant across the scenarios, while vehicle composition was varied. Therefore, the reported speed and delay responses represent the sensitivity of the modeled road segment under the tested baseline and HV-proportion scenarios and should not be directly generalized to other traffic-demand levels, geometric conditions, or arterial corridors without additional analysis. Future studies may extend the present analysis by examining variations in traffic demand, geometric characteristics, and other operational conditions together with changes in heavy-vehicle composition.

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