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Research Article

Platoon-Based Assessment of Two-Way Two-Lane Roads Performance Measure: A Classification Method

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Two-way two-lane roads have a significant impact on road transportation infrastructure. Platoon formation on two-lane roads is one of the factors that affect the quality of traffic flow on two-lane roads. More specifically, the creation of a platoon increases the density of vehicles and the number of overtaking maneuvers and decreases the traffic performance of two-lane roads. The present study made an effort to investigate the effect of the platoon characteristics on the traffic flow of vehicles on two-lane roads. Moreover, it strived to develop the nonlinear regression model with a new approach to capacity calculation. Finally, a method for estimating the level of service (LOS) based on the number of followers per capacity (NFPC) and LOS classification using the KNN method was presented. Considering these aims, first, the relevant variables (which were related to platoon) including time headway (H_t), average travel speed (ATS), platoon size (PS), average platoon speed (APS), percentage of heavy vehicles (HV), percent time spent following (PTSF), number of overtaking (NO), density (ρ), and traffic flow were investigated on the examined roads. The results showed that the speed and the H_t were the most effective and the least effective platoon characteristics, respectively. Moreover, it was accompanied by the increase in PTSF which resulted in the increase in overtaking maneuver. Finally, the results regarding the developed model showed that the NFPC measure was able to predict the traffic flow of two-lane roads in a more satisfactory way compared to the two criteria, namely, PTSF and ATS in the Highway Capacity Manual (2016) since it increased ATS by 65% and decreased the capacity of two-lane roads by 21%.

1. Introduction

Two-lane roads make up the majority of road networks, encompassing both urban and suburban areas. In fact, the quantity of these roads surpasses that of any other road type, not only in the United States but also in numerous countries worldwide [1]. According to the report of Road Maintenance and Transportation Organization [2, 3], about 29% of the roads in Iran are two-way roads. If we exclude the roads that provide access to villages, approximately 85% of Iran's rural road network consists of arterial roads and collector roads, which are predominantly two-way two-lane roads [2, 3]. Two-way two-lane roads play an important role in road transportation facilities. The creation of platoons on two-lane roads is one of the factors that affect the characteristics and quality of traffic flow such as the average travel speed (ATS) on two-lane roads. For instance, the creation of a platoon results in an increase in the density of vehicles (ρ) and the number of overtaking (NO). On the other hand, it leads to a decline in the traffic performance of two-lane roads and the level of service (LOS) [4–6]. The decline in the traffic performance of two-lane roads due to the creation of platoons has a negative effect on drivers' safety [7]. The Highway Capacity Manual 6th [8] provides two performance indicators, namely, the percent time spent following (PTSF) and the average travel speed (ATS) which can be used for determining the LOS of the two-lane roads. Al-Kaisy and Durbin [9] defined ATS (average time spent) as the average percentage of travel time for vehicles traveling in platoons at a speed lower than the average travel speed. HCM [8] defines PTSF as a function of the percentage of follower vehicles with time intervals which are less than 3 seconds. Hence, by determining the extent to which the relationship between ATS, PTSF, and platoon characteristics impacts the traffic performance of two-lane roads, it becomes feasible to enhance the estimation and prediction of the traffic flow and LOS.

This study aimed to provide a model for evaluating the impact of platoon characteristics including time headway (H_t), number of overtaking (NO), average platoon speed (APS), platoon size (PS), percentage of heavy vehicle (HV), and number of follower vehicles (NF) on the traffic flow of two-lane roads. Moreover, we tried to provide a classification of LOS based on the developed model. Considering these objectives, the study examined the creation of traffic platoons on two-lane roads which stemmed from the leader and follower vehicles including light or heavy vehicles. A nonlinear regression equation was obtained and was used for predicting the traffic flow by evaluating the variables of platoon characteristics and traffic flow and establishing a relationship between the variables. First, the number of followers per capacity (NFPC) parameter [10] was defined using the nonlinear model and the NF. Next, the LOS of the examined roads was checked and evaluated based on the model which was developed on the basis of NFPC and PTSF. Finally, the LOS was categorized based on the NFPC-HCM-platoon relationship using the k-nearest neighbor (KNN) algorithm.

2. Literature Review

An examination of the previous studies on the capacity of two-lane roads reveals that these studies have primarily concentrated on three key aspects: LOS and capacity, platoon changes, and time headway and spacing headway. In the first group of the aforementioned studies, several research works have investigated the influence of various parameters, such as the number of platoons formed by vehicles [11], the HV [12–14] [15], the NFPC [16, 17], speed of followers and critical H_t as functional characteristics [18, 19], the PTSF and the ATS [20–22], geometric parameters (longitudinal slope and superelevation of the road) [23, 24], geometric features of the road and traffic conditions (density, speed, and the traffic flow rate) [25–27], and density [28] and travel speed using passenger car equivalent [29] on the LOS and road capacity.

In the second group of the previously mentioned studies, specific research works have emphasized parameters related to platoon formation, such as identifying the timing of platoon creation based on the volume of vehicles passing through [30], H_t [31–33], the speed of followers, the average time and spacing headway [34], HV [35], and the NO [36, 37]. Finally, in the third group of the abovementioned studies, a number of studies have investigated the impact of certain parameters such as density and speed and traffic flow rate on time and spacing headway [38, 39];. Among these studies, the works conducted by Penmetsa et al. [16], Al-Kaisy et al. [40], and Jain et al. [10] carried out more comprehensive investigations than other studies. Penmetsa et al. introduced an auxiliary parameter known as NFPC. This parameter addressed the attributes of follower vehicles and road capacity. The calculated value of NFPC is utilized to determine a parameter known as the percentage of followers (PF) [41]. According to the HCM [42], PF is considered as an alternative measure that can be employed to calculate PTSF. The equation of NFPC, which was provided by Penmetsa et al., examines the volume value based on 6 parameters, namely, ATS, ATSPC, ATS/FFS (free flow speed), ATSPC/FFSPC, PF, and FD (follower density). The examination of the abovementioned categories of studies shows that various studies have investigated one or several parameters of the platoon characteristics or the traffic flow.

In recent years, none of the relevant studies has comprehensively examined the effect of platoon characteristics including H_t, ATS, PS, APS, HV, PTSF, NO, and ρ on the volume and quality of traffic flow. The present study examined the impact of platoon characteristics on the quality of traffic flow on two-lane roads. Moreover, it developed a model based on capacity and LOS. Finally, the study compared the effect of platoon characteristics on the LOS (in the form of PF) and PTSF based on HCM [8]. The last objective of the study constituted one of its innovative aspects. Moreover, this study carries out LOS classification based on all platoon parameters using the KNN algorithm for the first time.

3. Research Methodology

For this study, four case study sites in Iran were chosen to assess the impact of platoon characteristics on the quality of traffic flow on two-lane roads. The platoon parameters were assessed using the videography analysis methodology. Following the initial investigation, a Pearson correlation statistical analysis was conducted to validate the data, examining the relationship between each platoon variable and traffic flow. Subsequently, a nonlinear regression model was developed to explore the impact of platoon characteristics on traffic flow. After establishing the nonlinear regression model for traffic flow on two-lane roads, an alternative parameter was proposed as a substitute for ATS and PTSF, as indicated in HCM [8], to evaluate LOS. Lastly, the KNN model was employed to classify the LOS by assessing the extent to which the relationship between platoon characteristics influenced the obtained NFPC. Figure 1 provides an overview of the steps undertaken in this study.

3.1. Case Study Sites and Data Collection. To investigate the impact of vehicle platoon characteristics on the quality of traffic flow on two-lane roads, four road sections were selected in Iran: Fuman-Saravan (site 1), Rasht-Jirdeh (site 2),

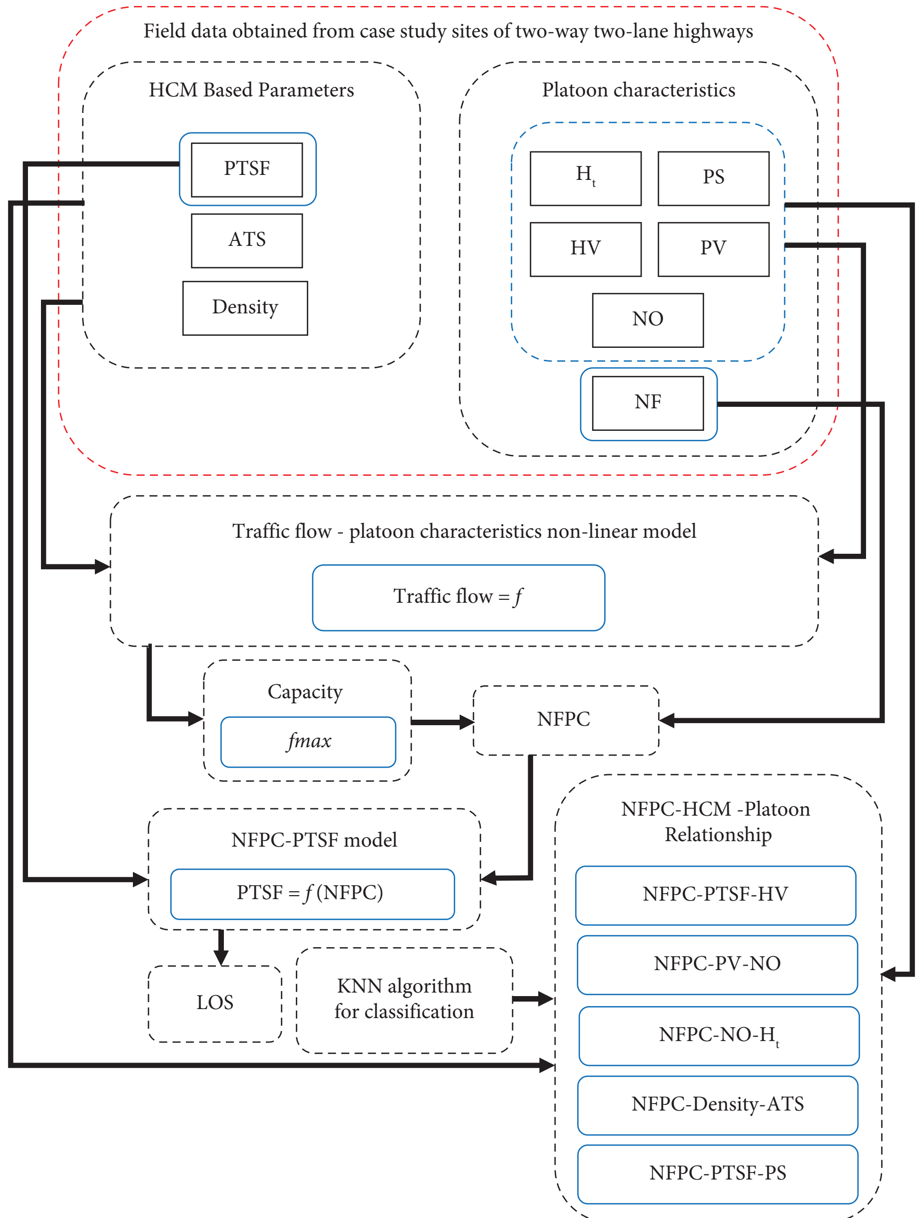
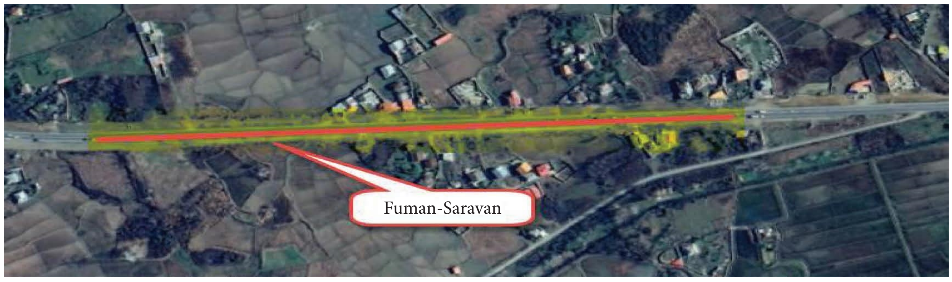


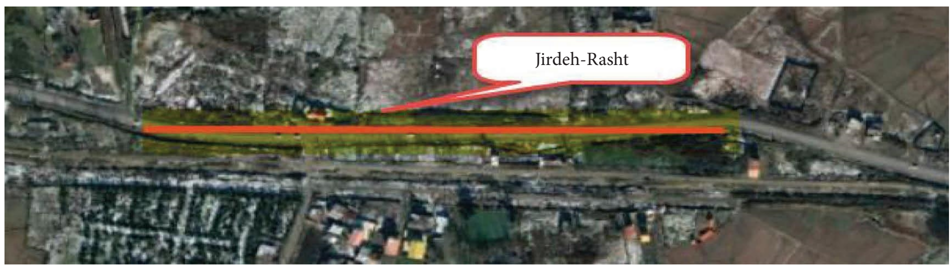
Figure 1: Research methodology.

Rasht-Somesara (site 3), and Kiasar-Sari (site 4). These road sections belong to the rural class I road category. Figure 2(a)–2(d) (obtained from the free online resources of Google Earth (GE)) displays the selected sites. The traffic flow volume varied from relatively high to low, with a mix of light and heavy vehicles. Consequently, a straight and longitudinal stretch of 60 meters was chosen as the measurement location for flow, ATS, and platoon characteristics. Videography analysis was conducted at a frame rate of 30 frames per second to extract field data. The weather conditions during the analysis were daylight, clear, and sunny, with the pavement in good condition. Furthermore, the study disregarded the effects of the longitudinal slope, intersections, and horizontal alignments in the straight sections of the road. The speed limit on the examined roads was 90 km/h, and each lane had a width of 3.65 meters. Figure 2 provides an overview of the case study sites.

As shown in Table 1, the data, which were used in this study, were the data on the flow and platoon characteristics such as ATS, H_t, ρ, HV, PTSF, NO, PS, and APS. The data were collected in a 5-minute interval during an 8-hour period of time. As shown in Table 1, the minimum traffic flow had 70 Veh/h. On the other hand, the maximum traffic flow had 1810 Veh/h with a maximum density of 55 Veh/km. Furthermore, while the ATS of passing vehicles was 67 km/h with the minimum H_t of 2 seconds, the maximum H_t of the vehicles was 35 seconds and the average value of all of the examined roads was 7.69 seconds. The maximum and the minimum speeds of the platoons were 68 and 25 km/h, respectively. The maximum observed NO was 96 N/h. In

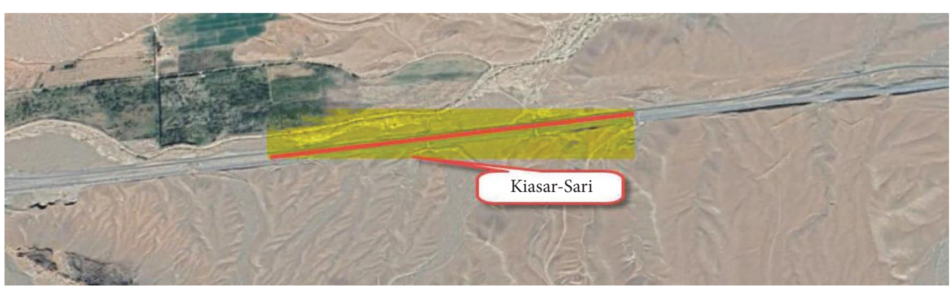


(a)



(b)

(c)



(d)

Figure 2: Filed study sites. (a) Site 1. (b) Site 2. (c) Site 3. (d) Site 4.

Table 1: Statistics of the flow and platoon characteristics in two-lane roads.

Percentages of light and heavy vehicles	Site 1	Site 2	Site 3	Site 4	Minimum	Maximum	Average	Standard deviation
*LV (%)	88	92	82	96				
HV (%)	11	8	18	4				
Platooning characteristics								
Flow (Veh/h)					70	1810	825.96	534.74
H_t (s)					2	35	7.69	8.99
Density (Veh/km)					3	55	15.82	12.17
PTSF (%)					5	91	64.92	12.72
ATS (km/h)					36	81	66.87	10.75
NO (N/h)					0	96	33.38	21.45
PS (N/h)					0	225	85.76	56.34
APS (km/h)					25	68	52.19	10.98

*Note: LV = light vehicle.

addition, the maximum PS was equal to 225 N/h, and the maximum HV and PTSF were 18% and 91%, respectively.

4. Results and Discussion

In order to determine the effect of the platoon characteristics on the quality of traffic flow, the results of Pearson's correlation analysis were examined. These results expounded on the effect of each of the variables on the other variables. Moreover, they showed the impact of each of the relevant variables on the traffic flow. The researchers used nonlinear regression modeling to improve the accuracy of the developed traffic flow model based on the Pearson correlation results regarding the relationships between the platoon characteristics and the traffic flow and the relationships between each of the platoon characteristics and the other platoon characteristics.

4.1. Analysis of Platoon Characteristics on Traffic Flow. Figure 3 illustrates the distribution of field data collected from the examined sites, categorized by traffic flow. This figure showcases the variations in platoon parameters based on the traffic flow. Figures 3(a)–(3e) specifically depict the changes in Ht, PS, NO, PTSF, and APS, respectively. Heavy vehicles have the potential to generate more platoons within the traffic flow due to their tendency to assume leadership positions. Given the composition of heavy vehicles in the traffic flow across the four examined road sites, it was observed that a significant portion of the traffic flow was attributed to heavy vehicles. Consequently, the creation of platoons and an increase in the traffic flow led to an increase in PS (Figure 3(b)). This increase in PS, in turn, contributed to an increase in PTSF (Figure 3(d)). In addition, the rise in PTSF resulted in a decrease in APS and Ht (Figures 3(a) and (3e)). Ultimately, these changes in the traffic flow led to an increase in NO (Figure 3(c)).

Pearson's correlation test was used to check the significance of field statistics for platoon characteristics and to determine their relationships with traffic flow. Table 2 shows the results of Pearson's correlation test regarding the relationships between the platoon characteristics and the traffic flow and the relationships between all of the platoon characteristics. A negative correlation indicates an inverse relationship between the parameters. For example, as APS increases, NO decreases ($r = -0.876$). According to the distribution of field data, the highest correlation between the flow and platoon characteristics was related to APS. On the other hand, the lowest correlation was related to H_t.

The most positive correlation was established between ATS and APS. It can be stated that the increase in the ATS was accompanied by the increase in the APS. Moreover, the highest negative correlation was the correlation between ρ and APS. Consequently, it can be argued that the decrease in the average platoon speed was accompanied by an increase in the density.

Figure 4 shows the effect of vehicle density on traffic flow in the 4 examined sites. The results showed that the increase in the density of vehicles was accompanied by an increase in the rate of traffic flow. The increase in this rate continued until the flow reached its maximum value. After passing the maximum point, the traffic flow rate decreased. Figure 5 shows the effect of vehicle density on ATS. Moreover, it shows that the increase in the density of vehicles was accompanied by the decrease in the ATS of vehicles.

4.2. Nonlinear Regression Model. Pearson's correlation test was used to determine the correlation between the independent variables. The examination of the results of this test showed that the relationships between some of these variables were not significant. Moreover, based on the results, the aforementioned correlations were not linear. For example, in Table 2, the significance level of the correlation between the flow and APS was 0.046. This level is not acceptable at the 99% confidence level. Moreover, the direction of the data (positive or negative) regarding a certain independent variable differed from the direction of the data regarding the other indirect variables. For instance, there were negative correlation between the traffic flow, and H_t, APS, and ATS. Therefore, in this section, nonlinear regression was used to increase the accuracy of the model (equation (1)). The data on platoon as an independent variable and the data on flow as a dependent variable were entered into SPSS in order to develop the model. The R^2 value of the developed model was equal to 0.87. Consequently, there were good correlations between the relevant variables.

$$f = 0.008(\mathrm{ATS})^2 + 16.99(\rho) + 0.101(\mathrm{HV})(\mathrm{NO}) + 0.091\sqrt{(\mathrm{PTSF})(H_t)(100 - HV)} + 0.117\,(\mathrm{PS})(\mathrm{APS}), R^2 = 0.87, \tag{1}$$

where f is the traffic flow (Veh/h), ATS is average travel speed (km/h), HV is heavy vehicles (%), PS is the platoon size of vehicles (N/h), NO is the number of overtaking (N/h), APS is the average platoon speed (km/h), H_t is the time headway (s), PTSF is the percent time spent following (%), and ρ is the density (Veh/km).

4.3. Model Validation. Two statistical tests were employed to validate the developed nonlinear model of traffic flow and the independent variables (equation (1)). The first test aimed to demonstrate the absence of collinearity among the independent variables of the nonlinear regression model, while the second test was conducted to assess the accuracy of the

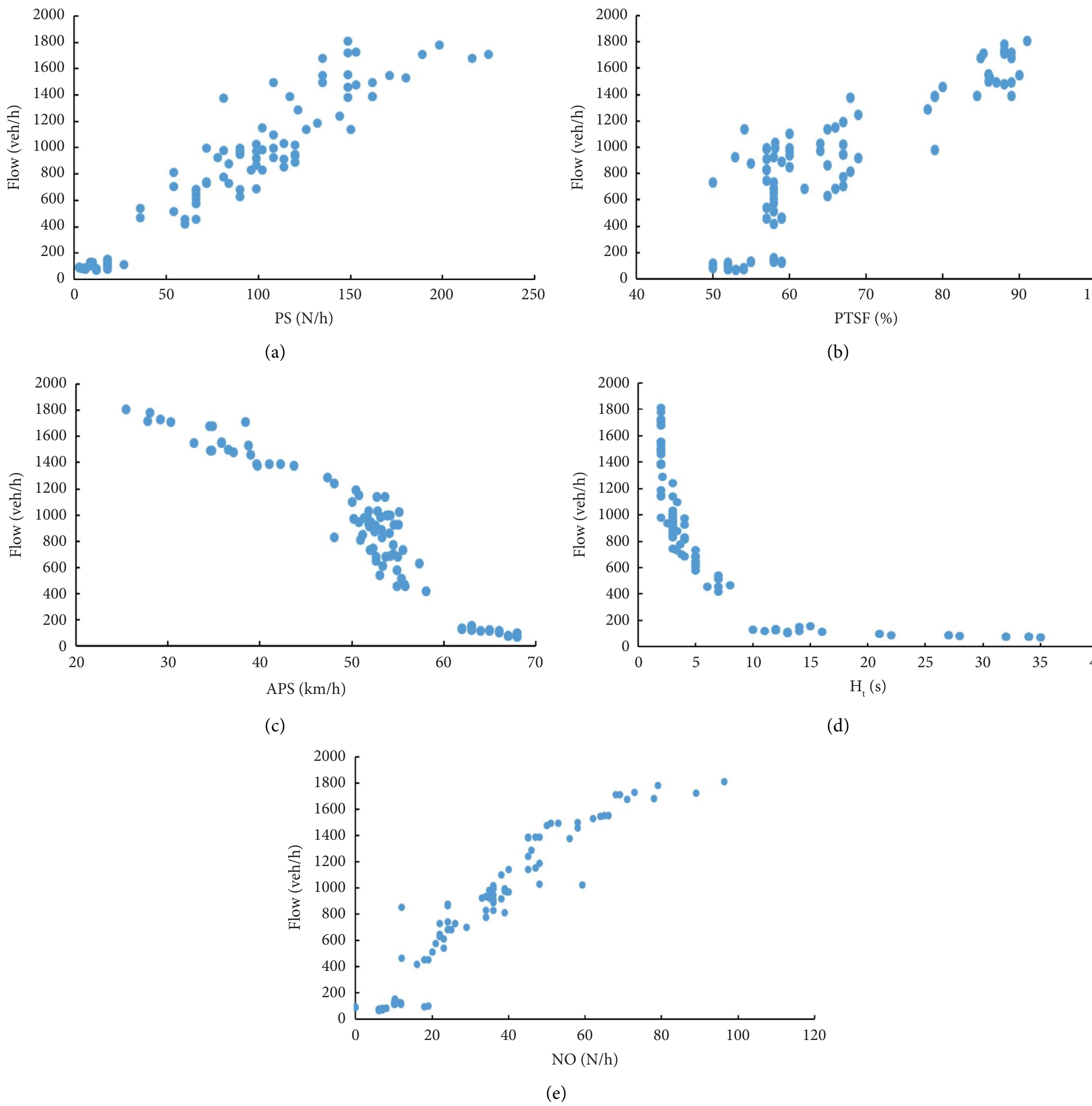


FIGURE 3: Relationship between flow and platoon parameters: (a) flow-PS, (b) flow-PTSF, (c) flow-APS, (d) flow-Ht, (e) flow-NO.

proposed model. The statistical test for multicollinearity was utilized to examine the absence of strong correlations within the correlation matrix of the regression model's independent variables. This test employs two criteria, namely, the variance inflation factor (VIF) and tolerance to validate the data. As a general rule, if the VIF value exceeds 10, it suggests the presence of collinearity among the variables. Furthermore, if the VIF value exceeds 100, it unequivocally confirms the presence of collinearity among the variables. In the developed model (equation (1)), the tolerance value was calculated using the equation $T = 1 - R^2$, and the VIF value was determined using the equation $\mathrm{VIF} = 1/T$. In the regression model, $T = 1 - 0.87 = 0.13$, resulting in a VIF value of 7.69. Thus, the model did not exhibit any issues of data collinearity. According to Figure 6, the proposed nonlinear regression model gives a good performance in terms of regression coefficients (R^2) in the prediction model. The proposed model was able to predict the traffic flow on two-lane roads in a satisfactory way. Moreover, the regression coefficient of the model was approximately 0.928 compared to the actual data.

4.4. NFPC-PTSF Model. After providing the nonlinear regression model, equation (2) was proposed as a function of NF and capacity on two-lane roads to examine the influence of the vehicle platoon characteristics on the quality of traffic flow and to determine the LOS based on the NF and capacity. Equation (2) was obtained by substituting the NF for the maximum flow function as the NFPC variable.

Table 2: Effect of platoon characteristics on traffic flow using Pearson's correlation coefficient.

Platoon characteristics		Flow (Veh/h)	H_t (s)	ρ (Veh/km)	PTSF (%)	ATS (km/h)	NO (N/h)	PS (N/h)	APS (km/h)	HV (%)
Flow (Veh/h)	Pearson correlation	1	−0.753	0.920	0.863	−0.922	0.951	0.947	−0.956	0.850
	Sig. (2-tailed)	—	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.000
H_t (s)	Pearson correlation	−0.753	1	0.567	−0.540	0.658	−0.669	−0.730	0.718	−0.610
	Sig. (2-tailed)	0.000	—	0.000	0.000	0.000	0.000	0.000	0.596	0.000
ρ (Veh/km)	Pearson correlation	0.920	−0.567	1	0.915	−0.917	0.945	0.850	−0.958	0.848
	Sig. (2-tailed)	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000	0.000
PTSF (%)	Pearson correlation	0.863	−0.540	0.915	1	−0.885	0.858	0.795	−0.905	0.815
	Sig. (2-tailed)	0.000	0.000	0.000	—	0.000	0.000	0.000	0.000	0.000
ATS (km/h)	Pearson correlation	0.922-	−0.658	−0.917	−0.885	1	−0.876	−0.900	0.952	−0.820
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	—	0.000	0.000	0.001	0.000
NO (N/h)	Pearson correlation	0.951	−0.669	0.945	0.858	−0.878	1	0.883	−0.932	0.822
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	—	0.000	0.008	0.000
PS (N/h)	Pearson correlation	0.947	−0.731	0.850	0.795	−0.900	0.883	1	−0.883	0.778
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	—	0.000	0.000
APS (km/h)	Pearson correlation	−0.956	−0.718	−0.958	−0.905	0.952	−0.932	−0.883	1	−0.851
	Sig. (2-tailed)	0.046	0.000	0.000	0.000	0.001	0.000	0.000	—	0.000
HV (%)	Pearson correlation	0.850	−0.610	0.848	0.815	−0.820	0.822	0.778	−0.851	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	—

Note. Correlation is significant at the confidence level 0.01 (2-tailed).

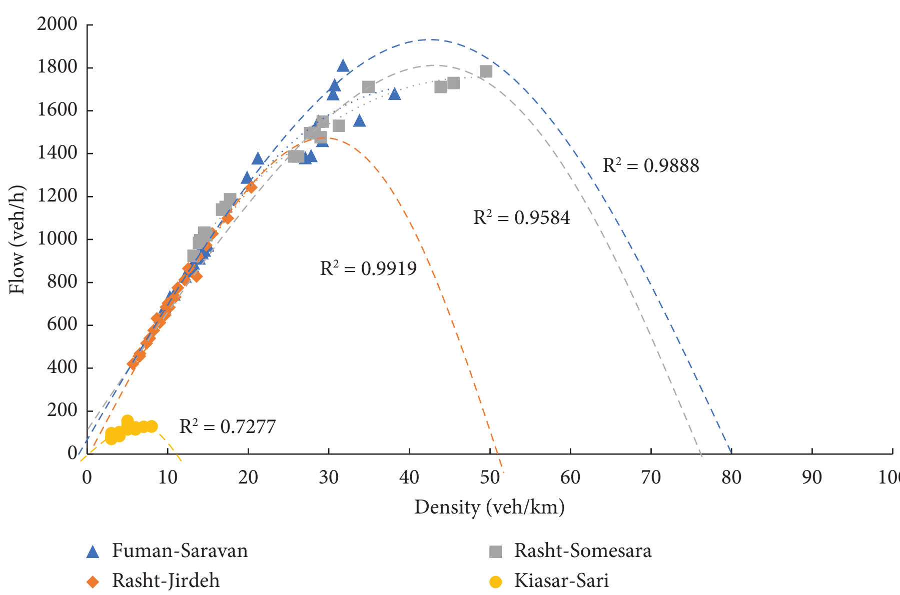


Figure 4: Relationship between density and traffic flow.

$$\mathrm{NFPC} = \frac{\mathrm{NF}}{f_{\max}}, \quad (2)$$

where NFPC is the number of followers per capacity in two-lane roads, NF is the number of followers (Veh/h), and $f_{\max}$ is the maximum traffic flow (Veh/h).

Furthermore, Figure 7 shows the results of the effect of platoon characteristics on the LOS as a function of NFPC and PTSF by substituting equation (2) in equation (3). According to equation (3) and Figure 7, the LOS was classified into five categories ranging from category A to category E based on the NFPC and PTSF in the examined roads. It can be observed that the increase in the NFPC was accompanied by the increase in the PTSF and platoon and the reduction in the LOS.

$$\mathrm{PTSF} = 120.07\mathrm{NFPC} + 54.32. \quad (3)$$

According to the results, which are shown in Figure 7, in order to provide a model for evaluating the LOS on two-lane roads under the influence of platoon, there was a need to examine NFPC. Table 3 provides the results regarding NFPC. According to Figure 7 and Table 3, LOS classification was divided into 5 parts from LOS A to LOS E as a percentage. As shown in Table 3, the proposed method was able

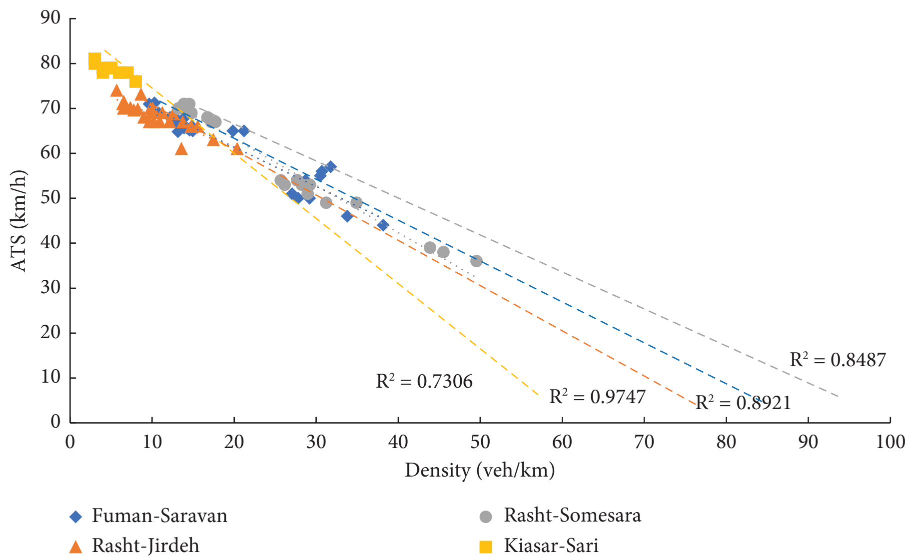


Figure 5: Relationship between density and ATS.

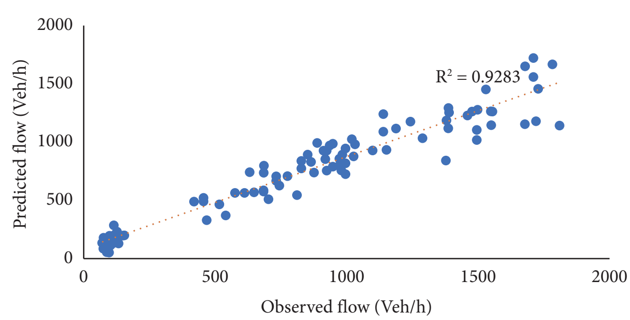


Figure 6: Results of nonlinear regression models: predicted values against observed values.

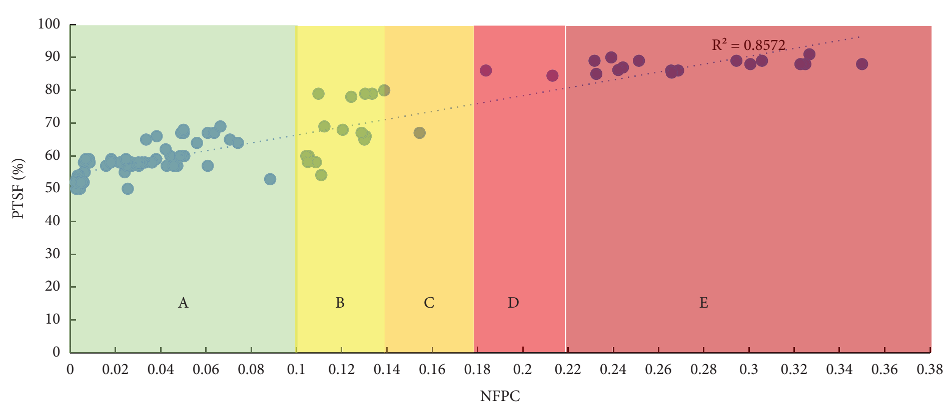


Figure 7: LOS classification using NFPC and PTSF.

Table 3: LOS classification based on the present study and other studies.

LOS	PTSF [8]		Penmetsa et al. [16]	The present study
	ATS (km/h)	PTSF	NFPC	NFPC
A	>88	35≥	0.15≥	0.1≥
B	>80–88	>35–50	>0.15-0.31	>0.1-0.14
C	>72–80	>50–65	>0.31-0.51	>0.14-0.18
D	>64–72	>65–80	>0.51-0.75	>0.18-0.22
E	64≥	>80	>0.75	>0.22

to classify LOS A and LOS B under the 0.1–0.14 interval based on the NFPC. Moreover, it was able to classify LOS C, LOS D, and LOS E under the 0.18–0.22 interval. However, the HCM [8] method provides ATS and PTSF for LOS A and LOS B and considers ATS to be greater than 88 km/h and PTSF to be less than 35%. Moreover, regarding LOS C, LOS D, and LOS E, it considers the ATS to be between 64 and 72 km/h and the PTSF to be between 50 and 80%. Furthermore, Penmetsa et al. examined the classification measure of NFPC and proposed the LOS in the intervals which were shorter than the intervals in the range of 0.15–0.75 under the unsaturated and saturated conditions on two-lane roads.

In order to use the proposed model in the examined roads, the capacity and LOS of the two-lane roads were compared with these values in HCM [8] and the study by Penmetsa et al. based on the NFPC and PTSF. Table 4 shows the results of this comparison. In site 1, the capacity was obtained as LOS E according to the NFPC. However, in site 4, the capacity was determined as LOS B. Moreover, the examination of the influence of the PTSF on road capacity (according to Table 4 and equation (2)) showed that the proposed two-lane road capacity became 1810 Veh/h (equivalent to 2080 pcu/h) due to the 65% increase in the average PTSF which was accompanied by 21% reduction in capacity compared to the capacity of two-lane roads in HCM [8] which was equal to 2650 Veh/h.

In addition, the investigation of HCM [8] for two-lane roads in the examined roads indicated that HCM [8] classified LOS on these roads under three categories ranging from C to E by means of ATS and PTSF, respectively. Nonetheless, in the present study, the LOS was classified into three categories ranging from A to E according to NFPC and PTSF. Furthermore, the examination of the classification based on the LOS of each road relative to HCM [8] showed that the LOS of site 2 was B on the basis of the proposed method. Nonetheless, in HCM [8], the LOS was C. Consequently, the proposed method was able to classify the LOS properly under unsaturated-to-saturated conditions and high PTSF by taking account of the effect of the capacity of each road in comparison with HCM [8] which used ATS and PTSF.

In site 3 (where the traffic flow was high), the LOS did not change compared to HCM [8]. Accordingly, the proposed method was able to predict the LOS under the unsaturated-to- saturated conditions on two-lane roads in a more satisfactory way compared to HCM [8]. Nonetheless, LOS was the same in the saturated and oversaturated conditions in comparison with HCM [8]. Therefore, it can be concluded that on the examined class I roads, the NFPC measure was able to predict the LOS of the two-lane roads in a more satisfactory way in the unsaturated-to- saturated conditions compared to the two measures of HCM [8] including PTSF and ATS.

Comparing the present study with the study of Penmetsa et al. in Table 4, it can be shown that in the unsaturated and saturated conditions, the present study is able to consider the LOS B and LOS C for the unsaturated condition and LOS E for the saturated condition considering the platoon characteristics on the traffic flow. However, in the study of Penmetsa et al., the comparison between the results of the present study and the results of the study by Penmetsa et al. in Table 4 show that in the unsaturated and saturated conditions, the present study was able to provide LOS B and LOS C in the unsaturated condition and LOS E in the saturated condition considering the effect of the platoon characteristics on the traffic flow. Notwithstanding, in the study by Penmetsa et al. [16], LOS A and LOS B were provided for the unsaturated condition and LOS C was provided for the saturated condition without considering the effect of platoon characteristics on the traffic flow. According to the roads which were examined in this study, the LOS that was provided by Penmetsa et al. based on the traffic flow and NF was overestimated in the unsaturated condition and was underestimated in the unsaturated condition. Consequently, the LOS did not match the conditions of the two-lane roads. This inappropriate assessment stemmed from the failure to determine the conditions of platoon characteristics which affected the traffic flow on two-lane roads in the study by Penmetsa et al., but the present study was able to evaluate the effect of the platoon characteristics on the traffic flow using the nonlinear regression model and the measures which contributed to NFPC and PTSF and provided the LOS in a satisfactory way in the unsaturated and saturated conditions.

4.5. Effect of Platoon Characteristics on LOS Using KNN. K-nearest neighbor (KNN) is a method used to explore the impact of two independent variables on a dependent variable. In this method, the effect of the independent variables is referred to as the nearest neighbor search (NNS). It is employed to identify the nearest neighbors in metric spaces, such as M, where the set S consists of multiple neighbors and a search neighbor $q \in M$. The objective is to find the closest neighbor to q within S.

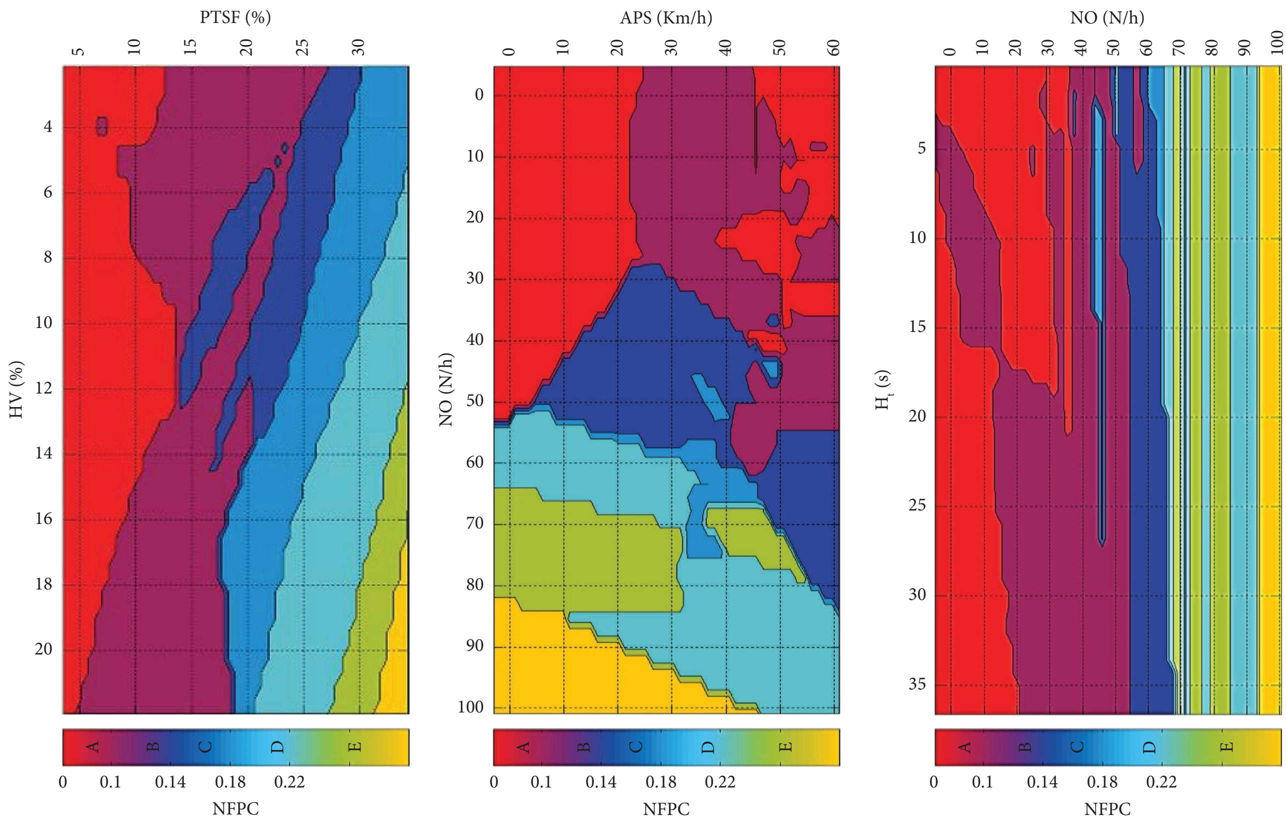
Thus, to determine the influence of two independent variables related to platoon characteristics on the level of service (LOS) of two-lane roads using the proposed NFPC equation, we first define the two independent variables of platoon characteristics based on the service level set (S) as $M1$ and $M2$, with corresponding search neighbors $q1 \in M1$ and $q2 \in M2$. Next, the variables are evaluated using the NFPC equation according to the proposed LOS classifications.

To evaluate the LOS under the influence of platoon characteristics on two-lane roads, equations (2) and (3) and the nearest neighbor (NN) method were utilized. These results are depicted in Figures 8(a)–8(e). Figure 8(a) illustrates that higher HV and PTSF were associated with higher NFPC values. Furthermore, an increase in NFPC coincided with an increase in traffic flow and PS, as well as a decrease in LOS.

Figure 8(b) displays the correlation between NO and APS, demonstrating the impact of these parameters on NFPC. As depicted in Figure 8(b), a decrease in APS corresponds to an increase in NO and NFPC, leading to a reduction in LOS. Figure 8(c) illustrates the relationship

Table 4: Comparison between capacity and LOS with HCM [8] for two-lane roads.

Two-lane roads	Capacity (Veh/h)	Capacity (pcu/h)	NFPC	ATS (km/h)	PTSF (%)	The present study LOS	HCM [8] LOS	Penmetsa et al. [16] LOS
Site 1	1810	2080	0.32	61	93	E	D	C
Site 2			0.11	68	67	B	C	B
Site 3			0.35	59	96	E	E	C
Site 4			0.008	79	55	A	C	A



(a) (b) (c)

Figure 8: Continued.

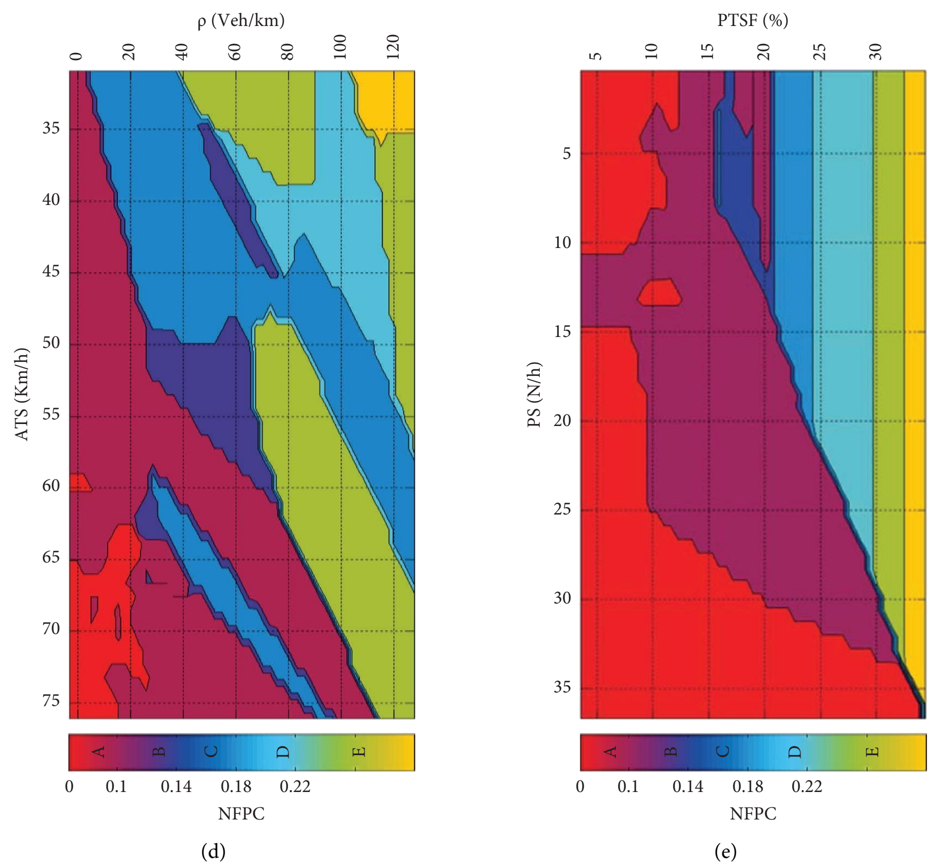


FIGURE 8: Relationship between NFPC, HCM, and platoon characteristics: (a) NFPC-PTSF-HV, (b) NFPC-APS-NO, (c) NFPC-NO-H_t, (d) NFPC-ρ-ATS, and (e) NFPC-PTSF-PS.

between Ht, NO, and NFPC. According to Figure 8(c), a decrease in Ht between the vehicles corresponds to an increase in NO and NFPC, resulting in a reduction in LOS. Figure 8(d) illustrates the relationship between ATS and the density of vehicles and its effect on NFPC. As shown in Figure 8(d), an increase in ATS coincides with a decrease in density. This reduction in density leads to a decrease in NFPC and an increase in LOS. Figure 8(e) displays the relationship between the platoon and PTSF and its effect on NFPC. As shown in Figure 8(e), an increase in the PS of vehicles is accompanied by an increase in PTSF. In addition, an increase in PTSF corresponds to an increase in NFPC and a reduction in LOS.

5. Conclusion

In this study, a model was created considering the impact of vehicle platoon characteristics on the quality of traffic flow on two-lane roads, taking into account the capacity and LOS. Furthermore, the influence of platoon characteristics on LOS (in terms of follower vehicles) and the percentage of time spent following was examined based on HCM [8]. The obtained results can be summarized as follows:

(1) The results of the Pearson correlation analysis regarding the impact of platoon characteristics on traffic flow on two-lane roads revealed that the traffic flow exhibited the highest correlations with platoon speed, number of vehicles (NO), platoon size (PS), average travel speed (ATS), density, percent time spent following (PTSF), heavy vehicles (HV), and headway time (Ht).

(2) Furthermore, analyzing the direction (negative or positive) and significance level of the relationship between platoon characteristics and traffic flow revealed a strong and significant nonlinear correlation between them. This indicates that the relationship can be accurately calibrated and utilized to predict the traffic flow on various two-lane highways.

(3) The results obtained from the platoon-based nonlinear traffic flow model, using the proposed NFPC and PTSF parameters, demonstrated that the NFPC measurement provided a more accurate prediction of the level of service (LOS) on two-lane roads under unsaturated-to-saturated conditions compared to the two performance criteria (PTSF and ATS)

proposed in HCM [8]. The results indicated that a 65% increase in the average PTSF resulted in a 21% decrease in the capacity of two-way two-lane roads, thereby improving their LOS.

Data Availability

The generated or analyzed data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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