Lecture Notes in Civil Engineering

G. L. Sivakumar Babu
Raviraj H. Mulangi
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Technologies for Sustainable Transportation Infrastructures

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Preface

Annually, huge funds are invested in the infrastructure that helps us as well as our goods transport from one place to another. It is the need of the hour to make the transport infrastructure industry sustainable with low carbon emission. This can be achieved only through innovative technologies that can address the challenges of the modern world.

This volume presents the select proceedings of the G20 C20 International Conference on Sustainable Infrastructure: Innovation, Opportunities and Challenges 2023 (SIIOC 2023) which showcase the remarkable diversity of thought and expertise that defines the field of civil engineering today. The main emphasis is on the vital mission of creating sustainable communities that will benefit not only our present but also the generations to come. The volume brings together a diverse array of cutting-edge research, methodologies and insights from leading researchers in the field. It explores the latest advancements in civil engineering that are not only transforming our urban landscapes but also nurturing environments where people can thrive while minimizing their ecological footprint.

We extend our heartfelt gratitude to all the authors, presenters, participants and reviewers who contributed to the success of the G20 C20 International Conference on Sustainable Infrastructure: Innovation, Opportunities and Challenges 2023 (SIIOC 2023).

We thank all the staff of Springer Nature for their full support and cooperation at all the stages of the publication. We hope that this book shall be beneficial to students, academicians, professionals and researchers.

Bengaluru, India — Prof. G. L. Sivakumar Babu
Surathkal, India — Dr. Sreevalsa Kolathayar
Surathkal, India — Dr. Raviraj H. Mulangi

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About the Editors

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Study on Platoon Dispersion at Signalized Intersection in Heterogeneous Traffic Condition

Harsha M. Manjunath and N. H. Siddarth

Abstract Rapidly rising urban mobility causes more vehicle usage, which raises traffic volume, and ultimately causes congestion on Indian roads with a variety of traffic. One of the crucial places where traffic jams happen is at signalized intersections. Traffic congestion at junctions raises the saturation level at downstream and interferes with signal coordination. Signal coordination will enhance traffic flow while reducing delay and journey time in one direction. Therefore, the platoon characteristics between upstream and downstream should be assessed to combat this oversaturation and the consequence of signal coordination. This study aims to determine platoon dispersion at a signalized junction by analyzing speed data. Two study sections in Bengaluru were chosen for the investigation of platoon dispersion. Data regarding the speed characteristics of traffic flow were collected using videography method. Recording was done on weekdays and weekends, and peak and off-peak traffic data were collected. Platoon characteristics were assessed every 30 m throughout the 600 m stretch at downstream of the signalized intersection. The data pertaining to three levels of traffic volume: low, moderate, and heavy were clustered together. This research pinpointed the platoon dispersion pattern under the ideal traffic circumstances of Kodigehalli Gate Road and the non-ideal, heterogeneous traffic conditions of Old Madras Road. The initial and final platoon dispersions were detected at 150 and 330 m for light and moderate traffic circumstances, respectively, based on speed parameters assessed at every 30 m interval in first road section. While for heavy traffic situations, beginning and final platoon dispersions were seen at 240 and 330 m, respectively. In the second section, speed is investigated together with friction conditions. Based on speed parameters, initial and final dispersion is measured at 150 and 390 m, respectively, under low and moderate traffic circumstances, and it has been shifted to 450 m under heavy traffic situation.

Keywords Heterogeneous traffic · Platoon dispersion · Signalized intersection · Relative speed difference

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1 Introduction

Urban productivity influences the transportation system's capacity to carry people and products to various origins and destinations. The entire performance of the urban road or highway system is heavily influenced by traffic operation at the signalized junction. Congestion (delay), stops, bottlenecks, and accidents can all be caused by poor traffic control at signals. The research works on platoon dispersion models currently in existence either lack analytical solutions or describe heterogeneous traffic flow characteristics by analyzing field data. In traffic flow modeling and analysis, the pattern of a platoon dispersion or spreading out as it moves downstream at any point along the road plays an important role. This dispersion is caused by variations in vehicle speeds, presence of obstructions such as pedestrians and parked cars, and interaction caused by merging and changing lanes. Due to the existence of driver's vehicle types, lack of road rules and lane discipline, bad driver behavior, etc., the platoon dispersion effect in heterogeneous traffic is a difficult matter due to different types of vehicles and breaking the rules and regulations of traffic. Due to weak lane discipline, the driver of the following vehicles tends to rush ahead frequently, with or without lane shifting action, to overtake. Numerous studies have been done on the characteristics of platoon speed in homogeneous traffic, but similar studies have not been done well enough when considering the variety of traffic and the lack of lane discipline seen in heterogeneous traffic. Therefore, in this study an effort is made to find out the pattern of the platoon dispersion and also identify the initial and greater levels of platoon dispersion. Platoon dispersion occurs downstream of traffic signals at various volume levels dependent on speed variation measurements such as speed of different types of vehicles, standard deviation, relative standard deviation, relative speed difference and speed of the platoon, platoon size headway of the vehicle, and also platooned and non-platooned vehicles.

2 Literature Review

Robertson's platoon dispersion model (RPDM) was calibrated under heterogeneous traffic, and the downstream traffic flow characteristics were predicted based on upstream variations [3]. RPDM parameters were scaled using the optimum method. The dispersion of the platoon was subsequently expressed using an empirical model developed based on the vehicle's composition, the normalized flow, the link's trip duration, and the size of the modeling step. Praveen and Ashalatha [5] studied the uses of a variety of techniques that assess speed fluctuation to identify areas where early and greater dispersion occur at signalized intersections of urban arterials under diverse traffic situations. At three distinct volume levels, the pattern of platoon dispersion along the downstream of traffic signal was discovered. Paul et al. [4] developed methodology for the calibration of Robertson's platoon dispersion model by lining vehicles with a tolerable margin of error. Instead of comparing the observed and estimated vehicle arrivals over various modeling time intervals, the authors focused on comparing the period downstream. The study of platoon dispersion factors is necessary to determine the beginning and ultimate platoon dispersion. The HCM platoon dispersion model was assessed by Forde and Daniel [1] in both frictional and non-frictional conditions. When compared to urban street parts that have friction, the researcher claims that the model performs better when applied to road segments without side friction activities. Sudheer et al. [10] utilize an automated method for the identification of platoon in traffic stream. Three different methods, namely cluster-based approach, modified Gaur and Mirchandani method, and an image processing-based technique, were investigated for platoon detection. Among which the image processing showed better outcomes compared to other methods. The initial and greater platoon dispersion locations downstream of a signalized intersection were determined using the change in the relative standard deviation of platoon speed. Paul et al. [3] calibrated Robertson's model, on an urban highway setting in India, taking into account the degree of variation in transport demand and journey time. Li et al. [2] suggested CV MPC-based coordination can significantly boost other CV-based signal control applications in the early stages of CV technology adoption by further enhancing the system performance of signal coordination in a low penetration situation. The traffic flow data from the vicinity of a signalized urban arterial was analyzed to derive PCU values for various vehicle types using three different approaches [6]. The study evaluated the PCU values for different vehicles traveling downstream of the intersection while accounting for the impact of vehicle speed fluctuation. Vanajakshi et al. [11] examined the features of platoon dispersion under heterogeneous traffic using an approach based on diffusion theory which stands out among the described modeling techniques. The impact of a mixed traffic platoon made up of 3 distinct classes of CVs on the flow, density, and speed of interstate traffic under two separate traffic regimes (regimes A & B) was evaluated [9]. It was found that the effect of CVs on the overall traffic mix during mixed traffic platooning circumstance considerably reduces the speed at capacity, density at capacity, and traffic ability. Saha et al. [8] developed a model to estimate the platoon dispersion after passing the stop line using simulated data. The field traffic situation is replicated using VISSIM, a micro-simulation programmer. The suggested model may be utilized to predict the platoon dispersion distance with a certain level of exactness only. Praveen and Ashalatha [6, 7] examined traffic flow information gathered at the starting of a signalized urban arterial to calculate PCU values for various vehicle types using three different techniques. The principle of speed differential–area ratio was found to be more rational than other approaches which considers the wide range of static and dynamic features of different vehicles moving downstream of junctions. Vanajakshi et al. [11] analyzed the properties of platoon dispersion in lane-less and diverse traffic situations. And for comparison purpose, the normal distribution was calibrated with a diffusion theory-based model. According to the literature, numerous studies on platoon dispersion have been carried out under homogeneous settings, but no comparable studies have been carried out. Therefore, under heterogeneous traffic conditions, this study attempts to assess the platoon dispersion at various traffic scenarios (low, medium, and high traffic volume).

3 Methodology

The methodology followed to analyze the platoon dispersion in the current study has been presented in Fig. 1. The steps are explained in detail in the following paragraphs.

3.1 Data Extraction

The platoon dispersion is widely studied under homogeneous and lane-regulated traffic situations, and it has not been fully addressed under heterogeneous traffic. Therefore, the Bengaluru City in Karnataka, India, with heterogeneous traffic conditions was chosen for data collection. The ideal site for data collection was chosen on the basis of road's geometry and characteristics of traffic stream. The study section chosen was a ten-lane divided arterial road having service road with an at-grade junction without friction conditions was chosen. Using a video-graphic survey in the selected urban arterial road at Kodigehalli Gate Road—KGR areas (study corridor 1), and Old Madras Road—OMR in Bangalore (study corridor 2), second most congested road in Bengaluru. The lengths of study corridor 1 and 2 are 1000 m

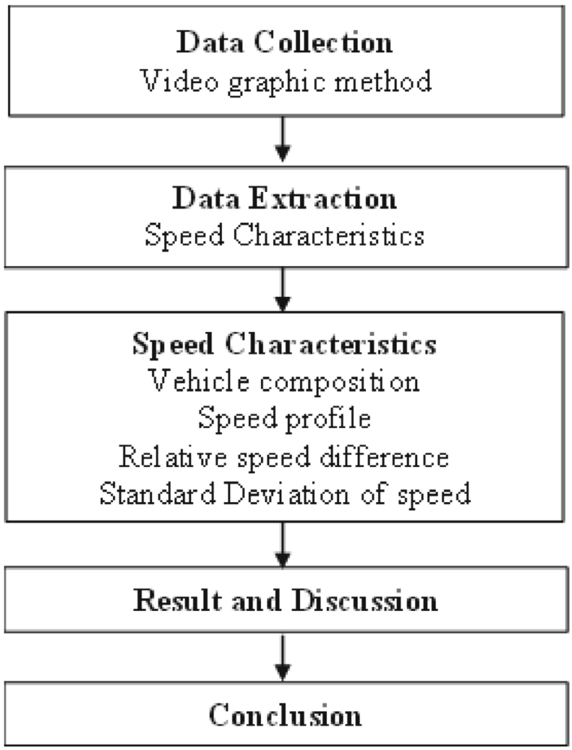

Fig. 1 Methodological framework

1006 m, respectively. Video data were collected on weekdays and weekends during peak and off-peak hr. in the morning (8:30 to 11:00 am) and evening (4:00 to 6:30 pm) for both study corridors. The details of study stretches and the vantage points are given in Fig. 2.

The research region was chosen based on how well it met the data requirements of the study. Traffic data were collected using video-graphic technology that covered complete stretches of the road up to 600 m downstream of the signal. The cycle time of the first study intersection is 136 s with green time of 45 s, red time 88 s, and an amber time of 3 s. Buses, light commercial vehicles (LCV), cars, three-wheelers, heavy commercial vehicles (HCV), and two-wheelers are the five study categories. The manual extraction of data was done with consumed significant magnitude of time of this work. Vehicle volume is extracted every 5 min from traffic data. Also, the data regarding speed profile, standard deviation, and relative speed difference were extracted manually.

Fig. 2 Sample pictures of study area **a** Kodigehalli Gate Road—KGR, **b** Old Madras Road—OMR

3.2 *Vehicle Compositions of Both Study Corridors 1 and 2*

Figure 3 depicts the average composition of traffic volume recorded at the learning segment at various traffic levels. A high proportion of smaller vehicles (two-wheeler and cars) has been observed which is common observation in heterogeneous traffic. The small-sized vehicles impact highly on traffic flow behavior as they tend to occupy and move through the available small gaps. The lateral movement observed in the highway segment during overtaking is not much observed under homogeneous traffic. In both the study sections, two-wheelers are higher in percentage (around 45–52%). The percentage of cars is higher in study corridor 1 with an approximately 10–12% difference with study corridor 2. The percentage of three-wheelers is lesser than 10% in study corridor 1 and greater than 10% in study corridor 2, which is due to the presence of a metro station. The proportion of buses in study corridor 1 is lesser and is nearly 3–4% in study corridor 2. The percentage of LCV (2–5%) and HCV (1–3%) is nearly equal in both study corridors.

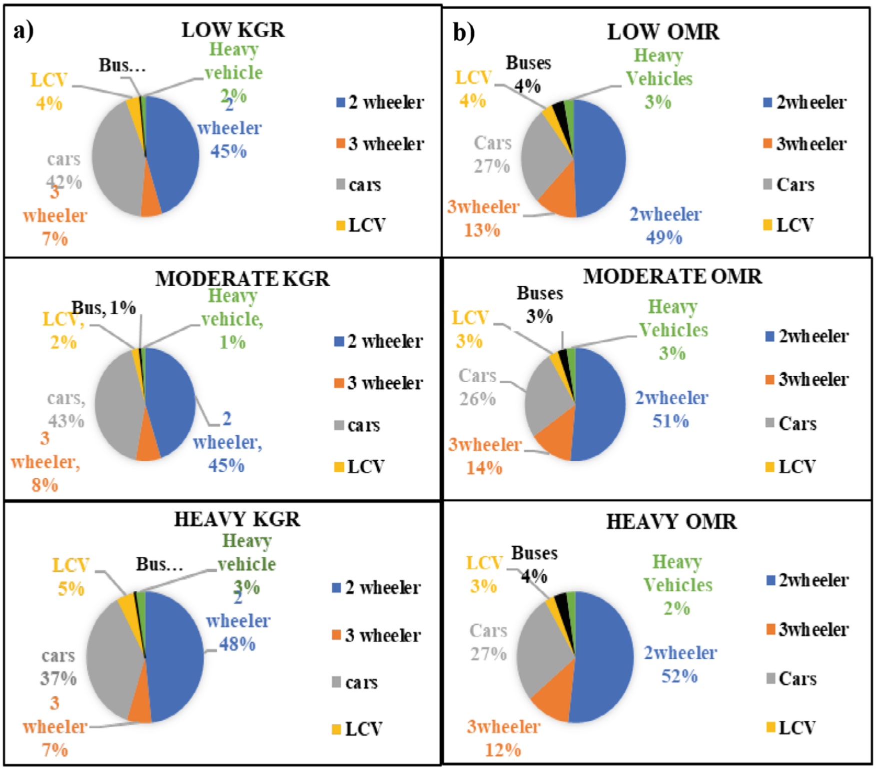

Fig. 3 Vehicle composition of study sections **a** KGR and **b** OMR

3.3 Development of Speed Profiles

The speed values of different vehicle categories vary between upstream and downstream which is generally considered as a measurement indicating the quality of traffic. During low traffic volume, drivers move at their desired speeds. The average speed decreases, and the freedom to move at the preferred speed diminishes as the volume increases. Therefore, the quality of progression can be inferred from the speed profiles of various vehicle types. Based on the inventory of the study portions and earlier research, a space interval of 30 m was chosen. The time taken to move every 30 m along the study corridors was calculated using the arrival time of vehicles. The speed profiles for various vehicle types have been obtained by computing the each section's travel time values.

3.4 Determination of Relative Speed Difference

The fluctuations in speed differences along the corridors under observation were analyzed at different levels of traffic volume in order to know the trend in relative speed difference variation toward the downstream. The pattern speed fluctuation is represented by the relative speed difference plots, and the range of speeds in which the vehicles are traveling along the road stretch relative to one another can also be observed. The difference in average speeds between the two consecutive reference lines that were computed for different vehicle categories was visualized.

3.5 Determination of Standard Deviation of Speed

The variation in vehicle speeds and their pattern is inferred by the standard deviation (SD). The computation of SD was done by considering the vehicles passing the study corridors during the entire green time. The speed SD for different type of vehicles indicates the amount of speed fluctuation at different traffic conditions (low, moderate, and high traffic volumes). E.g., at high volume levels due to interaction between vehicles, the difference in the speed SD values is generally low due to less chances of overtaking.

4 Results and Discussion

This section discusses the experimental results in the construction of platoon speed profiles. This section contains a detailed analysis of the speed profile platoon characteristics in heterogeneous traffic. The stretch was divided into 30 m intervals to compute the speed of vehicles at regular intervals. The vehicles belonging to other categories were found to progress at a rate either slower than cars and two-wheelers or faster than the three-wheelers or buses.

Two-wheelers require lesser area for their movement compared to HCV and hence opt to travel with desired speed. Figure 4a shows that after 150 m distance, the two-wheeler and cars are driving at 40 to 50 kmph and other vehicles traveling at a lower speed of 30 to 40 kmph. The speed values start being stable after 150 m. The speed curves of LCV, three-wheeler, buses, and HCV are observed to be flat from 150 to 240 m. The speed values are found to have more variation for two-wheelers and cars after 150 m and a higher dispersion observed after 330–360 m.

Under moderate traffic conditions, headway is less compared to low traffic volume, so the speed of the platoon decreases (Fig. 4b) and the maximum speed of the vehicles observed is 60 to 70 kmph. In moderate traffic, the drivers of two-wheelers and cars start to travel at desired speed before the other vehicles. It is inferred from Fig. 4b that after 150 m, every vehicle moves at a different speed so that the minimum dispersion takes place from 150 m onward. Speed variation changes significantly from 330 to 360 m, so the dispersion takes place at 330 m.

Figure 4c presents the speed profiles of difference vehicle categories for different volume levels at regular intervals. The speed profiles show how different types of vehicles traverse the corridor. They also demonstrate where changes in driving speeds occur. According to the speed trend, two-wheelers progress the fastest, followed by cars, and three-wheelers, heavy commercial vehicles (HCV), and buses progress the slowest. The speed profiles show that speed progression in heavy traffic condition is slower when compared to low and moderate traffic conditions. The maximum speed in heavy traffic is nearly 50 to 60 kmph. The speed of progression was higher for two-wheelers and cars and lower for other categories (three-wheelers, buses, and other multi-axis vehicles). As there are less chances of collision and headways are shorter, the speed of the entire vehicle remains constant up to 150 m. The chances of lane changes and merging are low in this situation. At 180–210 m, a two-wheeler diverts from the other traffic volume. The pattern in speed variation is clearly reflected between 330 and 360 m.

Study corridor 2 is four-lane urban arterial road in Bangalore which had a different situation compared to study corridor 1 (Kodigehalli Gate Road). A significant impact of the metro station and bus stops resulted in traffic congestion, particularly at bus stops. On a daily basis, over 1,500 buses utilize this study stretch that connects the terminal. However, the lack of good road network and the interconnection of terminal areas with metro stations and other modes of transportation have been a source of the problem in the study area.

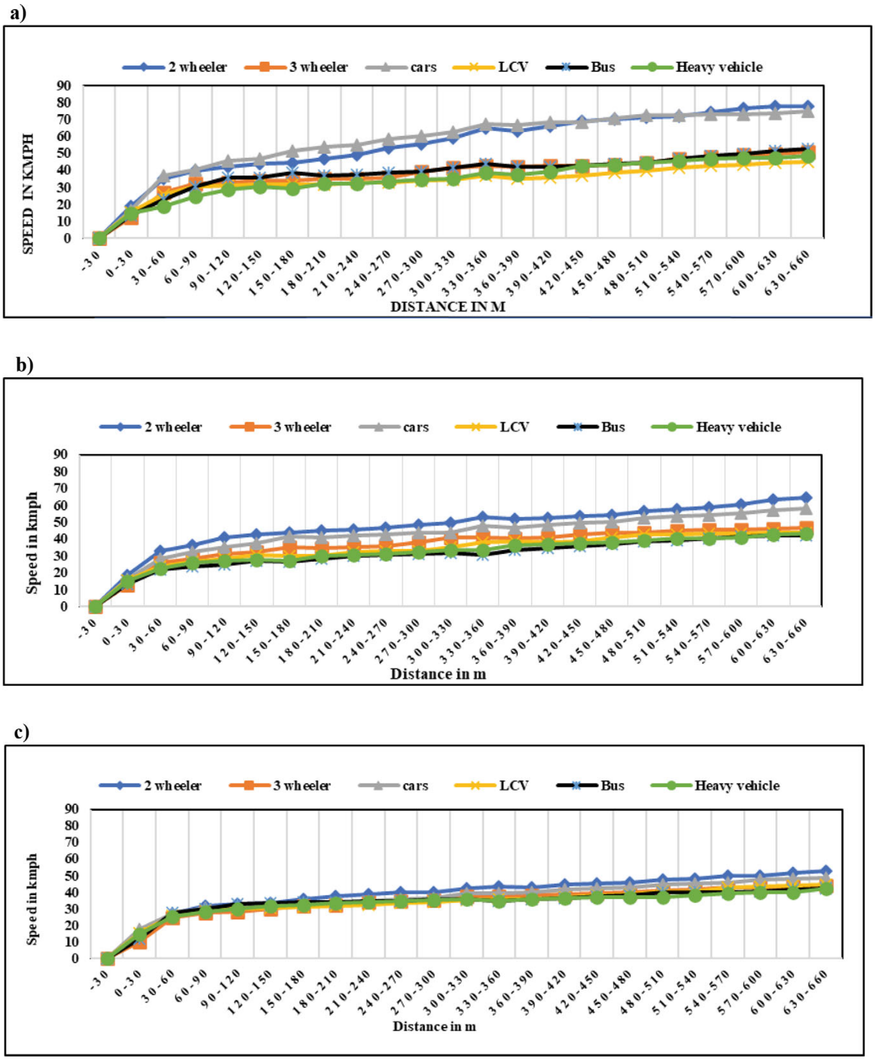

Fig. 4 Speed profiles of vehicles (KGR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** heavy traffic

Study corridor 2 Old Madras Road. This stretch is always congested because of additional no. of vehicle travels related to the metro's final station. The segment of the entire roadway from upstream to downstream is 1006 m. Figure 5a shows that the maximum speed of the platoon in the above study starch is 50 kmph. Two-wheeler is separating from the platoon soon at the segment between 30–60 m having a speed 30–40 kmph. The speed variation is low from 90 to 240 m, and the two-wheeler curve is at desired speed till 240 m. From Fig. 5a the significant fluctuation in speed from upstream to downstream is observed only for the two-wheelers that exhibit more fluctuation. Speed curve shows variation from 150–180 m when the minimum dispersion occurs. The platoon speed reduces from 240 to 270 m, and heavy vehicles such as LCV and HCV prefer to avoid curb side lane due to friction caused by the bus stops and the frequent stoppages by buses, three-wheelers, and taxis. These types of stoppages at bus stops result in bottlenecks and increase platoon dispersion which can be observed at segments 390 m–420 m.

Figure 5b presents the speed profiles during the intermediate traffic situation under heterogeneous traffic. Under this condition, the vehicles travel with a lower speed variation when compared to low traffic volume. In the Fig. 5b, we can observe that the maximum speed is 40kmph. Similar to the low traffic volume in the moderate traffic the speed reduction started from 240 m. Initial dispersion occurs in the segments 150–180 m. In the segments after 390–410 m, the speed variation is not significant. Vehicles such as buses, three-wheelers, and cars are experiencing increased delays due to the presence of the metro station. Ahead of 390 m, the speed of HCVs, LCVs, and two-wheelers increases in comparison with other vehicles such as buses and three-wheelers as these vehicles stop for passenger pickup and drops.

The average speed drops as the volume rises, making it difficult for the drivers to maintain their intended speeds. From Fig. 5c under congested conditions, the headways are observed to be lower compared to low, moderate volume conditions, and therefore, minor dispersion occurred at 180 m. It is difficult to find initial dispersion in heavy traffic condition. The chance of two-wheeler separating from platoon is low and causes reduction in segment 240 m. As the speed reduction occurs from 240 m, the platoon dispersion occurs at 330 to 360 m. The peaks in speed curve are shifted to segments 390–420 m to 450–480 m. Platoon dispersion occurs during this trend of curve that occurs at 480–510 m.

Figure 6 shows the relative speed variations in the study corridor 1 (Kodigehalli Gate Road—KGR) at different traffic volume levels. It is inferred that the variations are more at lower volume levels when compared to higher volume levels. As shown in Fig. 6a, the section 0–90 m showed the highest difference in speed of different vehicle categories. The platoon with different categories of vehicles reaches mean desired speed quickly, and it requires further distance for the dispersion to occur. The speed differential values are lower in the 90–120 m range. The speed reduces at 120 and 150 m, and the dispersion is observed ahead of 150 m.

The speed differential values of two-wheelers and three-wheelers rise with increasing speed. In Fig. 6a, it is observed that the differential is low at 300–330 m, increases ahead of this segment, and the platoon dispersion occurs at 330–360 m.

Figure 6b shows the speed variation along the different segments in heterogeneous traffic at moderate flow conditions. Speed variation of two-wheelers and cars is higher in comparison with that of three-wheeler, LCV, HCV, and buses. Figure 6b shows that the initial speed of platoon variation is in peak starting from stop line same as low traffic. Speed gets decreased at a stretch of 90–120 m; later on speed gets increased which means it tends to disperse was started at 150 m; also platoon speed gets minimal variation in the segment 150 to 300 m. Segment at the selected stretch 120–150 m and 300–330 m has the lowest variation. The speed of the platoon gets

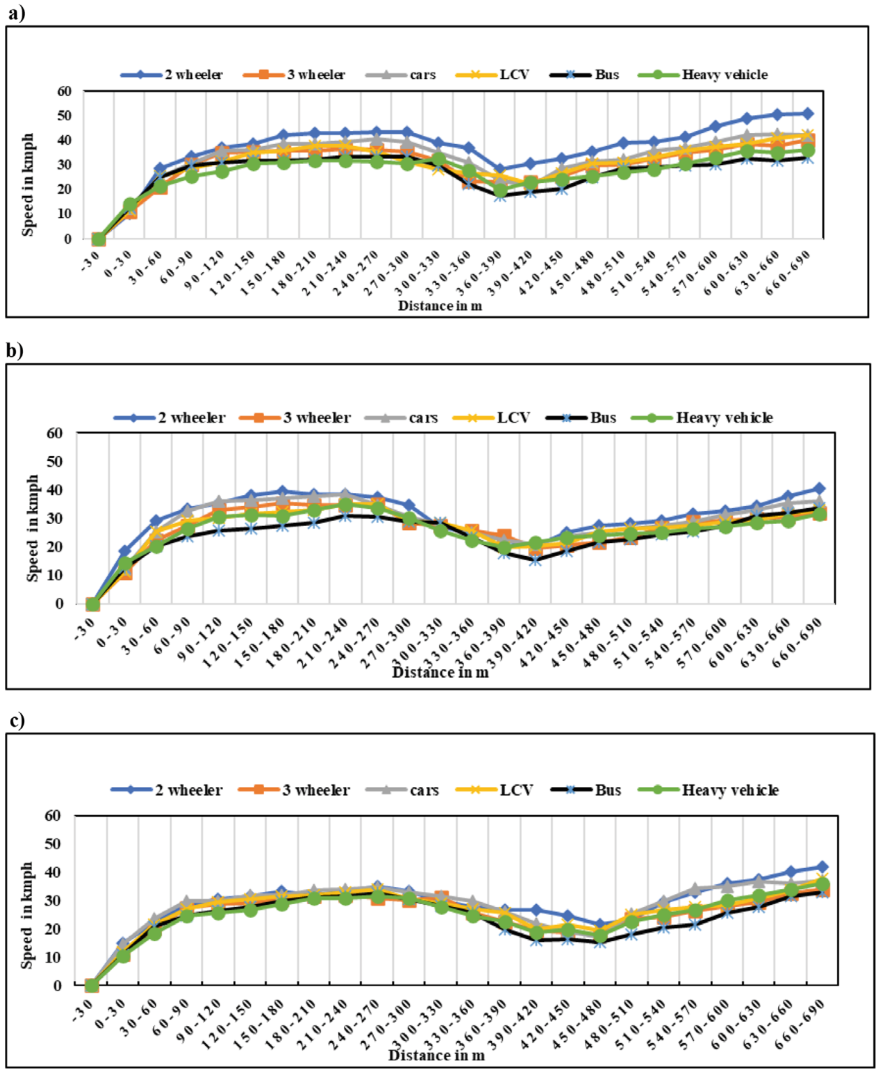

Fig. 5 Speed profiles of vehicles (OMR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** heavy traffic

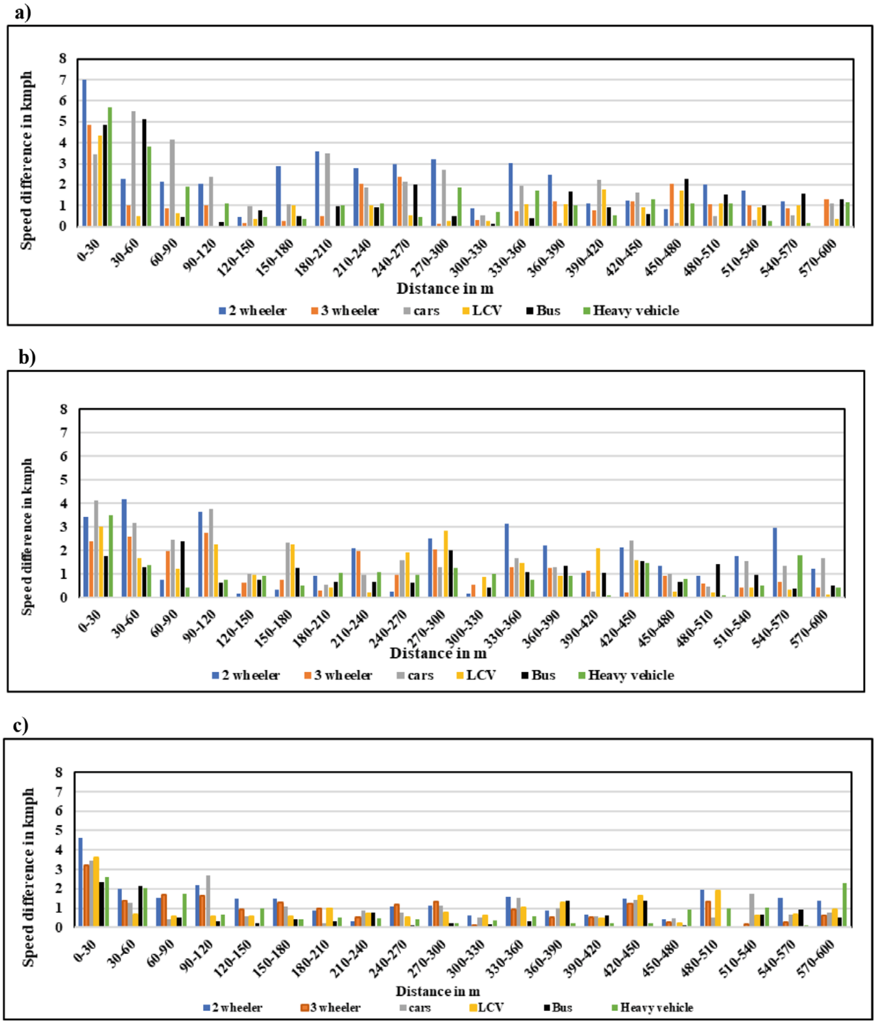

Fig. 6 Relative speed difference of vehicles (KGR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** heavy traffic

flattened from segment 150 to 300 m which has minimal variation. The dispersion of the platoon takes place after 150–180 and 330 m.

From Fig. 6c, it is inferred that variation of speed is lower than that in low traffic flow, and the maximum speed difference is 4–5 kmph. Under heavy traffic condition, the two-wheeler and cars have varied speeds in comparison with the vehicle categories. Speed difference of platoon varies less from the segment 150 to 300 m. It shows that the speed variations at segments 300–330 m are low. Ahead of this segment, the fluctuation in speed difference is higher and the platoon gets dispersed at 330 m.

Figure 7a illustrates the variation of relative speed difference for different vehicle types at study corridor 2. It shows the maximum speed difference starting at 0–100 m, and the speed difference from the segment 120 to 240 m is lower. The platoon speed at 240–270 m drops due to stoppages of buses, auto rickshaw, and cabs in bus stops at 370 m from the upstream. Old Madras Road, one of the busiest networks in Bangalore, had more no. of vehicles travelers daily due to the stretch containing end station of a metro station.

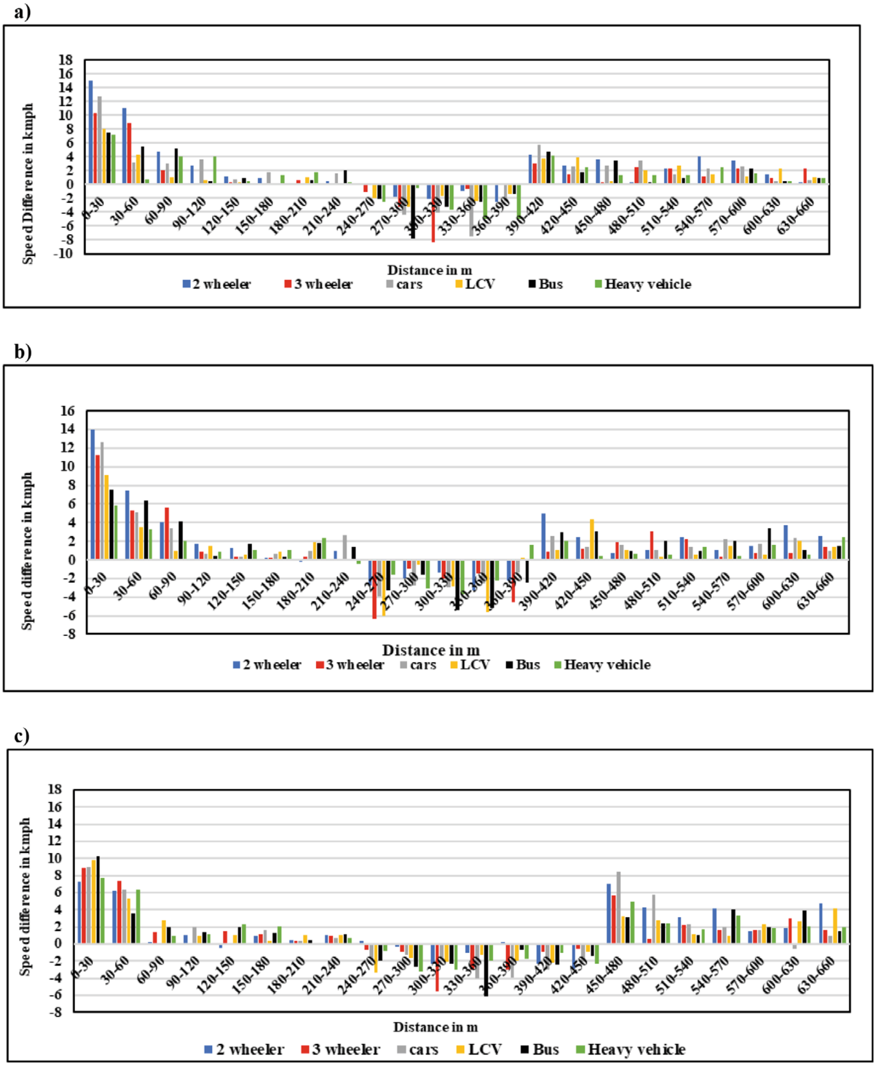

Fig. 7 Relative speed difference of vehicles (OMR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** heavy traffic

Due to the aforementioned factors, a bottleneck situation is formed, and the platoon gets dispersed after 390 m. At segment 390–420 m, the speed of every vehicle in platoon increases resulting in dispersion. In moderate traffic volume, speed difference is low due to smaller headways, and hence it is difficult to tackle the front vehicle unlike low traffic volume. Figure 7b shows that the two-wheelers and cars have higher variation in speed differences, and also the maximum speed difference is 14 kmph. Further variation is observed from upstream up to 100 m of the study stretch. The drop in speed values after 240 m which was due to presence of bus stop in the stretch can be observed from Fig. 7b. It seems that the stoppages are fewer at the starting of stretch, and it increases near metro station. Speed reduces from 240 to 390 m, and platoon is dispersed when vehicles reach their desired speed at 390 m.

In heavy traffic volume, every vehicle moves at same speed with a higher speed difference. Similar to low and moderate volume conditions, the speed is observed to drop at 240 m from the upstream in heavy traffic volume (Fig. 7c). The largest speed difference is 10 kmph which shows that speed of vehicles reduced due to the smaller space headways between vehicles. Figure 7c shows that the speed difference increases at 450–480 m. It shows that the maximum speed of platoon is shifted from 390 to 450 m due to the congestion at bus stops during heavy traffic flow conditions.

The variation in standard deviation is given by Fig. 8 along the study corridors. When compared to other types of vehicles, these figures show that two-wheelers and cars exhibit more variation in standard deviation over the stream for all volume levels.

Figure 8a infers cars and two-wheeler have greater variation in standard deviation than the other vehicles. It is also observed that the HCV travel at desired speed in the segment 240–270 m and HCV and LCV always choose the right lane to avoid diversions and side frictions. Standard deviation values are higher in the region between 150 to 180 m and also in the segment 330 m to 360 m. The region with higher deviation segment is the place where dispersion takes place.

In moderate flow conditions, deviation is lower than the low traffic volume conditions. Figure 8b shows that similar to low traffic volume conditions, two-wheelers and cars get separated than the other vehicles, and the variation in speed is higher at 150–180 m. Higher fluctuation at segments 330 to 360 m is observed, and hence it can be considered as the region of platoon.

In heavy traffic condition, speed deviation of vehicles is lesser compared to low and moderate flow conditions. The chances of overtaking the front vehicles are low as the available gaps are small. Deviation in speed of platoon is low throughout the stretch. Figure 8c illustrates that the two-wheelers and cars are merged in the platoon due to shorter headways. The fluctuation in standard deviation is lesser from the segment 180 to 270 m and 450 to 660 m. In the region 120 to 150 m, the vehicles start to travel at desired speed, and the dispersion of vehicles occurs. After 450 m, two-wheeler and cars are observed to get separated from platoon. The deviation is higher in the segment 330 to 360 m. It can be seen from Fig. 8c that the dispersion takes place at 330–360 m and 420–450 m due to the higher deviations in respective segments.

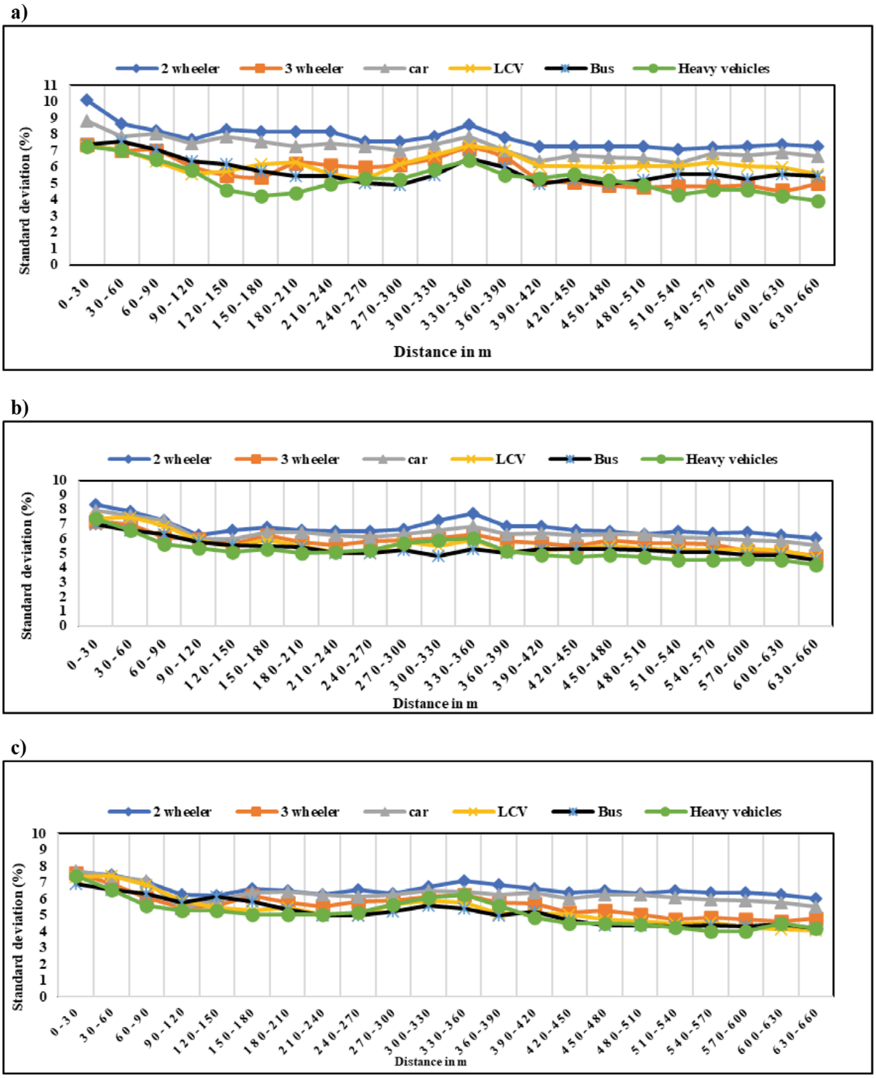

Fig. 8 Standard deviation of speed (KGR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** Heavy traffic

In low volume conditions, deviation in speed is lesser throughout the study corridors. Similar to study corridor 1, the two-wheelers and cars deviate more but overtaking opportunities are less unlike study corridor 1, due presence of bus stops. Figure 9a shows that the deviation in speed of vehicles is higher in the segment 240 m, buses and three-wheeler are reducing their speed, whereas LCV, HCV increase their speed, and due to this vehicle not willing to stop prefers the right lane, and vice versa. Chances of lane changing are higher by the vehicles willing to stop after the segment

240 m. Deviations that seem to decline at 390–420 m and 450–700 m have minimal deviation.

In moderate traffic conditions, two-wheelers are separated in the segment 90–120 m, and cars are merging with the platoon. The deviation of speed is lower for HCV as they choose the right lane to avoid stoppages and therefor move with minimal

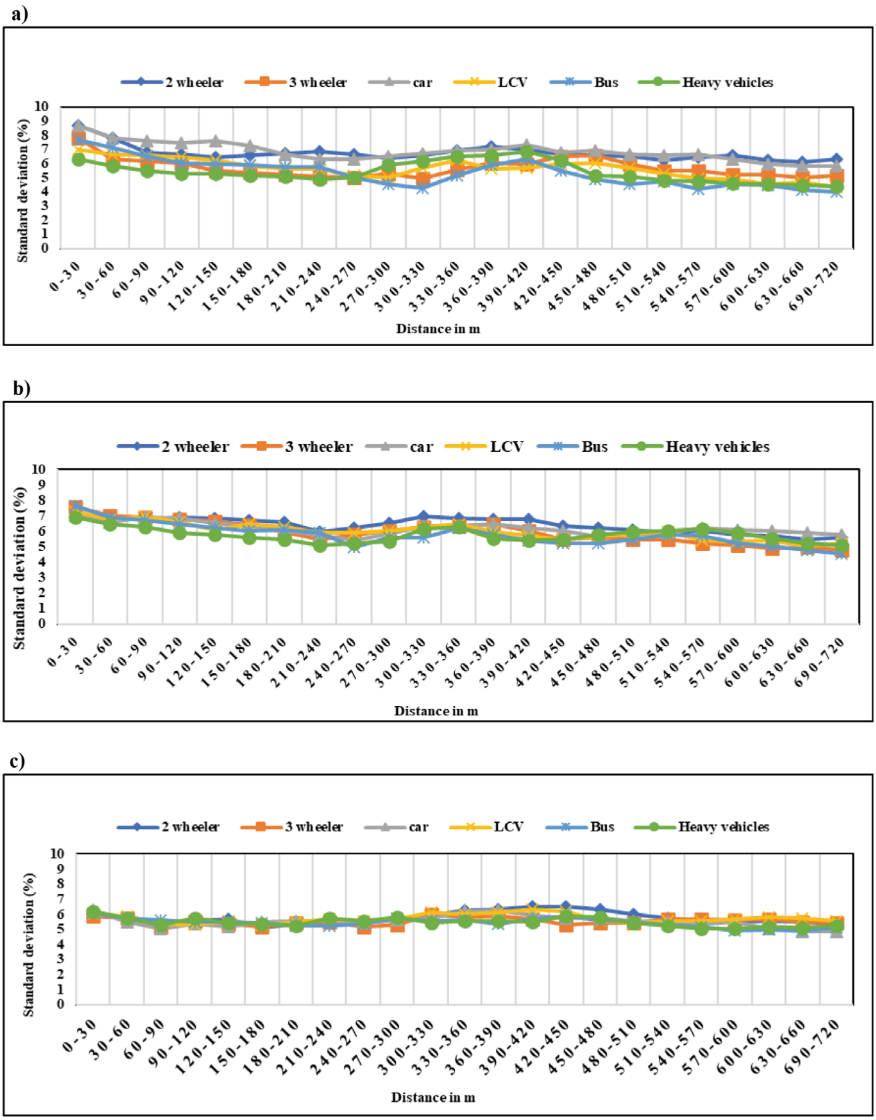

Fig. 9 Standard deviation of speed (OMR) under different traffic condition **a** low traffic, **b** moderate traffic, and **c** heavy traffic