# Traffic data analysis using image processing technique on Delhi–Gurgaon expressway

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**With the advancements in video image processing system (VIPS), detection mechanism has made a significant improvement over traditional methods for traffic data analysis. Traffic on Delhi–Gurgaon expressway is heterogeneous in nature with non-lane based behaviour. Moreover, automation and instrumentation are also not implemented. In view of this, TRaffic AnalyZer and EnumeratoR (TRAZER), a VIPS was used to process video-captured data on Delhi–Gurgaon expressway to check accuracy based on traffic count, speed and lateral placement. The motivation behind using TRAZER is to evaluate its efficiency and robustness for extracting micro and macro-level traffic parameters under heterogeneous traffic conditions. To achieve this, data were extracted manually on above parameters and compared with those obtained from TRAZER. The volume count data from TRAZER generated a lesser accuracy of 60% detection under heavy traffic conditions, using default parameters. Thus, refinements were carried out in the software as part of calibration: (i) redefining maximum and minimum detection widths for each vehicle category, and (ii) selecting the optimum trap length for reducing the occlusion effect, which increased the detection percentage as well as reduced the error. After implementing these refinements, 80% of the vehicles were detected. Further, relationships between vehicle speed and its lateral placement from median across road width, at a given point were also developed. The models were developed for both aggregate (considering all vehicles) and disaggregate (vehicle category-wise) levels. The polynomial relationship was found to be best fitted function to estimate vehicle speed based on its lateral placement.**

**Keywords:** Lateral placement, speed, TRAZER, video image processing system.

TRAFFIC data collection provides basic information required for planning, operation and management of roadway facility. Several techniques and methodologies have been used for this purpose, which may be broadly classified as manual methods and automatic detection techniques. Detection techniques are emerging techniques of traffic data collection and have been classified as intrusive and non-intrusive. The intrusive technologies include inductive loop detector and pneumatic tube detector and weigh-in motion systems, whereas non-intrusive technologies include infrared sensor, pulsed and active ultrasonic sensors, microwave-doppler and radar, passive and active ultrasonic, passive acoustic array sensors and video image processing system (VIPS). VIPS has the ability to capture all desired traffic information, which includes some parameters that are not easily obtainable using other type of detectors. VIPS can collect and analyse microscopic as well as macroscopic and traditional traffic flow data; detect and verify incidents; classify vehicles; monitor intersections; read license plates, and perform image compression. The aforementioned ability makes it an emerging technology both in developing and developed countries.

Traffic in developing countries like India is significantly different from that in the developed countries because of its heterogeneous nature. Moreover, traffic on the Indian expressways is interesting to study due to two reasons. Traffic is multi-class with vehicles such as cars and pick-ups with their high manoeuvrability, and heavy vehicles such as trucks and buses. The speeds of these vehicles may vary from 40 to over 100 km/h. Traffic movement on the Indian expressways may be considered as quasi-lane disciplined, with some vehicles following a lane-based driving, while others may not. Higher design speeds, restriction on slow-moving vehicles, and varied traffic composition with higher number of cars characterize these roads. Moreover, the reason for non-lane-based behaviour of traffic is also because of variation in dynamic and static characteristics, and vehicles tend to occupy any lateral position on the roadway based on the space availability. So lateral placement is another important parameter to be studied as it represents how a lane is being utilized by different vehicle categories.

Traffic data collection is one of the difficult tasks faced by the researchers under heterogeneous traffic conditions. TRaffic AnalyZer and EnumeratoR (TRAZER), a video processing software as an image processing tool can be used effectively for traffic data collection and analysis under heterogeneous traffic conditions. It can be used with IP feed camera as well as for pre-recorded traffic

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video. Due to its underlying ability to detect, track and classify vehicles, when there is movement of vehicles both in longitudinal as well as lateral direction, TRAZER is extremely useful in collecting traffic data under varying traffic conditions. It has been designed especially based on the needs of the developing countries, where traffic is heterogeneous in character, and enables detection of different vehicle categories plying on the roads with its detection mechanism, even under dense traffic conditions. Most data-collection systems that were used in the past proved to be inefficient for mixed traffic. Therefore, for evaluating the performance of TRAZER the present study was conducted taking the Delhi–Gurgaon expressway as a case study. For this purpose data were retrieved using the software for microscopic as well as macroscopic traffic parameters at a reasonable accuracy, which were then used to develop a relationship between vehicle speed and its lateral placement from median at a given point.

## Literature review

This section gives details regarding studies conducted using VIPS for estimating microscopic as well as macroscopic traffic flow parameters. Initial attempts were made in 1973, where a system was developed to estimate vehicle speeds[1]. Further, several researchers investigated the application of image processing techniques to automatic road traffic data collection and analysis[2–4]. The literature reports other related efforts as well[5,6]. Requirement for high computational power is a major problem associated with a real-time vision-based application such as traffic data collection[7]. Several algorithms have been developed for the purpose of traffic data collection and monitoring. A pipeline-based system for off-line measurement of vehicle counts and speed was developed, using a full frame and background differencing approach[2]. An upgrade version of TRIP system based on an 80 386 computer was developed by Dickinson and Wan[8]. This system seems to have a better performance than the earlier version. Other researchers performed the traffic analysis using a low-cost image processing system (TULIP), which is capable of measuring different traffic parameters[9]. This system uses two methods for vehicle detection within a user-defined window. The first method applies a threshold at the road grey level and a predefined value. The second method involves using multiple thresholds to highlight much of the vehicle, including dark shadows just underneath the leading edge of the vehicles. A system called computer-aided traffic sensor (CATS) was developed in Belgium. This system uses background differencing technique and processes a small subset of a lane, about 20 pixels. The system can be used to count the vehicles and measure their speed[4]. The analysis of traffic images has proven that various surfaces and different parts and colours of a vehicle create significant edges, which can be detected when it is passing through a window[10]. Systems were also developed where image data scanner and controller (IDSC) was used for vehicle detection[10,11]. In India, few studies for vehicle detection and classification under heterogeneous traffic condition were conducted using kernel classifier[12,13]. Some studies were also conducted using TRAZER for traffic data collection as well as to analyse various traffic parameters like flow, speed and lateral gap under mixed traffic conditions[14–17]. Relationships were developed between speed and lateral position on curves of two-lane roadways[18]. Traffic volume count was made and reported in several studies[19–22].

From the available literature, it can be observed that the researchers have used several image-based detection systems for analysing vehicular movement. Also, there has been less number of studies using VIPS for analysing traffic conditions in developing countries, where traffic is mainly heterogeneous in character. Moreover, the available techniques and methods face problems when tested especially under congested traffic conditions, where detecting and tracking a single vehicle or a few vehicles becomes infeasible. Very few researches have checked the accuracy of the data obtained using video image-based detection system for parameters such as vehicle speed, lateral placement and volume count under such roadway and traffic conditions. Therefore, before using VIPS for extracting traffic flow data for modelling purposes, accuracy of the data obtained should be determined. Additionally, not many studies have been conducted on lateral placement behaviour of the vehicle in the traffic stream. Based on these research gaps, the scope and objectives are formulated in this study, as given in the next section.

## Objectives and scope

The following objectives are formulated for this study:

(i) To assess the performance of TRAZER under heterogeneous traffic conditions prevailing on the Delhi–Gurgaon expressway based on macroscopic parameters such as classified volume count and microscopic traffic parameters such as individual vehicle speed and its lateral position (placement) across road width.

(ii) To develop relationships between vehicle speeds and its lateral position across road width at a given point on the roadway, considering all vehicle categories (aggregate level) and also for each of the vehicle categories separately (disaggregate level).

The scope of the study is limited to evaluate the performance of TRAZER to process traffic flow data on the

**Figure 1.** Snapshot of traffic at the study location.

Delhi–Gurgaon expressway during daytime under clear weather conditions. We have also highlight the aspects about applicability of TRAZER under mixed traffic conditions in India. The study demonstrates use of the software to analyse traffic flow parameters at macroscopic and microscopic levels.

## Study location

The study was conducted on the Delhi–Gurgaon expressway, which is a 28 km expressway connecting Delhi, the national capital of India and Gurgaon, an important satellite city in Haryana. The general features of the Delhi–Gurgaon expressway are as follows: (i) Eight-lane carriageway with an average 7 m wide median. (ii) An extra lane is provided on each side as a hard shoulder. (iii) Plying of two-wheelers, three-wheelers is allowed. The width of the carriageway is 14 m each direction, separated by a median. A reconnaissance survey was conducted to select a mid-block section which should be free from gradient, potholes, etc. and should not affect the traffic flow. Figure 1 shows some of the snapshots taken at the study location.

## Installation of camera at study site

Mallikarjuna *et al.*[14] found that TRAZER gives high detection accuracies when video camera is aligned with the centre lane road and at a certain height. For the present study, the camera was placed on FOB, which is perpendicular to the direction of traffic flow across the carriageway width from a vantage point. From that point traffic flow video of study stretch was recorded from height, focusing vehicles front on its screen. However, a small deviation in camera position is allowed and may not create problems for vehicle detection while using TRAZER. It is mandatory that the angle of the camera should be perpendicular to the road width and deviation of maximum ± 15° is acceptable. Also there are chances of disturbances due to vehicles moving in another direction; so while capturing video, the camera should focus mainly on the concerned traffic flow direction of interest. Focus should give sharp video/images, so that vehicles can be retrieved from the camera. Zoom size also needs to be adjusted, so that it gives the optimal image size of the vehicles. If zoom size is increased or decreased chances of getting erroneous results are high. Lighting condition also affects video detection. Darkness may create problems during foggy weather in winter, where the vehicles cannot be detected properly. However, too much light falling on the camera may also create problems and the TRAZER software may not give good detection results. Thus, keeping in view all the aforementioned points, the camera position was fixed for good quality video-captured traffic flow data.

## Field data collection

After selection of the study stretch and installing the video camera, video photographic survey was conducted. The data were collected for 10 hrs from 8:00 a.m. to 6:00 p.m. during winter season when the weather was foggy (Figure 2 *a*) and vehicles were not detected because of poor visibility during morning and evening hours; only 5 h of data from 11:00 a.m. to 4:00 p.m. were selected for traffic flow analysis. For data collection, the camera was fixed on a foot over bridge (FOB) perpendicular to the road width and a section about 65 m long was identified in the video as the distance between two successive electric poles, placed parallel to each other across the carriageway width of 14 m. Thus, it forms trap length of 65 × 14 m, 130 × 14 m, 195 × 14 m, since three consecutive poles are visible in the video which has been shown in the Figure 2 *b*. Most of the vehicles were not detected at the upstream end of trap length of 130 × 14 m, 195 × 14 m, which is quite evident from Figure 2 *b* due to occlusion of vehicles at the upstream end. Therefore, considering the maximum detection of vehicles throughout the trap length of 65 × 14 m, it was selected for the study.

## Data extraction

Captured video-filmed data collected from the field were first converted into AVI format, to make them compatible

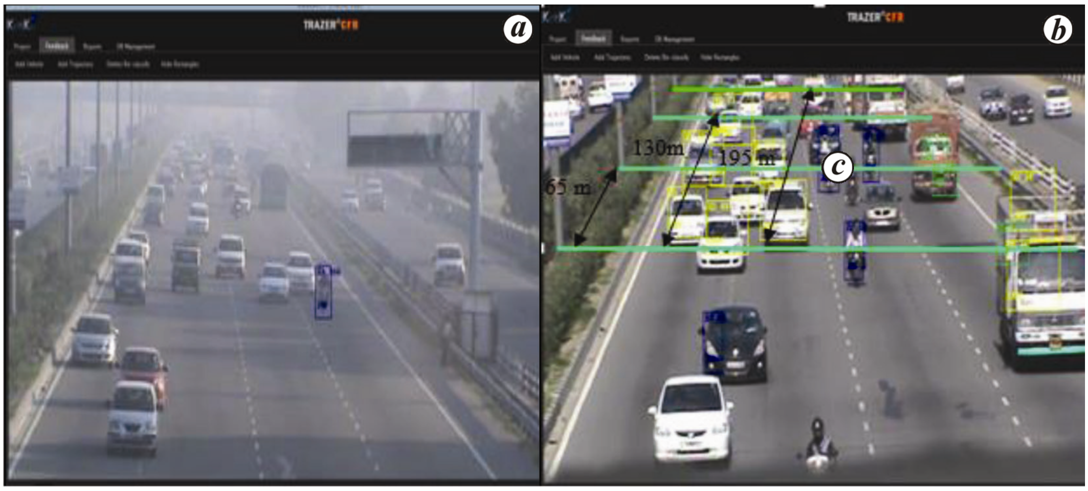


**Figure 2.** ***a***, Snapshot of TRAZER detection window during fog. ***b***, Different trap lengths marked on detection window.

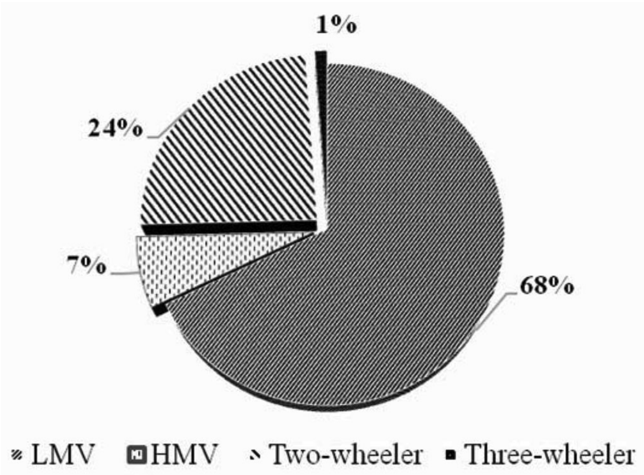


**Figure 3.** Composition of vehicles on the Delhi–Gurgaon Expressway.

with the TRAZER software. The marked 65 × 14 m rectangular trap area was then used for detecting vehicles and carrying out traffic flow analysis. A duration of 1 h and 10 min (2:00 p.m. to 3:10 p.m.) was selected for checking the accuracy and performance of TRAZER. This duration was selected since the volume was significantly high during the period from the available video and lighting condition was also favourable for the software to detect maximum number of vehicles. Moreover, a duration of 3 h (12:00 p.m. to 3:00 p.m.) was selected for model development and 1 hr (3:00 p.m. to 4:00 p.m.) for model validation.

For the purpose of evaluating the performance of TRAZER at micro-level, the data collected from the field were extracted using TRAZER and manually too. Details about both the data extraction techniques are given later in the text. As mentioned above, in the present study, 4 h of traffic data were considered based on the compatibility of lighting conditions. Out of 5 h (11:00 p.m. to 4:00 p.m.) of traffic data, the remaining 3 h (12:00 p.m. to 3:00 p.m.) were used for carrying out traffic analysis and developing relationship between vehicle speed as dependent variable and lateral placement or position of vehicle across the road width as the independent variable.

## Manual data extraction

Data extraction was done manually for volume count, average individual vehicle speed and lateral placement (position of vehicle at a given point) of the detected vehicle. For this purpose, the high volume data under favourable conditions for about 1 h and 10 min were used. This may be sufficient to check the accuracy of TRAZER based on reasonable sample size. Hence, the extraction of speed and lateral placement data was done for 30 vehicles for each 5-min interval randomly as sample observations. The procedure for extraction of these parameters has been explained below.

### *Volume count*

Exit end was marked using screen marker on the screen of running video in TRAZER software. The counted values were simultaneously entered manually in the Microsoft Excel sheet and recorded for every 5-min interval. As mentioned above, 1 h and 10 min (2:00 p.m. to 3:10 p.m.) data were used for accuracy check, but overall vehicle composition has been represented for the duration of 5 h (11:00 a.m. to 4:00 p.m.) in Figure 3. Classified volume count of vehicles passing through the section was done at the exit end of the trap length from the video (Figure 4). Flow rate during this time period was observed to be in the range 5000–7000 vehicles per hour.

### *Speed*

TRAZER software was used for playing video on the computer screen and screen marker was used for marking entry and exit lines at the entry and exit ends (Figure 4). Frame rate was selected at 25 frames per second. The frame number was recorded when a vehicle entered the section and exited it. The difference gives the travel time data for each vehicle, when divided by frame rate. The trap length was divided by the respective travel time of each vehicle to get their speed. As discussed for every 5-min, speed of 30 vehicle samples from different categories was calculated, which was also detected in TRAZER processor for the purpose of comparison.

### *Lateral placement*

Lateral placement on a given section of the road is determined as lateral position of a vehicle across the road width from median edge. The distance is measured from the median edge to the centre of that particular vehicle under consideration. The lateral placement was measured using the WINDOW RULER software, which is a measurement tool that can measure distance between two points on the computer screen on a centimetre scale (Figure 4). The ruler was overlapped at the exit end of the running video in TRAZER across the following road width in the direction of traffic flow under consideration. Lateral placements of vehicles were measured (cm) from the available ruler. Later they were converted to meter scale based on road width (14 m). This was also done for 30 vehicle samples comprising on different categories for each 5-min interval (which was also detected in TRAZER processor for comparison purpose).

The same parameters were also extracted using TRAZER for the purpose of checking accuracy of automatic vehicle detection system and its properties. Details about the extracted data using TRAZER are given in the following section.


**Figure 4.** Entry and exit lines marked with screen marker and WINDOW RULER used to measure distance across width.

## Data extraction using TRAZER processor

Before employing TRAZER suite for microscopic traffic flow data analysis, it is imperative that it should be well tested and calibrated for the prevailing mixed traffic conditions on Delhi–Gurgaon expressway. TRAZER software was used to process the pre-recorded video and output for different parameters of traffic such as (i) volume count and vehicle type, (ii) vehicle speed, (iii) lateral placement. The output was generated for each 5-min interval. Figure 5 *a* shows a snapshot of TRAZER suite, depicting coordinates marked on the road using TRAZER. The coordinates of the four corners for a selected area of 65 × 14 m rectangle were marked as (0, 0), (14, 0), (14, 65), (0, 65). Values on the *y*-axis are along the road length and those on the *x*-axis are across the road width. The width of road is 14 m (four lanes of 3.5 m width each) and length between entry and exit lines is 65 m, representing the coordinates. Figure 5 *b* shows the detection window of TRAZER. The number of vehicles being detected is updated on the right side of the window. Further, the output on different parameters such as speed, volume count, and lateral placement along with detected vehicle id is generated in the CFR (collate–feedback–report) module of TRAZER. Output on vehicle speed and volume count can be easily generated from TRAZER, but output on lateral position or placement cannot be obtained directly. To get output on lateral placement, vehicles trajectory data can be used. Trajectory data consist of frame number, vehicle type, vehicle id, photo coordinates and real-world coordinates of the vehicle. The *y*-axis in real-world coordinates refers to the distance from the reference line along the length of the road, whereas the *x*-axis refers to position of vehicle with respect to the median of the road. The value of *x*, where *y* tends to zero will give the lateral placement of vehicles. After getting output on lateral placement, frequency of each vehicle category is plotted over each metre of lateral position of vehicles (Figure 6). From vehicle category-wise frequency distribution over the road space can be observed.

## Corroborating traffic volume count data

The traffic volume count data obtained using manual count in TRAZER (which is considered as actual count (column 2, Table 1)) were compared with those obtained from the TRAZER software for the total duration of 1 h and 10 min (column 3, Table 1).

From Table 1 (column 4), it can be seen that the average accuracy percentage calculated after comparison of actual counts and counts by TRAZER is 59.02. This detection percentage is found to be on the lower side for the duration and may be attributed to the default settings of TRAZER. It basically detects vehicles based on certain


**Figure 5.** ***a***, Trap length marked on detection window. ***b***, Vehicle detection window of TRAZER.

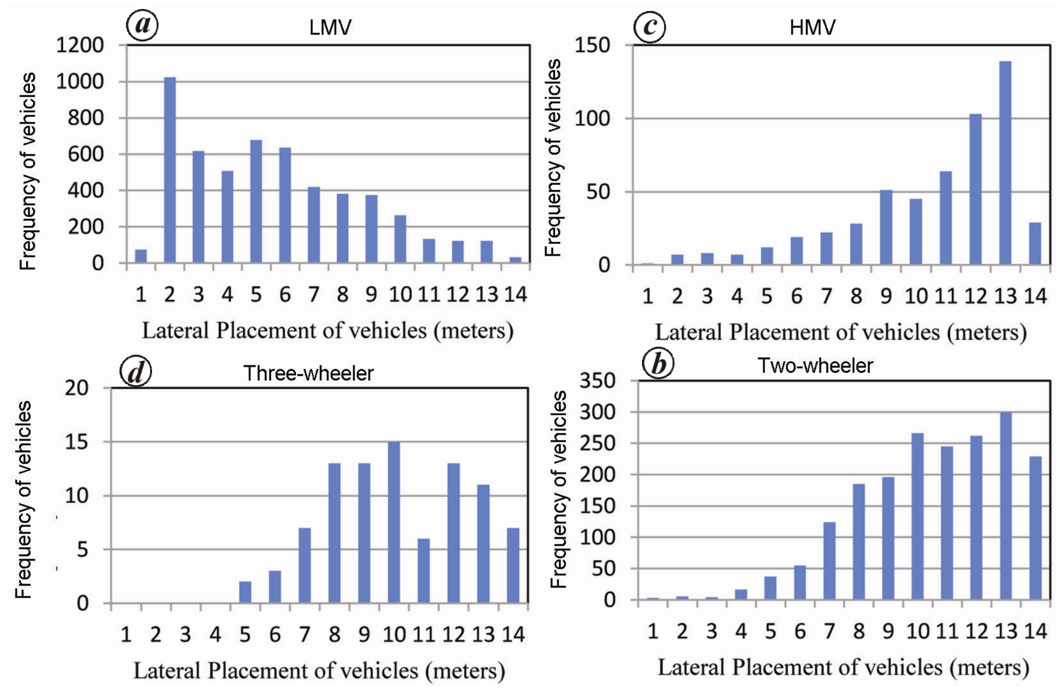


**Figure 6.** Frequency of vehicles across road width based on their lateral position for (***a***) light motor vehicle, (***b***) two-wheeler, (***c***) heavy motor vehicle and (***d***) three-wheeler.

**Table 1.** Results from vehicle detection and counting

| Vehicle category | Actual count | Count by TRAZER processor | Accuracy percentage |
|---|---|---|---|
| LMV | 5,394 | 2,589 | 47.99 |
| Three-wheeler | 74 | 43 | 58.11 |
| HMV | 486 | 309 | 63.58 |
| Two-wheeler | 1,004 | 667 | 66.43 |
| Overall accuracy | 6,958 | 3,608 | 59.02 |

Accuracy = 59.02%; HMV, Heavy motor vehicle; LMV, Light motor vehicle.

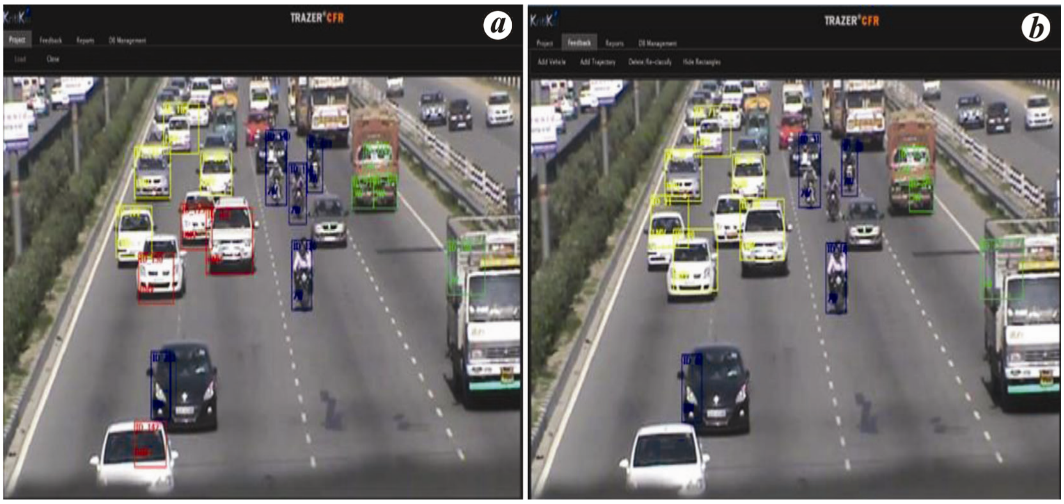

**Figure 7.** Vehicle detection with (***a***) default settings and (***b***) modified settings in TRAZER.

**Table 2.** Minimum and maximum detection width for each vehicle category

| Vehicle category | Minimum detection width modified (m) | Maximum detection width modified (m) |
|---|---|---|
| LMV | 1.5 | 2.5 |
| Motorized three-wheeler | 1 | 1.8 |
| HMV | 2.5 | 4 |
| Motorized two-wheeler | 0.2 | 1.2 |

**Table 3.** Results of vehicle detection after applying changes in detection width

| Vehicle category | Actual count | Count by TRAZER processor | Accuracy percentage |
|---|---|---|---|
| LMV | 5,394 | 4,177 | 77.44 |
| Three-wheeler | 74 | 59 | 79.73 |
| HMV | 486 | 392 | 80.66 |
| Two-wheeler | 1,004 | 799 | 79.58 |
| Overall accuracy | 6,958 | 5,427 | 77.99 |

pattern recognition with its default settings and it may not be able to detect variation in size within each vehicle type. Also, problem of misclassification between light motor vehicle (LMV) and heavy motor vehicle (HMV) is quite common, which affects detection accuracy. To improve the percentage detection accuracy, changes in minimum and maximum detection width for each vehicle category, namely light motor vehicle (LMV), motorized three-wheeler, heavy motor vehicle (HMV) and motorized two-wheeler were carried out so that variation in vehicle dimensions within each vehicle category can be captured. Table 2 shows the changes in minimum and maximum detection widths based on vehicle category.

Figure 7 *a* and *b* shows instantaneous snapshots of TRAZER detection window, both with default settings and modified settings, where yellow coloured square in the detection window represents LMV and red coloured square represents HMV. From the figure, it can be clearly observed that LMVs have been detected as HMVs with default setting. The changes made in minimum and maximum detection widths of different vehicle categories have resulted into significant improvement in the detection percentage. Table 3 shows the results of vehicle detection after changing the detection width.

From Table 3, it can be noted that the overall detection percentage has increased from 59.02 to 77.99 (19% increase). It may be noted that percentage accuracy increase is higher in case of LMVs (29.45) and motorized three-wheelers (21.62), considering percentage accuracy given Table 1 (column 4). However, it is relatively lower in the case of motorized two-wheelers (13%) and HMVs (17%). This may be attributed to the parallel and non-lane-based movement of motorized two-wheelers on Indian roads. Hence accuracy of about 78% may be considered reasonably good keeping in view non-lane-based traffic flow conditions on the Delhi–Gurgaon expressway. However, 100% accuracy can also be achieved by manually selecting the undetected vehicles in TRAZER CFR module. But, it is not included in the scope of the present study. The accuracy of 80% may be considered reasonably good since the flow is near capacity.

## Corroborating speed and lateral placement data

The calibrated TRAZER software was employed to check its credibility at micro-level of traffic flow data. For this purpose, the values of speed and lateral placement for different vehicle types obtained from TRAZER processor was compared with those obtained from the manually extracted data for the same vehicle on sampling basis. The comparison was done for a sample of 30 vehicles for

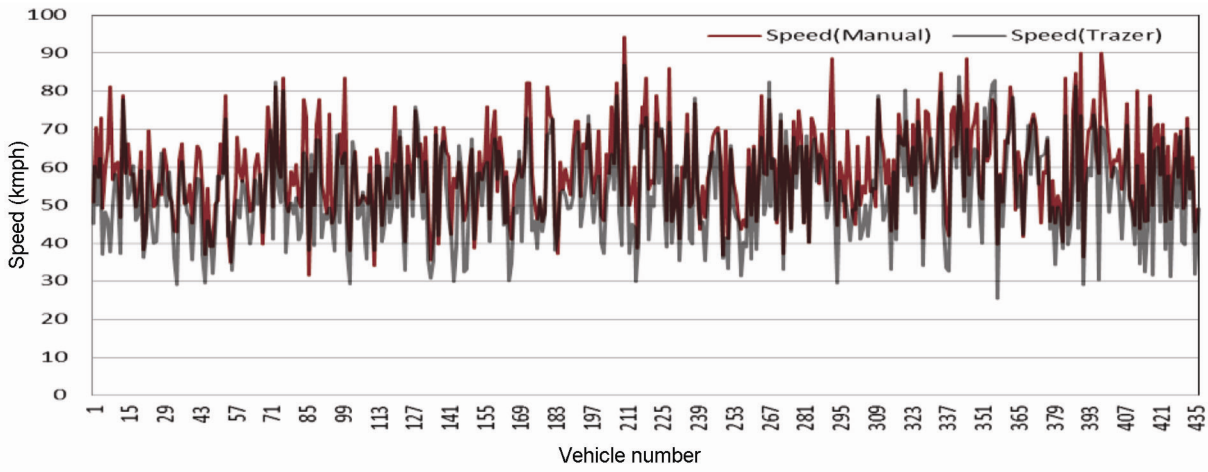


**Figure 8.** Comparison of actual and estimated value for lateral placement.

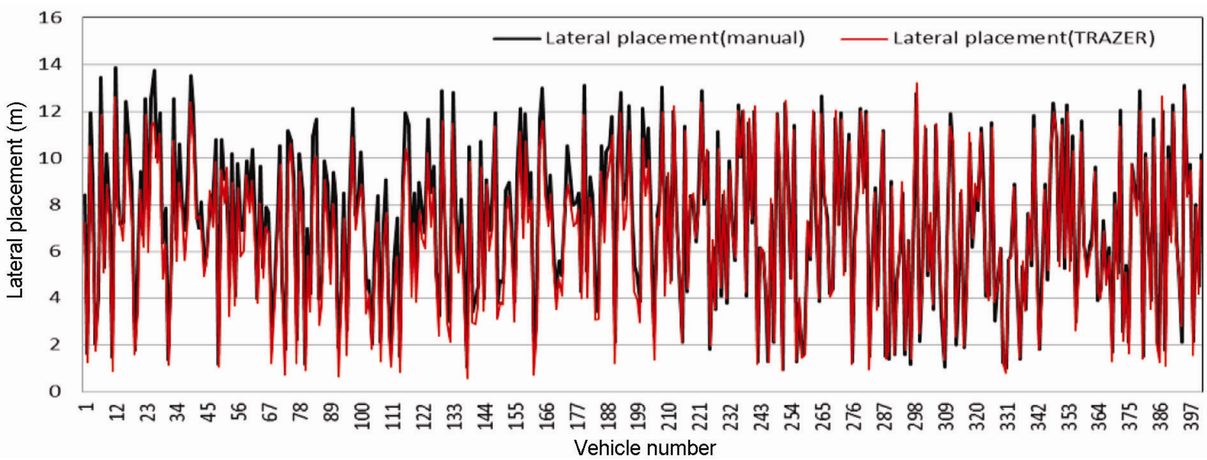


**Figure 9.** Comparison of actual and estimated value for speed.

each 5-min interval randomly comprising a total of 716 samples, which is about 11% of the total volume of about 6510 vehicles per hour depicting traffic state near capacity region. The values from TRAZER processor are considered as estimated value and manually extracted data as observed/actual value for vehicle speed and lateral placement. Figures 8 and 9 respectively, depict plots of actual versus estimated value for speed as well as lateral placement are presented. The performance of TRAZER processor for estimating speed and lateral placement was quantified using mean absolute percentage error (MAPE) value as in equation (1)

$$\text{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{z_i - \hat{z}_i}{z_i}\right|, \quad (1)$$

where $z_i$ is the actual value of the given parameter, $\hat{z}_i$ the estimated value of the parameter and $N$ is the total number of observations.

MAPE values calculated for speed and lateral placement were found to be 12.73% and 10.60% respectively. From the Lewis scale of interpretation of estimation accuracy[23] any prediction with a MAPE value less than 10% can be considered highly accurate, 11%–20% as good, 21%–50% as reasonable, and 51% or more as inaccurate[23]. The MAPE values for speed and lateral placement were found in the range 11%–20%. Hence, it can be inferred that TRAZER processor provides comparable results and a good estimate of lateral placement and speed value.

## Analysis of speed data

The vehicles of heterogeneous traffic such as the one prevailing on Indian roads may occupy any convenient lateral position on the road, based on the availability of space, without any lane-discipline. Under this kind of heterogeneous traffic conditions, it may be interesting to estimate the vehicle speed based on its lateral position

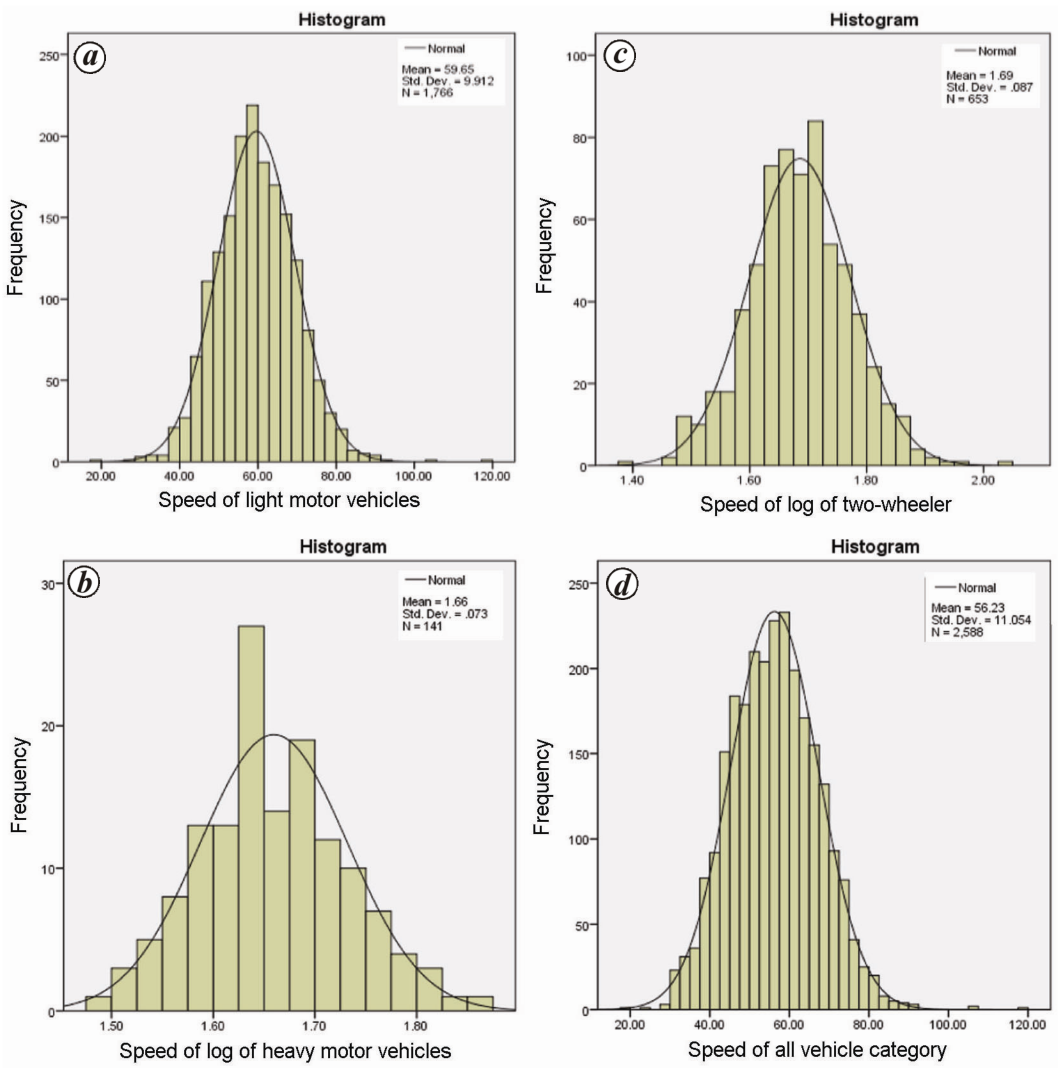


**Figure 10.** Normal distribution speed fitted for: (***a***) LMV, (***b***) HMV, (***c***) two-wheeler speed and (***d***) all vehicle categories.

**Table 4.** Test for normality of vehicle speed for each vehicle category

| | Kolmogorov–Smirnova test | | |
|---|---|---|---|
| Vehicle category | Statistics | Degree of freedom | Sigma |
| LMV | 0.019 | 1,766 | 0.129 |
| HMV | 0.052 | 141 | 0.200 |
| Two-wheeler | 0.022 | 653 | 0.200 |
| All vehicles | 0.018 | 2588 | 0.051 |

from the median edge. Keeping this in view, which is also a central idea of this study, speed of the vehicles has been analysed based on their lateral placement. Speed data for all vehicle categories were available with their respective lateral placement. Lateral placement of vehicles may not only vary based on the vehicle speed, but also based on the type of vehicle. For example, most of the LMVs would always like to be as near as possible to median-side lane compared to other adjacent lanes. Also, HMVs and two-wheelers would like to be more on shoulder side lane, particularly on expressways like Delhi–Gurgaon. Hence to study the variation in vehicle speed across the road width of 14 m, lateral placement of the vehicles has been segmented in the road of 0–3.5, 3.5–7.0, 7–10.5 and 10.5–14.0 m, where each range represents a space of the single lane. The range was measured from the edge of median side lane as origin to the edge of shoulder side lane, including all four lanes having total width of 14.0 m. Speed variation for each vehicle category was also analysed with the variation in lateral placement. For this purpose, relationship between speed as dependent variable and its lateral placement or position as independent variable was developed for different vehicle categories separately. Then model was also developed using data points of all the vehicles aggregate. To check for the normality of the observed speed data, Kolmogorov–Smirnova (K–S) test was conducted using SPSS. Table 4 provides the results of this test.

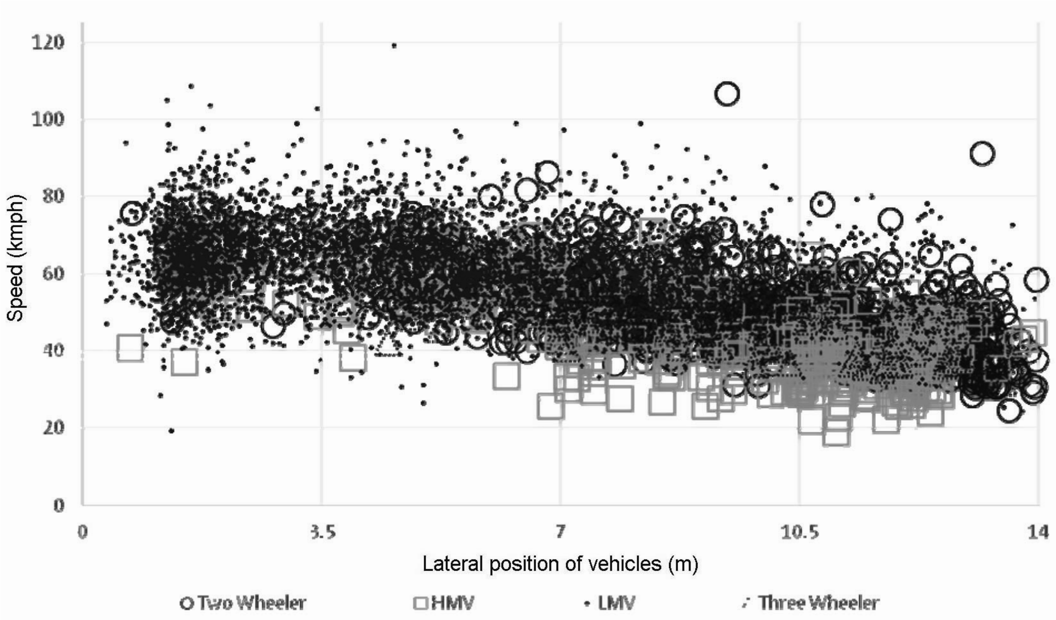


**Figure 11.** Variation in individual vehicle speed with lateral placement for all vehicle categories.

From Table 4, it can be inferred that at aggregate level, speed of all vehicles follows normal distribution at 5% level of significance. The random variation for speed of individual vehicle categories was also plotted for checking normality of speed data. For cars it is found to follow normal distribution. However, it may be noted that the speed of HMV and motorized two-wheeler are found to fit log–normal distribution well. Figure 10 shows the normality plots and other relevant details like sample size along with frequency distribution curve.

## Distribution of vehicles

One of the objectives of this study is to analyse distribution of vehicles across the road width and its effect on speed of different vehicle categories. For this purpose, the extracted data from TRAZER were analysed for a total duration of 3 h. The variation of speed for all vehicles in the traffic stream with respect to their lateral placement in the stream was observed from 11 : 00 a.m. to 2 : 00 p.m., i.e. 3 h period. The road space of 14.0 m width was divided into different segments: lateral placement between 0 and 3.5 m represents median-side lane and lateral placement between 10.5 and 14 m represents shoulder-side lane. The other two ranges of lateral placement, 3.5–7 m and 7–10.5 m represent middle lanes. Figure 11 shows the variation of speed based on lateral placement for all vehicle categories. From the figure, it can be noted that vehicle speeds decrease gradually from median-side lane to shoulder-side lane. The vehicles in median-side lane, move at higher speed compared to those in shoulder-side lane.

Further analysis was done for each vehicle category and its lateral placement behaviour. Table 5 presents the distribution of vehicles across road width of 14.0 m for a given speed range along with traffic volume and composition. It can be observed from the table that LMVs are well distributed over the road space of median-side lane and next to median-side lane and a small percentage of LMVs can be observed in road space of shoulder-side lanes. In case of HMVs, they mostly occupy shoulder-side lane and next to shoulder-side lane and a small percentage of vehicles can be seen on the other lanes. Two-wheelers and three-wheelers are mostly concentrated in the middle two lanes and are found avoiding median-side lane. Further, for each lane, the variation in speed range and composition of different vehicle category has been represented in Table 5 and the aforementioned conclusion can be justified.

## Model development

Based on one of the objectives of the study, mathematical models (equations) were developed and validated both at aggregate (all vehicles) and disaggregate (vehicle category-wise) levels. For this purpose, speed of the vehicle was regressed with its lateral position or vehicle placement from median (m) across the road to develop separate equation for each vehicle category and also considering all vehicle categories. Average vehicle speed (note 1) was plotted against its respective average lateral placement value for each 5-min interval over total 3 hrs (12:00 p.m. to 3:00 p.m.) of dataset. Figure 12 *a–d* is a plot of the developed relationships. The polynomial

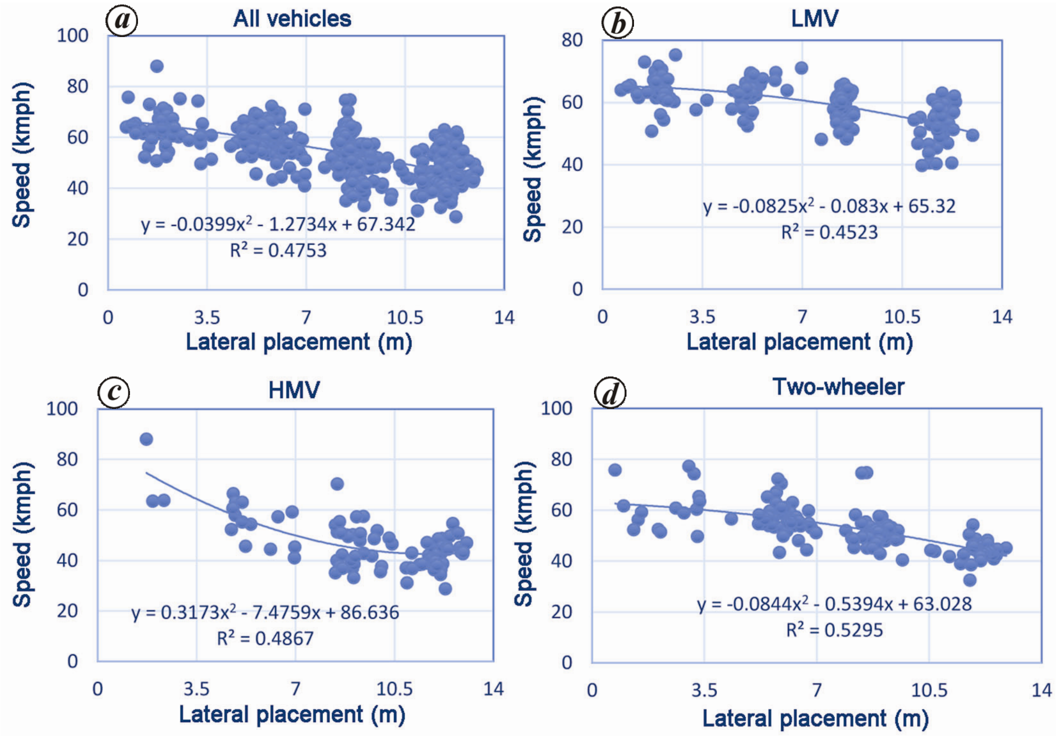


**Figure 12.** Relationship between individual vehicle speeds of (***a***) all vehicles with lateral placement, (***b***) LMV with lateral placement, (***c***) HMV with lateral placement and (***d***) two-wheelers with lateral placement.

function was found to give the best-fit equation to explain the variation of vehicle speed with its lateral placement. Since the composition of motorized three-wheelers (1%, as given in Figure 3) was less, it was not considered for developing model.

Further, for validating the developed models, it was decided to apply developed equations on extracted data for different time periods (which was not used in developing earlier models) and check their accuracy by comparing their output with the real data. For this purpose, micro-level traffic data (speed and lateral position) were extracted for 1 h duration (3:00 p.m. to 4:00 p.m.) by giving video-captured traffic data as input to TRAZER. The speed values were estimated using values of lateral positions in the model equation for all vehicles together (aggregate) and vehicle category-wise (disaggregate). Figure 13 *a–d* shows a comparison of vehicle speed thus estimated and observed speed (not used in developing models). From the figure, it can be observed that all the models fit well about a linear line passing through the origin (0, 0). Further, the applicability of the developed models was also tested by MAPE. The MAPE value (8.04%) for aggregate model was found to be in highly accurate range. Similarly, MAPE values for vehicle category-wise models were found in the range of 0%–10% (LMV – 4.4%, HMV – 8.17%, two wheeler – 6.02%), which may be considered as highly accurate estimates using Lewis scale of measurement, as given by Kenneth and Ronald[23].

## Applicability of TRAZER under heterogeneous traffic conditions

The task for TRAZER is complicated mainly due to variation of ambient lighting, shadows, occlusion and lane changing movement of vehicles under heterogeneous traffic conditions. The situation is more complex, when traffic is flow is near to capacity. Sometimes a vehicle can be detected more than once in TRAZER (Figure 14). Figure 14 shows some of the sample observations made during the present study. For such cases, the over counted vehicle can be deleted manually. Moreover, some vehicle classes may be detected wrongly using the software. Table 6 shows the matrix of vehicle classification using default setting is without calibrating maximum and minimum detection widths of each vehicle categories in TRAZER. With this default setting, it can be noted that some vehicles were wrongly classified by TRAZER. Thus, it has been presented in the form of matrix in Table 6. Diagonal element of matrix shows the vehicles which were detected as same by TRAZER. However, other elements in the matrix represents the vehicle which is detected as another vehicle category. Summation of horizontal elements shows the total number of each vehicle category detected based on which percentage of final accuracy was calculated. However, such vehicles were reclassified in this study but in order to check the accuracy in terms of classification, again 30 min of traffic video was processed using TRAZER. The overall accuracy of classification

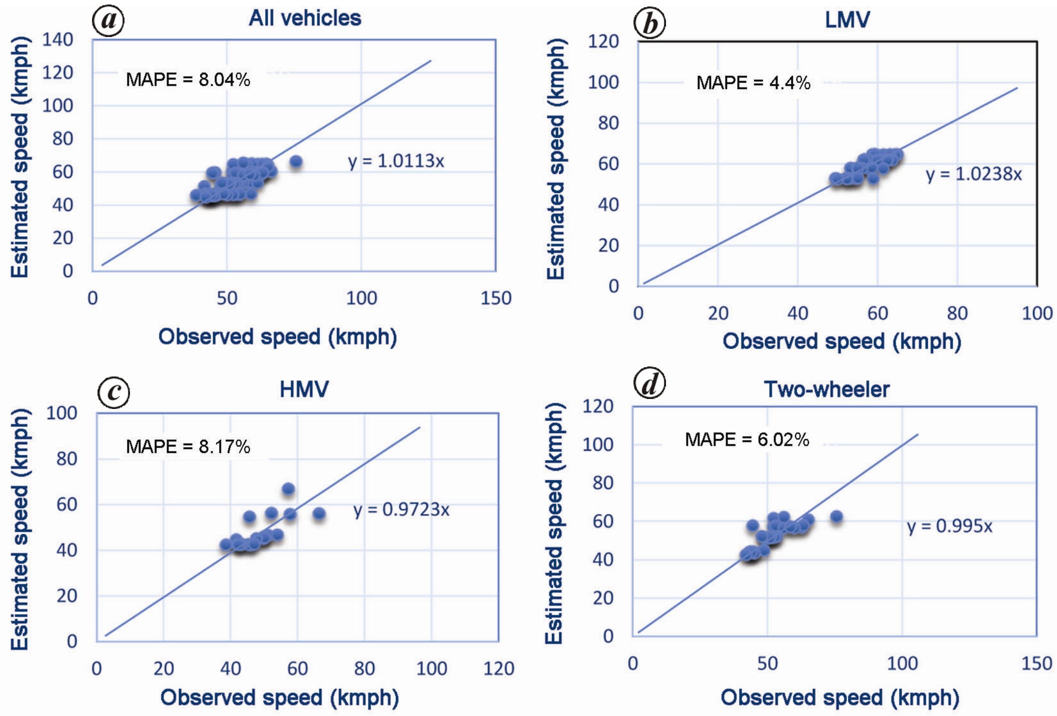


**Figure 13.** Comparison of actual and estimated values for (***a***) aggregate, (***b***) LMV, (***c***) HMV and (***d***) motorized two-wheelers.

**Table 5.** Distribution of vehicle categories over road space with the respective speed ranges

| Road space distribution (m) | Speed range (km/h) | Number of vehicles detected | | | |
|---|---|---|---|---|---|
| | | LMV | HMV | Two-wheeler | Three-wheeler |
| 0–3.5 | 20–40 | 9 | 1 | 1 | 0 |
| | 40–60 | 562 | 9 | 9 | 0 |
| | 60–80 | 1269 | 8 | 11 | 0 |
| | 80–100 | 102 | 1 | 0 | 0 |
| Vehicle composition (%) | | 36.2 | 3.57 | 1.09 | 0 |
| 3.5–7 | 20–40 | 16 | 3 | 4 | 0 |
| | 40–60 | 793 | 32 | 143 | 10 |
| | 60–80 | 1095 | 21 | 72 | 1 |
| | 80–100 | 89 | 1 | 2 | 0 |
| Vehicle composition (%) | | 37.07 | 10.71 | 11.48 | 12.22 |
| 7.0–10.5 | 20–40 | 20 | 42 | 61 | 3 |
| | 40–60 | 548 | 90 | 609 | 42 |
| | 60–80 | 501 | 15 | 114 | 0 |
| | 80–100 | 31 | 2 | 2 | 0 |
| Vehicle composition (%) | | 20.45 | 28.01 | 40.88 | 50 |
| 10.5–14.0 | 20–40 | 30 | 112 | 264 | 19 |
| | 40–60 | 215 | 180 | 589 | 15 |
| | 60–80 | 92 | 13 | 41 | 0 |
| | 80–100 | 0 | 0 | 2 | 0 |
| Vehicle composition (%) | | 6.26 | 57.70 | 46.54 | 37.78 |

from TRAZER was found to be 83.18%, where two-wheelers were misclassified the least (accuracy 91.9%) and percentage of misclassification for HMVs was the most, which is one of the drawbacks with default settings of TRAZER. Other problems such as shadows and lighting effects controlled by taking video during noon and preventing excessive light from falling on the camera screen, which may result in underperformance of the


**Figure 14.** Snapshot of same vehicle detected twice using TRAZER software.

**Table 6.** Vehicle classification from default settings of TRAZER

| | LMV | Three-wheeler | HMV | Two-wheeler | Accuracy percentage |
|---|---|---|---|---|---|
| LMV | 1,815 | 2 | 51 | 218 | 87.01 |
| Three-wheeler | 1 | 15 | 0 | 2 | 83.33 |
| HMV | 31 | 8 | 138 | 19 | 70.482 |
| Two-wheeler | 23 | 7 | 2 | 365 | 91.9 |

software. In the present study traffic flow analysis was conducted for three different trap lengths of 65, 130 and 195 m using TRAZER software. It was found that for 130 and 190 m trap length, less vehicles were detected at upstream end due to occlusion effect. To reduce the error due to occlusion effect, a shorter trap length of 65 m was finally selected for further data extraction. When traffic flow is higher or near to capacity region, it is suggested that TRAZER may not be accurate for classified volume count (CVC) under heavy traffic conditions (moderate to near capacity traffic volume) under prevailing traffic conditions (heterogeneous) in India, as it may not detect the vehicles at a selected point across the whole roadway width exactly. It was observed that it may detect vehicles at any point over the entire road space formed inside the selected detection window, which does not follow the definition of traffic volume. This mechanism may allow software to detect vehicles multiple times, particularly during lane-change operation. This may lead into erroneous volume count or flow rate based on the selected disaggregated time interval. Hence, the traffic count results may not be consistent over space. However, it was found that it may be desirable to set the point (line across the roadway width) as near as possible to the position of camera to enhance the vehicle detection accuracy. But, even after selecting most favourable point for extracting traffic volume data, it was found that accuracy may not be as high as desired. Also, average vehicle speeds are extracted based on these detections anywhere in the detection window. Although vehicles are detected randomly, once a vehicle is detected, TRAZER tracks its movements continuously till it clears the detection zone. Hence, it is obvious that the estimated speeds based on these detections are reasonably accurate because of shorter distances. However, the software has its own limitations while it has to perform over a larger road spaces. Hence, it may be inferred that TRAZER may work out better for measurement of traffic flow characteristics at micro-level such as lateral position of vehicles, individual vehicle speed, time headway, transverse gaps, etc.

Despite all these difficulties/problems, a vision-based traffic data collection system has several advantages over the conventional point-based alternatives such as magnetic loops. Vision can give time-variant and spatial information about a scene and can be recorded easily for further analysis. Ease of installation on a road, flexibility, and intrusive technologies of data extraction needs regular maintenance which is not required in case of

TRAZER, which encourage researchers to concentrate on this interesting area of research in traffic engineering. Also it reduces the manual effort (number of man-hours) required for extracting traffic data.

## Summary and conclusion

In the present study, TRAZER has been used as an image processing tool for analysing traffic data under heterogeneous traffic condition on the Delhi–Gurgaon expressway. We have evaluated the performance of TRAZER under denser traffic flow conditions (near capacity level flow) on the expressway, which is considered as an urban multilane road with higher speed limit (about 80 km/h). Hence, it has significantly different traffic flow characteristics, when compared to studies reported in the past. A check for the accuracy of the data retrieved from the software was done for traffic volume count (macroscopic variable), individual vehicle speed and lateral placement (microscopic variables) by comparing image processing-enabled extracted data with manually extracted data. After checking the accuracy of the software for traffic parameters (after calibration and validation), the extracted data obtained were used for further analysis regarding variation of speed with respect to lateral placement of the vehicles. The following conclusions have been derived from this study

1. The TRAZER processor gave an accuracy of about 78%, when used for vehicle detection under mixed traffic flow condition. However, percentage accuracy can be increased by manually selecting the undetected vehicles in TRAZER using CFR module and up to 100% accuracy can be achieved.
2. Sometimes TRAZER may fail to detect vehicles due to occlusion or lighting conditions. It may also over-count or misclassify a vehicle. In order to increase accuracy, over-counted vehicles should be deleted and misclassified vehicles should be moved to their respective vehicle category. However, these errors tend to cancel out over longer periods resulting into a relatively accurate count.
3. TRAZER is found to give good, consistent results for microscopic traffic parameters such as speed and lateral placement when compared with manually extracted data. MAPE for vehicle speed and its lateral placement (lateral position from median) was observed to be 12.73% and 10.6% respectively.
4. The vehicle speeds maintained by different vehicle categories are found to follow either normal distribution (LMVs) or log-normal distribution (HMVs and two-wheelers) based on K–S goodness-of-fit test. Speeds of the vehicles are found to be decreasing from median side lane to shoulder side lane based on its lateral position.
5. LMVs preferred to travel on median side lanes, whereas HMVs like buses and trucks preferred to travel on shoulder side lanes.
6. Speed of a vehicle is found to have polynomial relationship with lateral placement for both at aggregate (considering all vehicle categories) and disaggregate (considering individual vehicle category) levels.
7. The model is found to be accurate for disaggregate level (MAPE values of observed vs predicted speed for two wheeler, HMV and LMV are found to be 6.02%, 8.17% and 4.4% respectively),when compared to aggregate level (MAPE value of observed vs predicted speed for all vehicles is found to be 8.04%).

## Future scope

The following points may be considered for evaluating the performance of TRAZER and its employability for different applications:

1. Transverse gaps for Delhi–Gurgaon expressway can be studied using the software.
2. TRAZER can be a useful tool for trajectory formation and density measurement of traffic.
3. The performance of TRAZER may be checked for real-time detection in ITS applications.
4. Its performance may also be checked at night under heterogeneous traffic conditions. It is anticipated that the performance in terms of speed and other manoeuvres such as lane changes, lateral position of vehicles, transverse and longitudinal gap maintaining behaviour under head-light may be significantly different compared to the daytime traffic conditions.

## Note

1. Average speed of vehicles was calculated for every 5-min interval, having different lateral placement values over the entire carriageway width, starting from median-side lane to shoulder-side lane, i.e. 0–3.5 m, 3.5–7.0 m, 7.0–10.5 m and 10.5–14.0 m. Lateral placement value was extracted based on position of centre of front side of subject vehicle.


1. Hashimoto, N., Development of an image processing traffic flow measurement system. *Sumitomo Electronic Technical Review*, No. 25, January 1986, pp. 133–138.
2. Lindley, S. T., Estimation of population growth and extinction parameters from noisy data. *Ecol. Appl.*, 2003, **13**, 806–813.
3. Dickinson, K. W. and Waterfall, R. C., Image processing applied to traffic: a general review. *Traffic Eng. Contr.*, 1984, **1**, 6–13.
4. Fathy, M. and Siyal, M. Y., An image detection technique based on morphological edge detection and background differencing for real-time traffic analysis. *Pattern Recogn. Lett.,* 1995, **16**, 1321–1330.
5. Hoose, N., *Computer Image Processing in Traffic Engineering*, Taunton Research Studies Press, UK, 1991.
6. Fathy, M. and Siyal, M. Y., A window-based edge detection technique for measuring road traffic parameters in real-time. *Real-Time Imaging*, 1995, vol. 1, pp. 297–305.

7. Siyal, M. Y. and Fathy, M., Triple RISC image processor for real-time image processing applications. *Inst. Electron Eng. Electron Lett*., 1996, **32**(24), 2224–2225.
8. Dickinson, K. W. and Wan, C. I., Road traffic monitoring using the TRIP II system. In IEEE 2nd International Conference on Road Traffic Monitoring, London, UK, 1989.
9. Rourke, A. and Bell, M. G., Traffic analysis using low cost image processing. In Proceedings of the Seminar on Transportation Planning Methods, PTRC, Bath, UK, 1988.
10. Siyal, M. Y. and Fathy, M., Real-time measurement of traffic queue parameters by using image processing techniques. In Proceedings of the 5th IEE International Conference Image Processing Application (IPA95), Edinburgh, UK, 1995.
11. Takaba, S., A traffic flow measuring system using a solid state sensor. In Proceedings of the IEEE Conference on Road Traffic Data Collection, London, UK, 1984.
12. Mishra, P. K. and Banerjee, B., Multiple Kernel based KNN classifiers for vehicle classification. *Int. J. Comput. Appl.*, 2013, **71**(6), 1–7.
13. Mishra, P. K., Athiq, M., Nandoriya, A. and Chaudhuri, S., Video-based vehicle detection and classification in heterogeneous traffic conditions using a novel Kernel classifier. *IETE J. Res.*, 2013, **59**(5), 541–550.
14. Mallikarjuna, C., Phanindra, A. and Rao, K. R., Traffic data collection under mixed traffic conditions using video image processing. *J. Transp. Eng. – ASCE*, 2009, **135**(4), 174–182.
15. Mallikarjuna, C., Tharun, B. and Pal, D., Analysis of the lateral gap maintaining behaviour of vehicles in heterogeneous traffic stream. In Procedia – Social and Behavioral Sciences, Second Conference of Transportation Research Group of India (2nd CTRG), 2 December 2013, vol. 104, pp. 370–379.
16. Mallikarjuna, C. and Rao, K., Heterogeneous traffic flow modelling: a complete methodology. *Transportmetrica*, 2011, **7**(5), 321–345.
17. Mallikarjuna, C., Kalaga, R. and Seethepalli, N., Analysis of microscopic data under heterogeneous traffic conditions. *Transport*, 2010, 262–268; 10.3846/transport.2010.32.
18. Hallmark, S. L., Hawkins, N. and Omar, S., Relationship between speed and lateral position on curves. In 16th Road Safety on Four Continents Conference, Beijing, China, 15–17 May 2013.
19. Jabeena, M., Joshi, G. J., Arkatkar, S. and Ravinder, R., Traffic characteristics study through processing of video image for expressway in India. *J. Soc. Transp. Traffic Stud.*, 2015, **6**(2), 1–15.
20. Robichaud, K. and Gordon, M., Assessment of data-collection techniques for highway agencies. *Transport. Res. Record, J. Transp. Res. Board*, 2003, **1855**, 129–135.
21. French, L. J., Iskander, W. and Jaraiedi, M., Traffic volume monitoring related research. Final Report, The Pennsylvania Transportation Institute, USA, 2001.
22. Seaver, W. L., Chatterjee, A. and Seaver, M. L., Estimation of traffic volume on rural local roads. *Transport. Res. Record, J. Transp. Res. Board*, 2000, **719**, 121–128.
23. Kenneth, D. L. and Ronald, K. K., *Advanced in Business and Management Forecasting*, Emerald Book, Bingley, UK, 1982.

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