IMPACT OF HORIZONTAL ALIGNMENT ON TRAFFIC PERFORMANCE AT RURAL TWO-LANE HIGHWAYS

Mohamed Shawky
Department of Public Works Engineering, Faculty of Engineering, Ain Shams University
1st El-Sarayat St. Abassia, Cairo, EGYPT.
Phone: +20 (0)225888430
E-mail: m_shawky132@hotmail.com

Ibrahim Hashim
Civil Engineering Department, Faculty of Engineering, Menoufia University,
Gamal Abdel-Naser Street, Shebin El-Kom, EGYPT.
Phone: +20 (0) 48 220 395
Fax: +20 (0) 48 235 695
Email: hashim1612@hotmail.com

ABSTRACT

Two-lane, two-way highway facilities represent the majority of the total length of highway network at many countries. The geometric design of such facilities is considered as one of the most important factors affecting the traffic performance and safety issues, especially the horizontal alignment. However, the interaction between the horizontal curve design elements and the traffic performance still unclear and needs more investigations. This paper aims to explore the relationship between the characteristics of horizontal alignment and the traffic performance. The follower density, a new and promising performance measure, is herein used as a measure of effectiveness (MOE), since the currently used MOE (in HCM-2000), percent-time-spent-following (PTSF), is hardly observed in the field. In this study, the traffic data are collected from mid-tangent and mid-curve points at nine different sites with various horizontal alignment characteristics. Then, several relationships between the follower density, flow rate, horizontal alignment characteristics (curve radius, tangent length), and average speed are investigated. The results show that the horizontal alignment characteristics have a significant effect on the follower density, especially curve radius value, by decreasing radius, the follower density increases (i.e., traffic performance decreases). It is also noticed that a value of horizontal curve radius falling between 400 and 450m seems to be a threshold of the significant impact of curve radius on traffic performance. It is worth to mention that the results and relationships presented in this paper is a step towards understanding the interaction between horizontal alignment and traffic performance at two-lane highway facilities and more investigation at other locations and under different traffic conditions are recommended.

INTRODUCTION

Two-lane, two-way highways present a particular challenge to highway engineers as they constitute the majority of any network in terms of distance (kilometers), e.g. about 85% in the UK and 80% in the USA. Measuring traffic performance at these facilities is a complex issue due to their unique characteristics, since a single lane is provided for travel in each direction resulting in higher level of interaction between vehicles traveling not only in the same but also in opposing directions. Thus, attaining a desired speed movement in the two-lane highways traffic stream is dependent on the ability to pass slower vehicles ahead, which in turn is a function of oncoming traffic level and geometry characteristics.

The geometric design of two-lane highways, especially the horizontal alignment, is considered as one of the most important factors that affects the quality of service and safety of traffic. The interaction between the geometric design and traffic performance at two-lane highway facilities are still unclear and needs more investigations. Understanding how the horizontal alignment parameters affect the operational characteristics of traffic on two-lane highways could be very useful for highway practitioners.

Traffic performance measures for two-lane highways have been changed over the past Highway Capacity Manuals. The current Highway Capacity Manual (HCM-2000) methodologies use the percentage-time-spent-following (PTSF) as a measure of performance (1). This measure is not applicable and hardly to be observed in the real field. Accordingly, other measures of performance for two-lane highway facilities have recently been proposed and empirically analyzed such as overtaking ratio (2), percentage of followers, and follower density (3).

This paper aims to investigate the interaction between the traffic performance and horizontal alignment at rural two-lane highways. The follower density (number of follower vehicles per a kilometer) is used as a measure of performance in this study. Recently, the follower density is proved to be a useful measure of performance at two-lane highways in several studies (3), (8), and (9). On the other hand, the horizontal alignment is investigated in terms of tangent length and curve radius. The relationships between the follower density and the horizontal curve parameters, as well as between the follower density and average speeds at the mid-tangent and mid-curve points over 9 different sites are carried out.

LITERATURE REVIEW

Highway Capacity Manual Concept for Evaluating Traffic Performance of Two-Lane Highways

The Highway Capacity Manual (HCM) published by the Transportation Research Board (TRB) presents the widely accepted standards for analysis of two-lane highway capacity and quality of service. The first edition of the HCM was published in 1950 and included an analytical procedure for capacity analysis on two-lane highways (4). Practical capacity was used to account for operating conditions or “quality of service” on two-lane highways. It is defined as maximum traffic volume under prevailing conditions without traffic conditions becoming “unreasonable”. Operating speed was used as a performance measure for practical capacity.

The second edition of the HCM was published in 1965 (5). It provided more flexibility than the 1950 HCM edition by introducing the well known six levels of service (LOS), A to F, and corresponding service volumes, with level of service E corresponding to capacity conditions. It used operating speed and volume-to-capacity ratio as performance measures in determining LOS on two-lane highways.

In 1985 Highway Capacity Manual, level of service on two-lane highways is described by three parameters: average travel speed, percentage of time delayed and capacity use (6). The percentage of time delayed (PTD) measure, the primary measure of service, was defined as "the average percent of time that all vehicles are delayed while traveling in platoons due to inability to pass". Vehicles are considered delayed when they travel following a platoon leader at speeds less than their desired speeds. The 1985 HCM procedures suggested the use of percent of vehicles with headways less than five seconds as a good estimate of the PTD in the field.

The current edition of the Highway capacity manual, HCM 2000, continued the use of the PTD concept with slight modifications. The name of the measure was changed to percent time spent- following (PTSF) as it better describes the platooning effect and lack of passing opportunities on two-lane highways (1). Also, the 5 seconds criterion for percent following from the 1985 HCM was changed to 3 seconds for the HCM2000.

Other Proposed Concepts

Some of the studies that proposed or reported the use of performance measures on two-lane highways other than those used by the HCM are presented below.

Morrall and Werner (2) suggested the use of overtaking ratio, which is obtained by dividing the number of passings achieved by the number of passings desired, as a supplementary indicator of level of service on two-lane highways. The number of passings achieved is the total number of passings for a given two-lane highway, while the number of passings desired is the total number of passings for a two-lane highway with continuous passing lanes and similar vertical and horizontal geometry.

In Germeny, Brilon and Weiser (7) reported that the PTSF has never been considered as a substantial measure of effectiveness in Germany as larger values for PTSF do not directly express the degree of efficiency of traffic operation. They added that the average travel speed over longer stretch of the highway of passenger cars has been used in Germany as the preferred MOE, averaged over both directions.

In South Africa, Van As (3) investigated the use of other measures of performance on two-lane highways as part of developing new analytical procedures and a simulation model for two-lane highways. The study found follower density (number of followers per kilometer) a promising measure of performance on two-lane highways. It is the first study to use such performance measure, follower density. Other performance measures considered by the same study include follower flow (followers per hour), percent followers, and percent speed reduction due to traffic, total queuing delay, and traffic density.

In Japan, Catbagan and Nakamura (8) conducted a study to analyze and compare possible performance measures that describe the traffic operational characteristics of two-lane expressways, including follower density. It was found that follower density showed much promise strong relationships with flow rate, using off-peak data. Follower density should be strongly considered as the main performance measure in determining two-lane expressway LOS. The authors recommended further observations of follower flow to be done during congested or near-congested flow to establish follower density and volume relationships for all traffic conditions.

Al-Kaisy and Karjala (9) investigated six performance indicators on two-lane rural highways. The indicators are: average travel speed, average travel speed of passenger cars, average travel speed as a percent of free-flow speed, average travel speed of passenger cars as a percent of free-flow speed of passenger cars, percent followers, and follower density. The study examined the level of association between the selected performance indicators and major platooning variables, namely; traffic flow in the direction of travel, opposing traffic flow, percent heavy vehicles, standard deviation of free-flow speeds, and percent no-passing zones. Among all platooning variables investigated, traffic flow in the direction of travel was found to have the highest correlation with performance indicators. The study also found that follower density followed by percent followers were shown to have the strongest correlations with platooning variables. The follower density measure has exhibited the highest correlation with platooning variables, accounts for traffic level, and is easier to estimate in the field compared with the current HCM performance measure, the PTSF.

The only study that attempted to analyze the impacts of horizontal curve features on traffic performance was conducted by Reinfurt et al. (10). This study tackled the speed changes and vehicle encroachments over the centerline and edgeline as operational variables. They found that, as curves become sharper, there is a proportionally greater increase in speed reduction and edgeline encroachments on the inside lane (i.e., the lane on a curve where the motorist must steer to the right). Centerline encroachments in the outside lane increase more drastically than those on the sharper curves to the right. The study findings support the debate of drivers cutting the curve short, which can result in run-off-road crashes on the inside of the curve as well as head-on and opposite-direction-sideswipe crashes with oncoming motorists.

In summary, previous work has shown that achieving high quality traffic performance of two-lane highways is a very important target due to their unique characteristics. However, most of theses studies conclude that the current HCM performance measure, PTSF, could not be appropriate. Other measures were recommended by many authors in many countries. Follower density is one of the highly recommended performance measures for two-lane highways. So far, it seems that, no research has been done to explore the interaction between traffic performance measures and horizontal alignment characteristics.

STUDY SITES AND DATA COLLECTION

This paper used road sections from two counties (County Durham and Northumberland) in the North-East of England. The road sections were located in rural two-lane highways (rural single carriageways) with a speed limit of 60 mph (97km/h). A total number of 9 horizontal curves with various geometric characteristics (i.e. curve radius, length), were chosen for this study. The curve radii for the chosen curves were ranged from 175 to 750m. All of the chosen curves were connected with relatively long tangents, ranged from 200 to 2325m. Also, all of the chosen sites are located on relatively level terrain to minimize or avoid the effect of the longitudinal gradient.

Automatic roadside traffic counters made and supplied by MetroCount Company (11) were used to collect the traffic data used in this study. The counters are placed for at least 24 hours at two positions at the nine sites. In each site, the traffic data were collected at the midpoint of the tangent (point A) and the midpoint of the succeeding horizontal curve (point B), as in Figure 1. The collected data include traffic count, speed, vehicle type, headway time at each direction of travel. Then the traffic count of 5 minutes time interval and the corresponding average speed and headway times were obtained at the 18 points. The 5-minute traffic count was converted to one hour flow rate to be used in the analysis.

THE USED TRAFFIC PERFORMANCE MEASURE

Percentage of followers

The follower density is herein used as a traffic measure of performance of the two-lane highways. The follower density is defined as the number of follower vehicles per kilometer. The follower vehicle is recognized based on the definition presented in HCM-2000 of that "the follower vehicle as the vehicle in the traffic stream with time headway less than three seconds" (1). Accordingly, the observed number of headways less than three seconds at each time interval (i.e., 5 minutes) was obtained from the collected data and then the percentage of followers was calculated, as follows:

Percentage of followers(K) = number of observed headway less than three second at each 5 minutes / the total observed number of headways at the same time interval . . . . (1)

In the absence of traffic interruptions, the percentage of short headways in the traffic stream is mainly a function of traffic flow level and speed variation, as both influence headway distribution. As flow increases, so does the number of short headways; and consequently the percent followers. Also, as speed variation increases, the percent followers increase. The main drawback of using percent followers as a sole performance indicator is that it does not accurately reflect the effect of traffic level, which is an important performance criterion in the HCM quality of service concept. Theoretically, low traffic levels could still have high percent followers if speed variation is relatively high and passing opportunities are limited. Therefore, the use of percent followers alone could be misleading, particularly for decision making in regards to highway improvements and upgrades. Thus, the follower density is here used as discussed below.

Follower density

Follower density is the number of followers in a directional traffic stream over a unit length, typically one kilometer or one mile. The first use of this measure in South Africa was reported by Van As as part of developing national two-lane highway procedures (8).

To calculate the follower density, the ordinary traffic density should be firstly obtained. The ordinary traffic density is defined as "the number of vehicles occupying a given length of highway, usually taken one kilometer". In this study the density was calculated from the fundamental traffic flow relationship as follows:

Density (D) = flow rate (Q) / average speed (V) . . . . (2)

Then the follower density can be calculated as follows:

Follower density (FD) = density (D) × percentage of followers (K) . . . . (3)

The argument behind using the follower density performance indicator is that a road with low average daily traffic (ADT) and high PTSF should have a lower LOS than the same road with a higher ADT and equal PTSF (8).This is particularly true in the context of highway improvement decision making. The main advantage of using this performance indicator is that, unlike percent followers, it takes into account the effect of traffic level on performance. While density is difficult to directly measure in the field, it can be estimated at point locations from percent occupancy or from volume and speed measurements using outputs from permanent or temporary traffic detectors.

FUNDAMENTAL RELATIONSHIPS BETWEEN TRAFFIC FLOW PARAMTERS AND FOLLOWER DENSITY

Figure 2 presents an example of the main relationships of traffic flow parameters at one of the mid-tangent points, as an example. It shows that both of the percentage of follower and the follower density increase with the increase of the flow rate. In addition, the shape of the scatter plots proves that follower density is more correlated to the flow rate than the percentage of followers.

RELATIONSHIPS BETWEEN FOLLOWER DENSITY AND HORIZONTAL ALIGNMENT

A Comparison of the Observed Average Speed and Follower Density between Tangent and Curve Mid-Points at Different Sites

Figure 3(a-d) presents the relationship between average speed, at mid-tangent and mid-curve points, and traffic performance expressed in follower density for four sites. In Figure 3(a) where curve radius equals 175m and tangent length equals 200m, it can be noticed that there is a considerable difference between the two average speeds at the same follower density since the difference is about 23.5 km/h. For curve radius with 250m and tangent length with 1800m, as in Figure 3(b), the difference in average speeds was decreased to about 13.4 km/h. In the curve with 400m radius connected with 930m tangent, the difference is dropped to about 8.0 km/h, as in Figure 3(c). In the case of Figure 3(d) where radius equals 750m and tangent length equals 2325, the difference in average speeds is almost zero at the same follower density. These findings showed that traffic performance tends to increase its effectiveness (decreasing speed reduction value) when curve radius increases.

A Comparison of the Observed Flow Rate and Follower Density between Mid-Tangent and Mid-Curve Points at Different Sites

Figure 4(a-d) presents the relationships of traffic flow rate against follower density at the two surveyed points, mid-tangent and mid-curve, for four sites. Polynomial curves with 2nd order degree were used to look into the trend of the resulting scatter plots. The coefficients of determination (R^2), for the fitted curves, were ranged from 0.73 to 0.88. It was noticed that, as in Figure 4, the two fitted curves, for mid-tangent and mid-curve, are going to be close to each other as the radius of the horizontal curve increases. This means that the relationships between the traffic flow rate and follower density at horizontal curves and tangents are different, under the same traffic conditions, at low curve radii. These relationships are going to be similar in the case of flatter horizontal curves. In other words, the traffic performance level is enhanced when the curve radius increases. One of the important finding here is that a radius value falling between 400 and 450m could be considered as a threshold between the significant and non-significant impact of horizontal curve on the traffic performance.

IMPACT OF TANGENT LENGTH ON TRAFFIC PERFORMANCE

The tangent length is the straight segment between the start point of the studied curve and the end point of the previous one. Figure 5 shows the relationship of the flow rate with the follower density at mid-tangent point for five different sites. Liner regression was used to investigate the trend of the resulting scatter plot at each site. It can be recognized that the follower density decreases as the tangent length increases, at the same flow rate. This finding demonstrates that longer tangents assist drivers to be non-follower and therefore to achieve their desired speed.

IMPACT OF CURVE RADIUS ON TRAFFIC PERFORMACNE

a) Relationship with flow rate

Figure 6 shows the relationship of flow rate with follower density, at mid-curve point at curves with different radii. Several regression lines were created to fit the scatter plots, for each curve radius. It was found that the follower density increases as the curve radius decreases, at the same flow rate (i.e. the flatter the curve the higher the traffic performance).

b) Relationship with average speed

Figure 7 shows the relationship of follower density with average speed at mid-curve point at curves with different radii. No clear lines or curves were found to represent the trend of the scatter plots. However, it is clear to observe that the pal of the scattering points shifts to the left with the decrease of the curve radius. This means that the drivers tend to decrease their speeds as radius decreases. In such situations, platoons possibly will be formed due to inability of drivers to achieve their desired speed, or to pass vehicles ahead. Consequently the follower density will increase and the traffic performance will decrease.

CONCLUSIONS

The main objective of this paper is to study the impact of the horizontal alignment of rural two-lane highways on the traffic performance. This could be of massive significance to highway planners and designers as they can use the results to make effective operational improvements on such highways. The paper used the follower density as a performance measure, as pervious studies confirmed that it is a promising measure of effectiveness (MOE), for two-lane highways.

Analysis showed that the follower density increases as the curve radius decreases, at the same flow rate. Also, it was found that that the follower density decreases as the tangent length increases, at the same flow rate**.** Further analysis looked at the differences between the follower density on the curves and adjoining tangents. A threshold value of the horizontal curve radius falling between 400 and 450m seems to be a critical value from the traffic performance point of view, since the follower density is significantly affected by curve radius less than 400m and no significant impact was found for curves with radius bigger than 450m. However, it is recommended to investigate this issue using more data at more number of sites during congested and non-congested flow conditions.

The results presented here confirmed that horizontal alignment, expressed in terms of curve radius and tangent length, has a significant impact on the traffic performance, expressed in terms of flower density, of rural two-lane highways.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the Northumberland and Durham County Councils, and Newcastle University, in the UK, for their assistance with the acquisition of traffic count data. They greatly appreciate the help of Mr. Roger Bird, the senior lecturer of Highway Engineering at Newcastle University. They also acknowledge the assistance of MetroCount for the loan of traffic counters. (N.B. Some of this data was used before in other studies).

REFERENCES

1. Transportation Research Board (TRB). Highway Capacity Manual, Transportation Research Board, National Research Council, Washington, D.C., 2000.
2. Morrall, J. F. and A. Werner. Measuring Level of Service of Two-Lane Highways by Overtaking. In Transportation Research Record 1287, Washington D.C., 1990, pp. 62-69.
3. Van As, C. The Development of an Analysis Method for the Determination of Level of Service of Two-lane Undivided Highways in South Africa (Project Summary). South African National Roads Agency Limited (SANRAL), South Africa, 2004.
4. Highway Research Board (HRB). Highway Capacity Manual: Practical Applications for Research. Department of Traffic and Operations, Committee on Highway Capacity, United States Government Printing Office. Washington, D.C., 1950.
5. Highway Research Board (HRB). Special Report 87, Highway Capacity Manual. Department of Traffic and Operations, Committee on Highway Capacity, National Research Council, Washington, D.C., 1965.
6. Transportation Research Board (TRB). Special Report 209, Highway Capacity Manual. Third Edition. TRB, National Research Council, Washington, D.C., 1985.
7. Brilon, W. and F. Weiser. Two-Lane Rural Highways: The German Experience. In Transportation Research Record 1988, TRB, National Research Council, Washington, D.C., 2006, pp. 38-47.
8. Catbagan, J. L. and H. Nakamura. Evaluation of Performance Measures for Two-Lane Expressways in Japan. In Transportation Research Record 1988, TRB, National Research Council, Washington, D.C., 2006, pp. 111-118.
9. Al-Kaisy, A. and S. Karjala. Indicators of Performance on Two-Lane Rural Highways: In Transportation Research Record 2071, TRB, National Research Council, Washington, D.C., 2008, pp. 87-97.
10. Reinfurt, D. W., C.V. Zegeer, B. J. Shelton, T.R. Neuman. Analysis of Vehicle Operations on Horizontal Curves. In Transportation Research Record 1318, TRB, National Research Council, Washington, D.C., 1991, pp. 43-50.
11. MetroCount. (2002). "MetroCount Traffic Executive User Manual."

LIST OF FIGURES

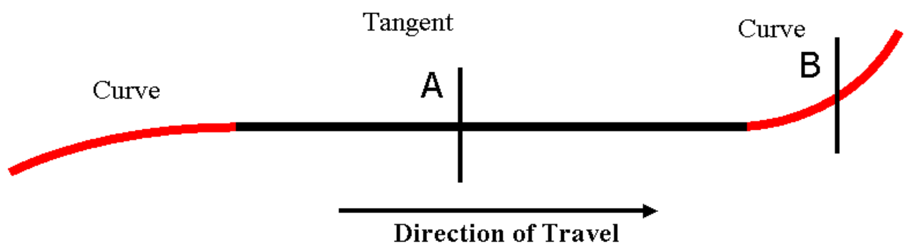
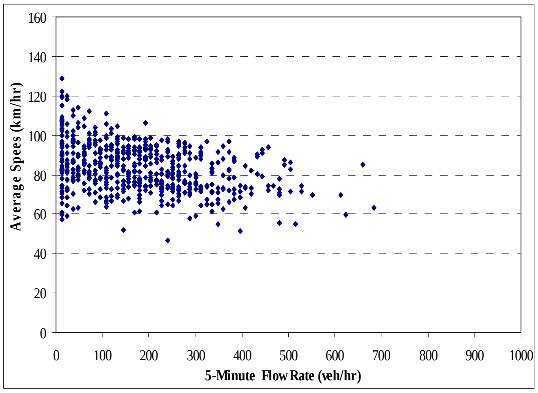
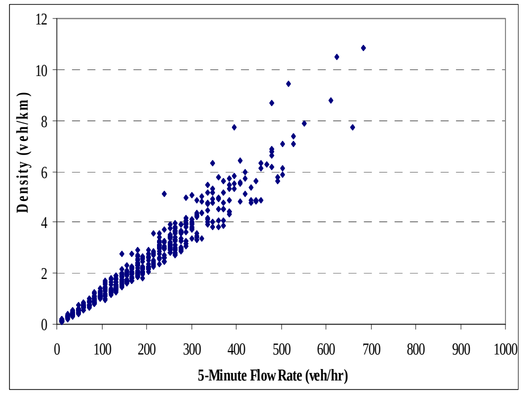


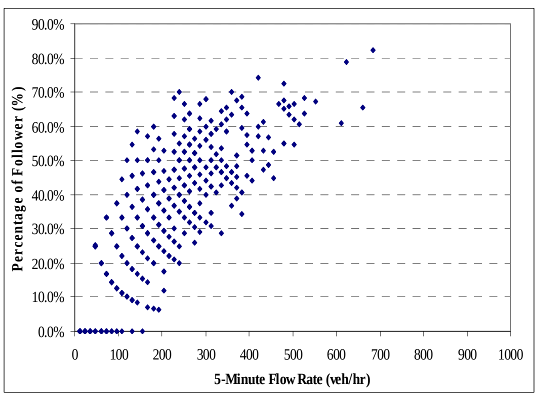
FIGURE 1: Positions of the Automatic Traffic Counters



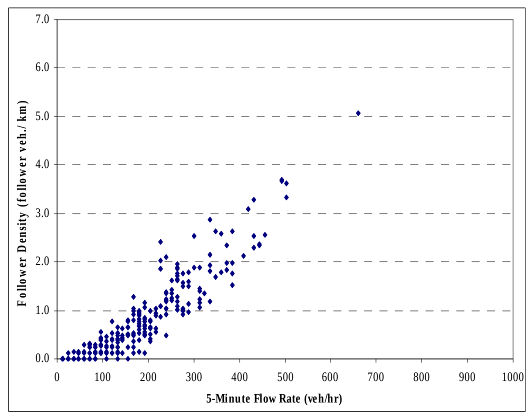
(a): Flow rate against average speed



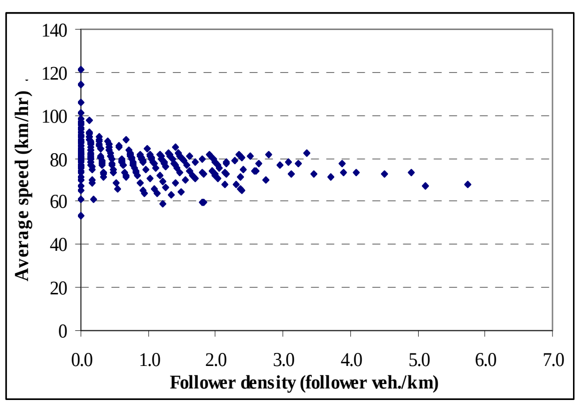
(b): Flow rate against traffic density



(c): Flow rate against percentage of follower

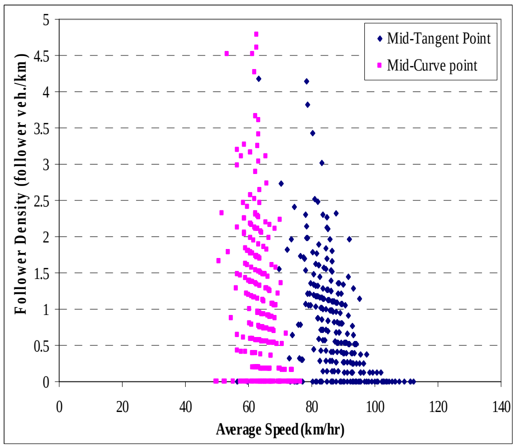


(d): Flow rate against follower density

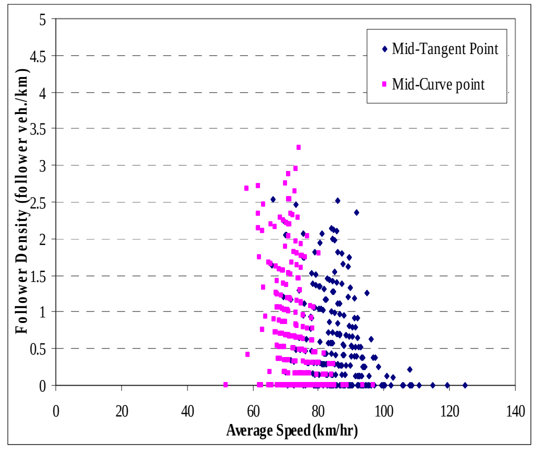


(e): Average speed against follower density

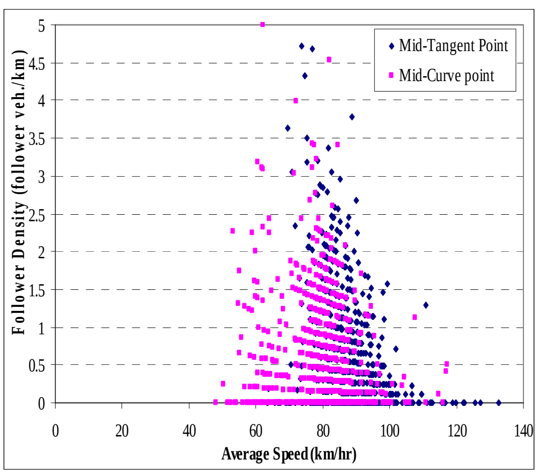
FIGURE 2: Traffic Flow Relationships at Mid-Tangent Point at One of the Surveyed Sites



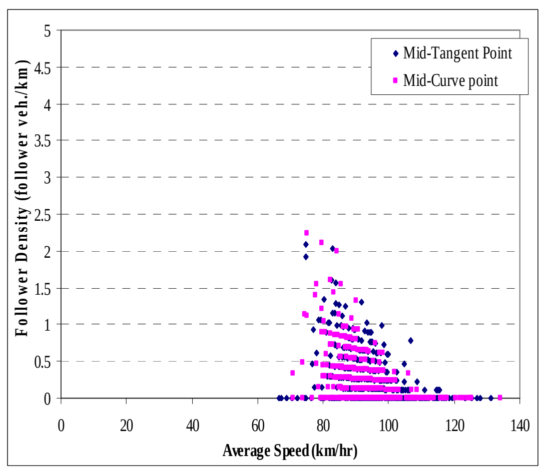
a) R= 175m and TL = 200m



b) R =250m and TL =1800m



c) R= 400m and TL= 930m



d) R =750m and TL = 2325m

FIGURE 3: Follower Density and Average Speed Relationships

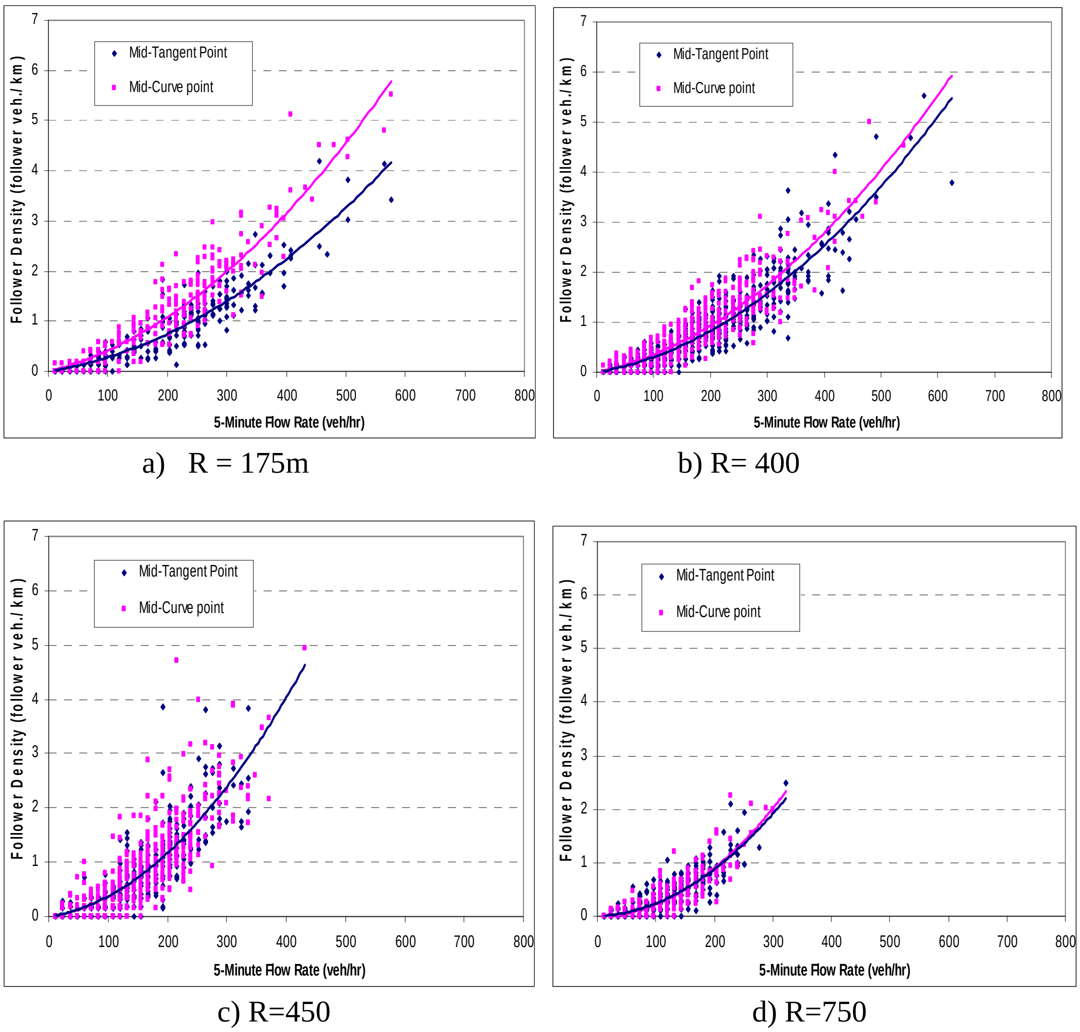


FIGURE 4: Follower Density and 5-minute Flow Rate Relationships at Mid-Tangent and Mid-Curve Points at Different Sites with Different Radii (R)

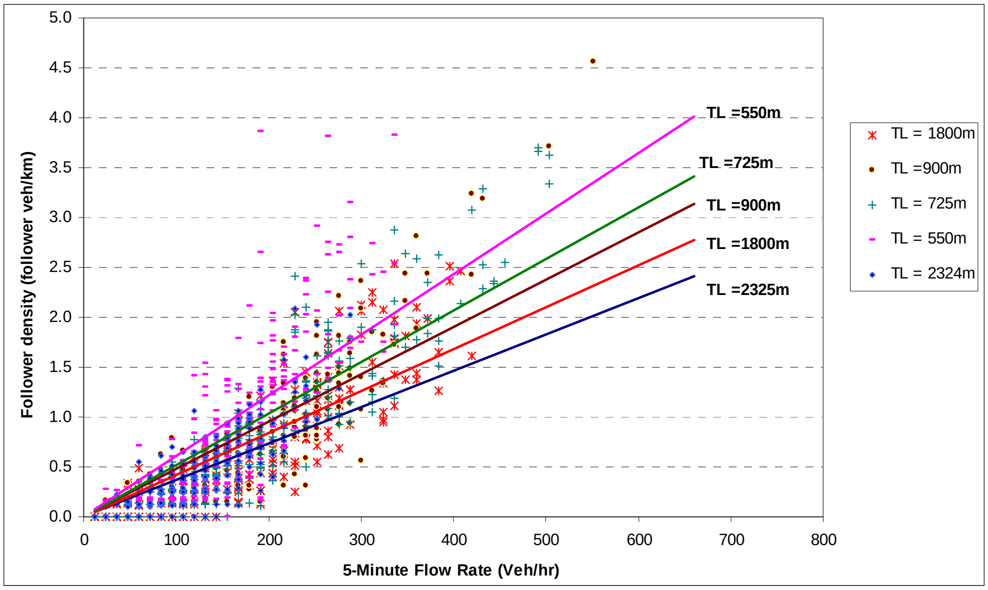


FIGURE 5: Follower Density and 5-minute Flow Rate Relationship at Mid-tangent point at Sites with Different Tangent Lengths (TL)

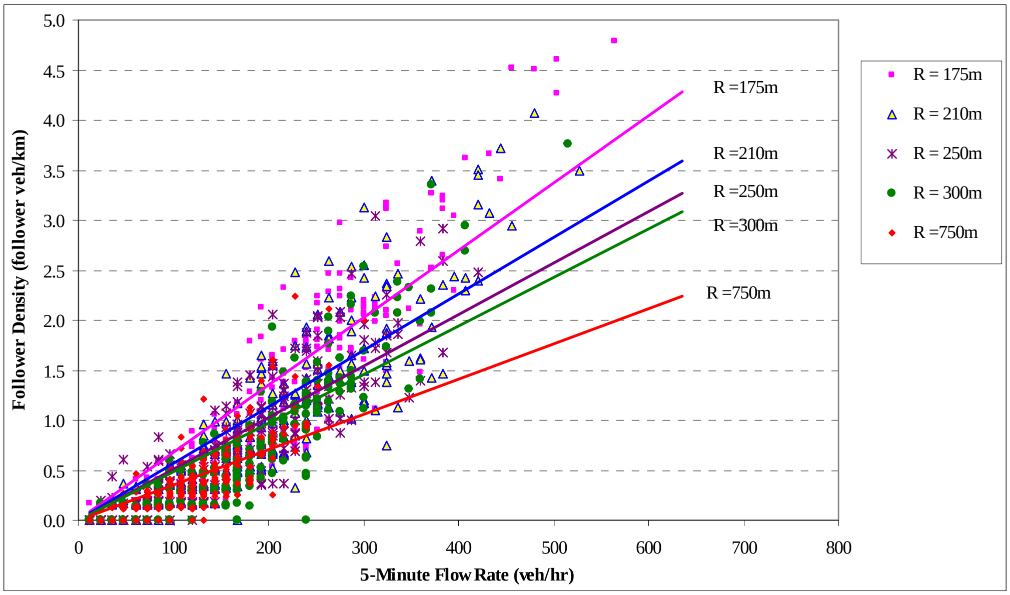


FIGURE 6: Follower Density and 5-minute Flow Rate Relationship at Mid-curve Point at Different Sites with Different Radii (R)

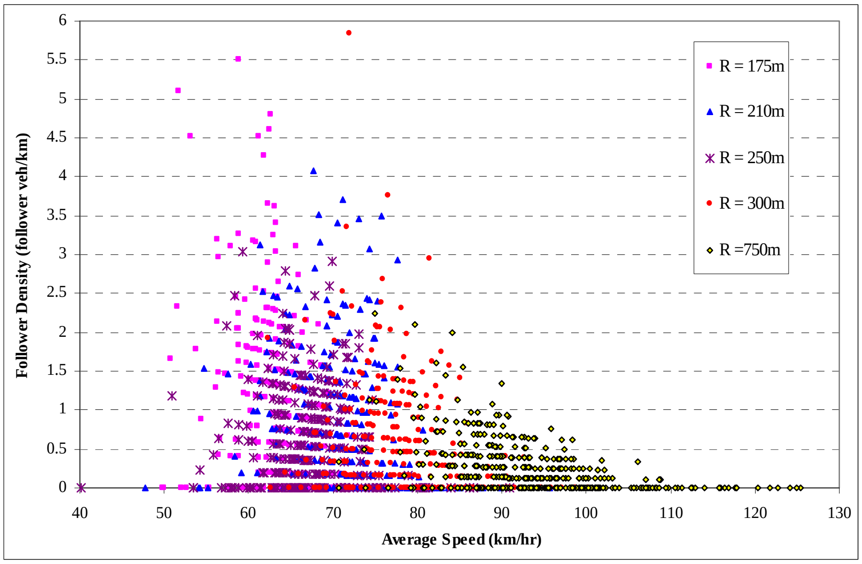


FIGURE 7: Follower Density and Average Speed Relationship at Mid-Curve Point at Different Sites with Different Radii (R)