TRAFFIC PERFORMANCE MEASURES ON TWO-WAY TWO-LANE RURAL HIGHWAYS

Abstract

The most appropriate service measure for a two-lane highway is the combination of average travel speed (ATS) and percent time spent following (PTSF). The local driver behavior and traffic operation characteristics in different countries affect the operational analysis results. The objective of this study is to evaluate the applicability of the HCM procedures on two-lane highways in Iraq. Ten highway segments in northern Iraq were selected and more than 28,000 vehicles were observed to record traffic characteristics.

The results show that for low flow rates, the HCM-2000 procedures tend to overestimate the ATS with an amount of $0.0085V_P$, while for moderate-to-high flow rates, the HCM procedures tend to underestimate ATS with an amount of $0.0025V_P$ for the considered highways. Moreover, the HCM procedures tend to overestimate PTSF. ATS decreases as PTSF, density, and follower density increase. Equations are developed for the evaluation of traffic performance on two-lane highways in Iraq.

Keywords: *average travel speed, time spent following, traffic performance, two-lane highway.*

1 Introduction

Percent time spent following (PTSF) is defined as "the average percentage of travel time that vehicles on a given roadway segment must travel in platoons behind slower vehicles due to inability to pass during some designated time interval" (Transportation Research Board, 2000). PTSF stands for maneuverability, as well as the comfort and convenience of traveling on a two-lane highway, both of which are crucial elements of the Level of Service (LOS) concept. While PTSF is difficult to measure in the field, it can be estimated as the proportion of vehicles traveling at a 3 second or less headway at a representative point (Harwood, et al., 1999; Transportation Research Board, 2000). The average travel speed (ATS) is the other component of the combined service measure. It is defined as "the length of the roadway segment under consideration divided by the average travel time for all vehicles for both directions to traverse that segment during some designated time interval" (Harwood, et al., 1999; Transportation Research Board, 2000).

2 Background

2.1 Speed-Flow Relationship

The HCM-1985 (Transportation Research Board, 1985) describes the reduction in speed as a function of the two-way volume. The curve is concave with a steeper reduction at lower volumes, but more level at higher traffic volume. HCM-2000 (Transportation Research Board, 2000) assumes that speed and flow rate are linearly proportioned:

$$ATS = FFS - 0.0125V_p - f_{np} \quad (1)$$

where;
ATS: average travel speed for both directions (km/h);
FFS: free flow speed (km/h);

f_{np}: adjustment for percentage of no-passing zone; and
V_p: passenger car equivalent flow rate (pc/h).

The shared road space nature of two-lane flow has been disguised in the capacity manuals by expressing the two-lane traffic stream models in terms of total flow rather than stream directional flow (McLean, 1989). Walker (1957) suggested that there is a linear relationship between flow and speed in the stable zone up to maximum flow.

For Australian studies, Casey and Tindall (1966) analyzed their speed-flow data in terms of directional flow. They found that primary flow had a greater effect on primary direction mean speed than did opposing flow.

As an example, for developing countries, comprehensive speed-flow data were collected as a part of the Road User Cost Study in India. Regression analysis for the data in a two-lane road in level terrain is expressed in (Central Road Research Institute, 1982):

$$V = 59.4 - 0.0105Q_T \tag{2}$$

where;
V: speed of vehicle (km/h); and
Q_T: observed flow (pc/h), $Q_T \leq 2500$ pc/h.

The impacts of mixed traffic on the capacity of two-way two-lane highways were investigated by Roy et al. (2017). Field data were collected from three different regions in India. They show that slower vehicles are responsible for forming the platoons, so if the percentage of slower vehicles increases, highway capacity will be decreased.

A study was undertaken to collect information on agency encounters with efficiency assessment on two-lane highways as part of a project funded by the National Cooperative Highway Research Program to improve the operational analysis methodology of a two-lane highway (Al-Kaisy et al., 2018). Agencies recognized that ATS is the most important feature of traffic control in two-lane highway operations.

2.2 Percent Time Speed Following-Flow Relationship

For two-way segments, the PTSF-flow relationship in HCM-2000 (Transportation Research Board, 2000) is an exponential function. The model that best fits the data for two-lane is:

$$PTSF = 100[1 - e^{-0.000879V_p}] \tag{3}$$

The percent time delay-flow relationship used in the 1985 edition of the HCM is virtually identical to this model for two-way segments.

Luttinen (2001a) investigated the PTSF on two-lane rural roads in Finland. Traffic flow data have been collected from 20 locations. He developed a model to predict PTSF based on the flow rate in the main and opposing directions. The final PTSF evaluation is:

$$PTSF = 1 - exp\,(-0.000572\,Q - 0.003203\sqrt{Q}) \tag{4}$$

where; Q is the flow rate in both directions pc/h, Q ≤ 3200 pc/h.

Luttinen concluded that the PTSF on the Finnish two-lane highway is lower than the PTSF predicted using the HCM-2000 approach.

Leong et al. (2019), recorded traffic flow at thirty-two sites in different states in Malaysia using a closed-circuit television and video camera. They used headway threshold values of 3.0 and 5.0 seconds to estimate PTSF in the field and developed six different PTSF models. Analysis indicates that the best model was formulated based on the headway value of 5 seconds with the implying of the percentage of no passing zone and opposing traffic flow rate.

Ibrahim et al. (2019) collected data from eighteen two-lane highway segments in Pahang and Johor States in Malaysia. Estimation from this oncoming was compared. They concluded that PTSF obtained from spot measurements do not differ significantly from those derived from a spatial approach.

Mathew et al. (2020) measured PTSF on two-lane highways of Himachal in India. They found that as volume increases, the difference in range of PTSF increases. The PTSF range measured is lower than that defined in the HCM.

2.3 Density and Follower Density

Density is "the number of vehicles presents per unit length of roadway lane" (Transportation Research Board, 2000). While follower density is "the number of follower vehicles per kilometer per lane" (Van As, 2004). These measures account for the experience of all users, while other measures may take into account the experience of individual road users and not all of them. Therefore, density and follower density provide a better indication to reflect the impedance experienced by drivers.

However, density was found to be an inadequate service measure for two-lane highways because density is much less equally distributed on a two-lane highway compared to a freeway or multilane highway due to the platoon nature of traffic (Luttinen, 2001b; Van As, 2004). Therefore, the percent time spent following does a far better job reflecting density (Harwood, et al., 1999).

Van As (2004) showed that the most suitable alternative measure is follower density. The advantage of follower density is that it integrates three metrics into one: percentage follower, travel speed, and traffic flow. The benefit of follower density is that it can be used to evaluate traffic operations on all kinds of roads, from two-lane highways to freeways, with a single metric. As a result, Van As suggested that follower density be used as a metric of efficiency.

Jain et al. (2021) used in their study a new performance measure known as density ratio. The average travel speed, percent of free-flow speed, and follower density measures revealed no considerable difference when conceived at similar density ratio ranges.

However; investigations and studies on the characteristics of two-way two-lane in Iraq are very few (Al-Zerjawi; 2020); therefore, this study is considered important.

3 Objective of the Study

The goals of the study are to:

1- Describe a framework of traffic operation on a two-lane highway by evaluation and development of local speed-flow and percent time spent following-flow models.
2- Develop regression models between actual PTSF and PTSF calculated using HCM procedures.
3- Find the relationships of ATS, PTSF, and flow with density and follower density.

4 Data Collection Methodology

The selected two-lane highway segments cover a range of traffic volumes and different topography locations at a level and rolling terrains with sufficient sight distance i.e. there is no obstacle preventing the vision in all the selected segments. A total of 10 field sites in three governorates in northern Iraq- Mosul, Erbil, and Dohuk- were selected in this study. These highways are the main two-lane highways in these governorates connecting major cities.

These segments located in both level and rolling terrain with high to moderate traffic volumes and different percentages of truck volumes with no paved shoulders. Highway segments were avoided in the vicinity of urban development or passes through villages.

Two video cameras were used at the side of the road at each end of the roadway section. Traffic measurements were taken simultaneously at both lanes. Marking was fixed at each end of the section and served as a reference point for measurements. Vehicle license numbers and type together with the time of passage were manually transferred into computer files. The minimum length of the section was 3.0 km as proposed by HCM (Transportation Research Board, 2000). Cameras were hidden from the view of the drivers to avoid any influence on their driving behavior. The record section was focused on the field of the camera and traffic was recorded for at least 3 hours for each site during peak periods on a typical weekday. Average travel speed, flow, density and percentage of trucks could be derived at successive intervals of 15 minutes. Site data collection is shown in Figure (1).

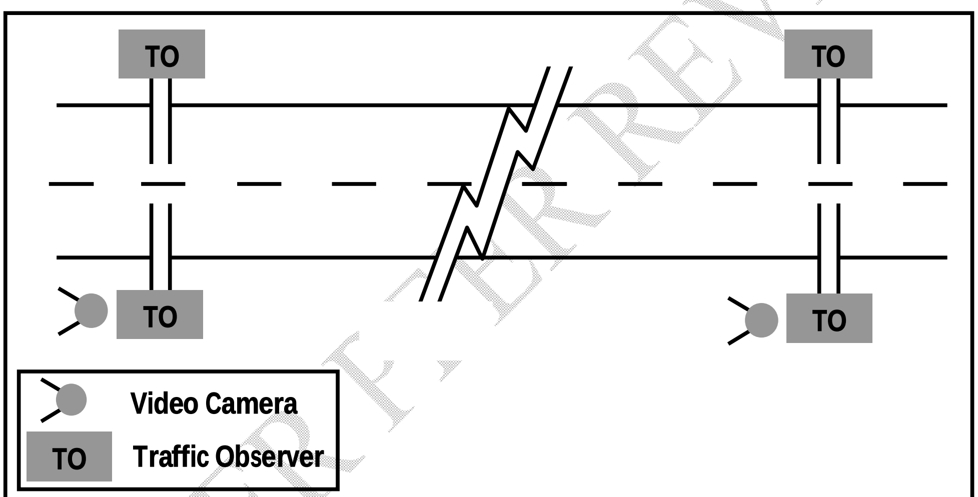


Figure 1. Site data collection for traffic operations

The recorded films were played on a monitor screen to extract the traffic data using Excel software. More than 28,000 vehicles were observed and the traffic characteristics recorded. For each of passage of a vehicle, the following data are extracted as described by Abdul-Mawjoud (2007): vehicle license number, type of vehicle, and arrival and departure time on the section.

The traffic characteristics, vehicle characteristics and operational performance measures are determined directly or indirectly in this study include:

- Flow rate derived for 15-minute intervals.
- Vehicle type i.e. passenger car or truck.
- Travel time and speed which are calculated on the basis of the measured time and distance.
- Percent time-spent-following, as described in Highway Capacity Manual (Transportation Research Board, 2000).

The extracted traffic data from the films were analyzed using SPSS software to develop the regression models. The characteristics for traffic operations on these segments were shown in Table (1).

Table 1. Study site locations and characteristics for traffic operations on two-lane rural highways

Highway	Length of section (km)	Highest 15 min. flow rate (veh/h)		Paved width (m)	Shoulder width (m)	% Truck	Location	Comments
		Highest direction	Two – way					
Mosul - Kirkuk	3.55	504	852	7.8	3.0	20	Start at km 23.5 from Mosul center	Highway in level terrain connects two major cities
Mosul – Bashaka	6.35	860	1276	7.3	2.5	6	Start at km 15.8 from Mosul center	Highway in level terrain arriving to towns and villages of the east Ninevia government
Mosul – Rabiya	3.05	620	856	7.3	2.5	12	Start at km 63 from Mosul center	Highway in level terrain arriving to the west gate border
Mosul – Talafir	3.05	562	830	7.5	2.5	18	Start at km 47.1 from Mosul center	Highway in level terrain arriving to Talafir and Singar regions
Mosul – Sahagy	6.80	604	803	6.6	2.5	14	Start at km 18.3 from Mosul center	Highway in level terrain arriving to towns and villages of the west Ninevia government
Erbil – Kirkuk	3.70	588	1140	7.5	3.0	12	Start at km 10.6 from Erbil center	Highway in level terrain connects two major cities
Erbil – Sulymaniya	4.70	316	580	7.5	2.0	9	Start at km 15.6 from Erbil center	Highway in rolling terrain connects two major cities
Erbil – Salahaldin	5.90	424	672	7.4	2.0	9.5	Start at km 23.8 from Erbil center	Highway in rolling terrain arriving to many regions in Erbil government
Dohuk – Mosul	5.60	504	804	7.3	3.3	28	Start at km 28 from Dohuk center	Highway in level terrain connects two major cities and arriving to the north gate border with high percentages of trucks
Dohuk – Zawita	3.85	1060	1884	7.4	2.5	1.5	Start at km 15.0 from Dohuk center	Highway in rolling terrain and recreational areas with high traffic volume in both direction

5 Analysis and Results

5.1 Speed-Flow Relationship

A concept of free-flow speed was introduced for speed-flow relationships to describe the quality of geometric design for a facility.

The most suitable functional form for speed-flow curves is a straight line (as suggested by HCM 2000) with the y-intercept representing free-flow speed and a negative slope representing the decrease in speed with increasing flow rate. Using SPSS software, regression analyses were first conducted on the data for each free-flow speed to produce models of average travel speed against two-way flow rate. The regression lines had slopes ranging from 0.0103 to 0.0258 (km/h)/(pc/h). These regression relationships had R2 values ranging from 0.71 to 0.89. However, the general form of speed–flow relationships was (Transportation Research Board, 2000):

$$\text{ATS} = \text{FFS} - aV_p \quad (5)$$

where;
ATS: average travel speed for both directions of travel combined (km/h);
FFS: free-flow speed of the vehicle (measured as mentioned in HCM-2000);
VP: passenger-car equivalent flow rate for peak 15-min period (pc/h); and
a: regression parameter.

Table (2) shows the speed-flow regression model parameters for each highway section.

Families of the speed-flow curve for different free-flow speeds were plotted as shown in Figure (1).

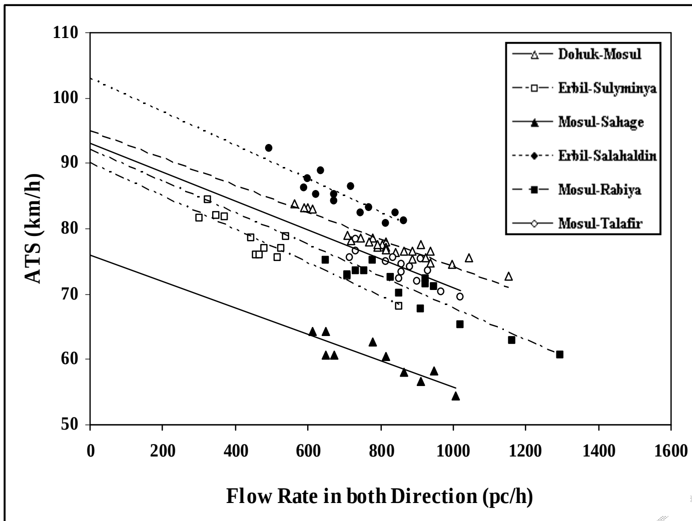
The flow rates in Figure (2-a) were less than 1300 pc/h, while the flow rates in Figure (2-b) exceed 1300 pc/h. The figure shows that the regression coefficient (*a*) for the low flow rate is greater than 0.02, while for moderate to high flow rate the coefficient is less than 0.02 and approaches the value of the HCM-2000 coefficient i.e., 0.0125. Therefore, for highways studied, the regression speed-flow relationships are:

$$ATS = FFS - 0.021V_p,\ R^2 = 0.75\ \ for\ V_p \leq 1300pc/h \quad (6)$$

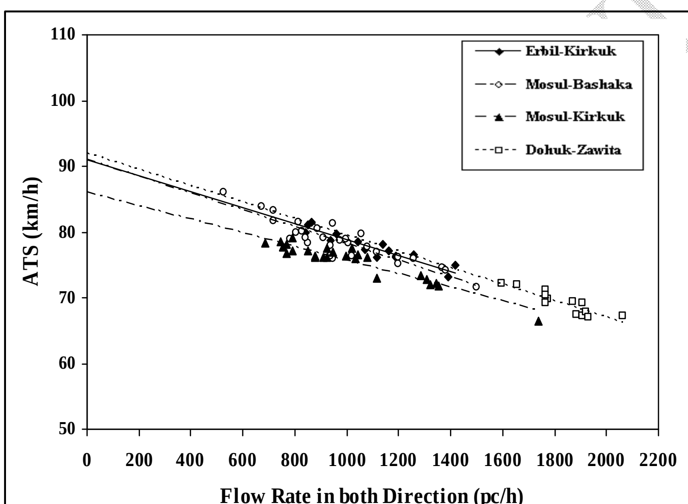
$$ATS = FFS - 0.010V_p,\ R^2 = 0.86\ \ for\ V_p > 1300pc/h \quad (7)$$

Table 2. Speed–flow rate regression parameters

Highway	FFS	a	R^2
Mosul – Kirkuk	86	0.0103	0.89
Mosul – Bashaka	91	0.0127	0.80
Mosul – Rabiya	92	0.0242	0.86
Mosul – Talafir	93	0.0221	0.71
Mosul – Sahage	76	0.0202	0.76
Erbil – Kirkuk	91	0.0150	0.71
Erbil – Sulyminya	90	0.0254	0.87
Erbil – Salahaldin	103	0.0258	0.81
Dohuk – Mosul	95	0.0208	0.79
Dohuk – Zawita	92	0.0124	0.80



(a) Low flow rate



(b) Moderate to high flow rate

Figure 2. Speed-flow relationships

This indicates that the speed-flow relationship appears to behave somewhat differently in the low traffic flow range than in moderate to high ranges. The general form of the developed speed-flow relationship in this study is:

$$ATS = FFS - 0.009V_p,\ R^2 = 0.62 \quad (8)$$

This indicates that the HCM-2000 procedures tend to underestimate ATS for the 10 highways under consideration in Iraq. However, this result coincides with the work carried by Akcelik (2002).

For the directional segment, a comparative analysis was performed including both primary direction and opposing flow rates. Linear regression analyses of average travel speeds in terms of directional flows show the form, Krumins (1981):

$$ATS_d = FFS - aV_d - bV_o \quad (9)$$

where;
ATS_d: average travel speed of vehicles traveling in the primary (highest flow) direction (km/h);
a and b: regression parameters;
V_d: flow rate in primary direction (pc/h); and
V_o: flow rate in opposing direction (pc/h).

The analysis is dependent upon a directional analysis of traffic flow. The results, given for data collection are shown in Table (3). The opposing flow rate does not have a large effect on average travel speeds compared to the flow rate in the primary direction. The final directional average travel speed is:

$$ATS_d = FFS - 0.022V_d - 0.012V_o,\ R^2 = 0.67 \quad (10)$$

Table 3. Speed-directional flow rate regression parameters

Highway	FFS	a	b	R^2
Mosul – Kirkuk	86	0.026	0.018	0.65
Mosul – Bashaka	91	0.026	0.015	0.79
Mosul – Rabiya	92	0.029	0.016	0.71
Mosul – Talafir	93	0.023	0.011	0.72
Mosul – Sahage	76	0.032	0.019	0.62
Erbil – Kirkuk	91	0.021	0.011	0.72
Erbil – Sulyminya	90	0.048	0.028	0.71
Erbil – Salahaldin	103	0.023	0.012	0.85
Dohuk – Mosul	95	0.016	0.005	0.71
Dohuk – Zawita	92	0.024	0.011	0.82

5.2 Percent Time Spent Following (PTSF)-Flow Relationship

An exponential function was shown to be the most suitable functional form to describe the PTSF-flow relationship for two-way segments (HCM-2000).

$$PTSF = 100(1 - e^{aV_p}) \quad (11)$$

Table (4) shows the regression parameter (*a*) for the highways under study with sufficient sight distance.

The following is a regression model for two-way segments that better fits all the measured data:

$$PTSF = 100\left[1 - e^{-0.000564V_p}\right],\ R^2 = 0.78 \quad (12)$$

Table 4. Values of the parameter (*a*) for estimating PTSF

Highway	a	R^2
Mosul – Kirkuk	-0.000634	0.85
Mosul – Bashaka	-0.000599	0.78
Mosul – Rabiya	-0.000580	0.62
Mosul – Talafir	-0.000607	0.73
Mosul – Sahage	-0.000437	0.69
Erbil – Kirkuk	-0.000552	0.76
Erbil – Sulyminya	-0.000678	0.75
Erbil – Salahaldin	-0.000653	0.76
Dohuk – Mosul	-0.000634	0.83
Dohuk – Zawita	-0.000551	0.75

The regression model indicates that the HCM-2000 procedures tend to overestimate PTSF for highways under study in Iraq. However, this result is close to that of Luttinen (2001) for Finnish highways. The plots of the data for all highways under study are presented in Figure (3). The figure shows that for the same directional flow, the PTSF increases with the increase in opposing flow.

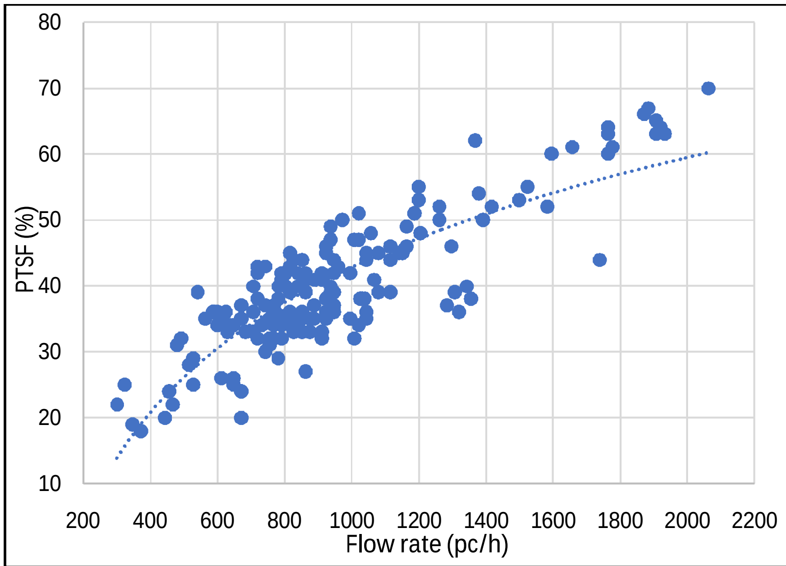


Figure 3. PTSF-flow relationship conducted for the two-way segments

5.2.1 Actual Percent Time Spent Following

Actual PTSF for level terrain is defined as the proportion of vehicles traveling with a headway of less than or equal to 3 seconds with gaps between vehicles in the opposing direction less than the value sufficient for passing say 15 seconds (Polus, et al. (2000)). However, the values of actual PTSF are always less than PTSF calculated as per HCM-2000 (HCM PTSF) which considers the following vehicles have a headway less than or equal to 3 seconds only. The relation between them is as the following equation:

$$actual\ PTSF = a + b(HCM\ PTSF) \quad (13)$$

The values of (*a*) and (*b*) for each highway and all highways are shown in Table (5).

Table 5. Values of parameters used in estimating actual PTSF from HCM PTSF

Highway	a	b	R^2
Mosul – Kirkuk	8.02	0.32	0.63
Mosul – Bashaka	1.64	0.62	0.71
Mosul – Rabiya	8.73	0.37	0.69
Mosul – Talafir	15.13	0.39	0.70
Mosul – Sahage	3.87	0.22	0.61
Erbil – Kirkuk	-7.80	0.86	0.69
Erbil – Sulyminya	1.01	0.28	0.65
Erbil – Salahaldin	0.48	0.44	0.71
Dohuk – Mosul	-1.47	0.59	0.68
Dohuk – Zawita	21.53	0.41	0.65
All highways	-3.52	0.69	0.79

The relation between actual PTSF with directional lane volume (*V*) and opposing percentage headway greater than or equal to 15 seconds ($\%H_{opp.} \geq 15$ sec) is:

$$actual\ PTSF = a + b\,(V) + c\,(\%Hopp. \geq 15\ seconds) \quad (14)$$

The values of the parameters *a*, *b*, and *c* for the highways are shown in Table (6).

Table 6. Values of regression parameters used in estimating actual PTSF from lane volume and opposing headway

Highway	a	b	c	R^2
Mosul – Kirkuk	24.52	0.021	-0.53	0.65
Mosul – Bashaka	14.88	0.059	-0.68	0.71
Mosul – Rabiya	23.77	0.027	-0.51	0.60
Mosul – Talafir	28.50	0.024	-0.61	0.62
Mosul – Sahage	10.90	0.001	-0.07	0.62
Erbil – Kirkuk	36.95	0.007	-0.48	0.60
Erbil – Sulyminya	2.47	0.047	-0.05	0.75
Erbil – Salahaldin	1.65	0.062	-0.10	0.66
Dohuk – Mosul	17.44	0.018	-0.52	0.60
Dohuk – Zawita	33.22	0.020	-0.71	0.63
All highways	16.97	0.037	-0.45	0.71

5.3 Speed-PTSF Relationship

Dohuk-Zawita highway is taken as a sample to find the relationship between speed and PTSF. Equation (15) represents the best-fit equation for the measured data shown in Figure (4):

$$ATS(km/h) = 40.804 + 1.373(PTSF) - 0.0146(PTSF)^2, \; R^2 = 0.82 \qquad (15)$$

Figure (4) shows that there is a reduction in ATS as PTSF increases.

5.4 Relations of ATS, PTSF, and Flow with Density and Follower Density

Relationships between ATS with density and follower density for Dohuk-Zawita highway as a sample is illustrated in equations (16) and (17) and shown in Figure (5):

$$ATS = 76.93 + 0.0129(density) - 0.0429(density)^2, \; R^2 = 0.89 \qquad (16)$$

$$ATS = 76.92 + 0.0.5426(followerdensity) - 0.0425(followerdensity)^2, \; R^2 = 0.89 \qquad (17)$$

Figure (5) shows that ATS decreases as density and follower density increases.

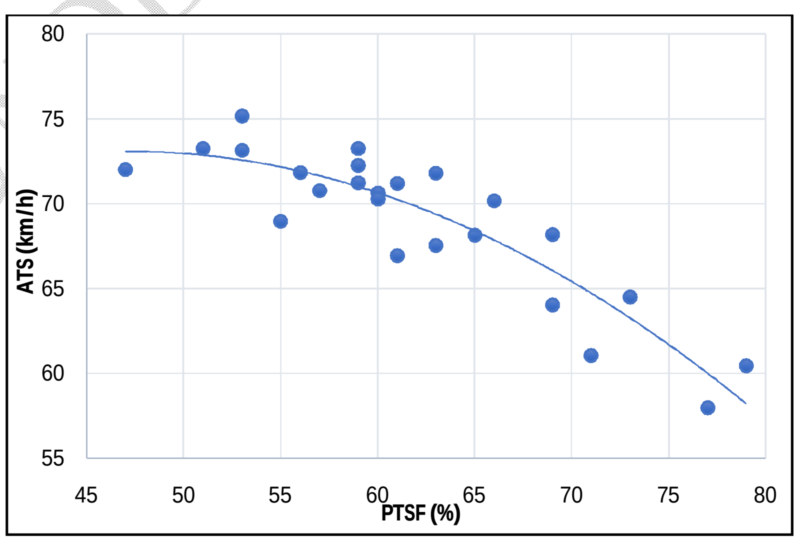
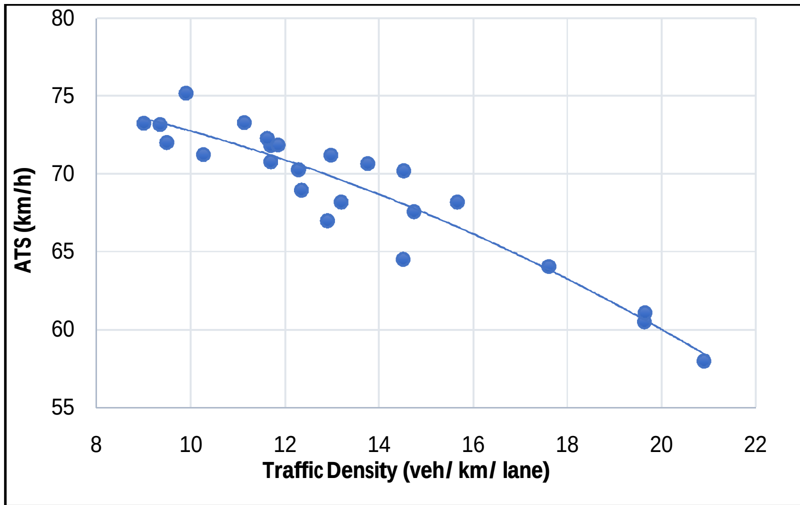
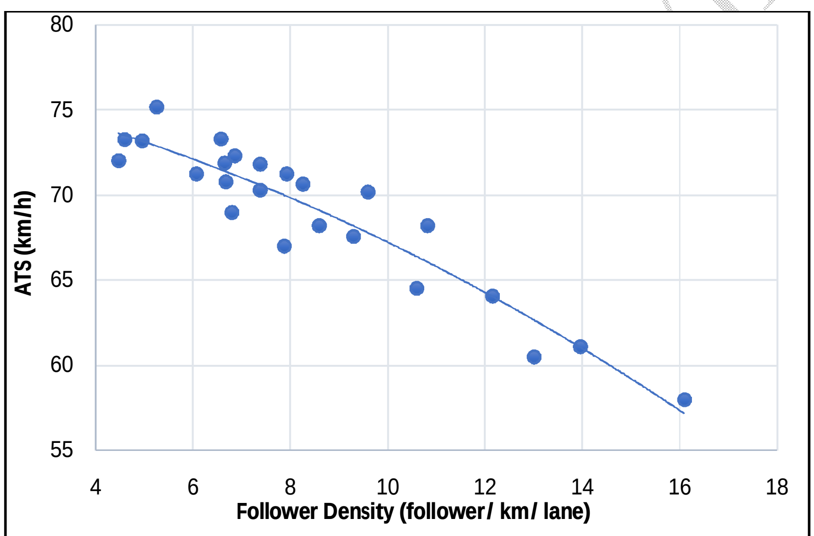


Figure 4. Speed-PTSF relationship for Dohuk–Zawita highway



(a) Speed-density relationship



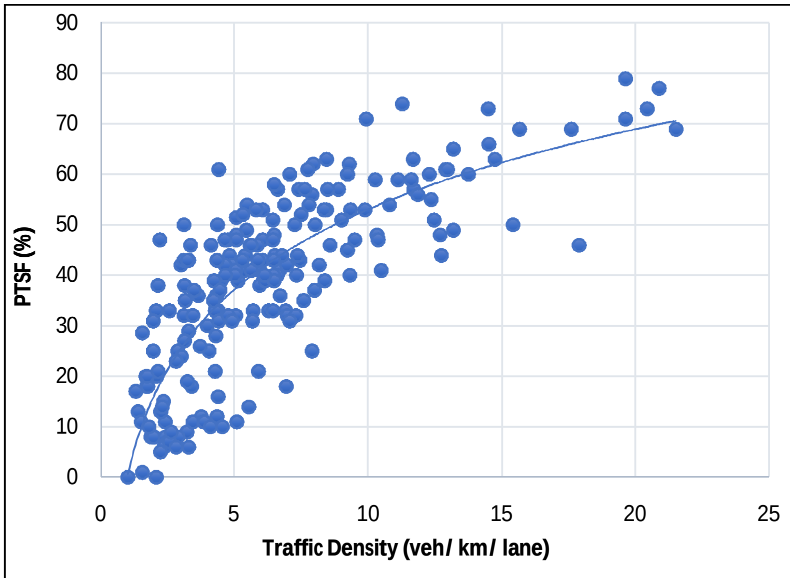
(b) Speed-follower density relationship

Figure 5. Speed-density and speed-follower density relationships for Dohuk-Zawita highway

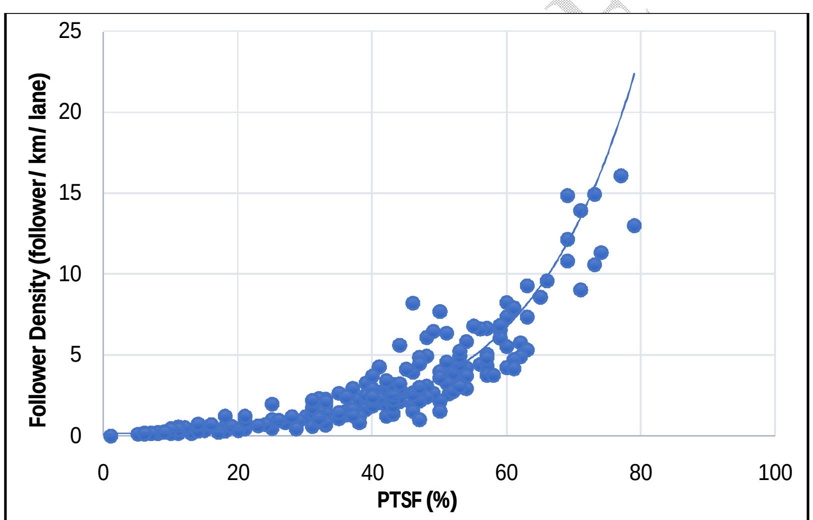
For all highways in this study, the relationships between PTSF with density and follower density are modeled as in the following equations, and shown in Figure (6).

$$PTSF = 0.274 + 22.8912\, ln(density),\ R^2 = 0.64 \tag{18}$$

$$follower\ density = 0.2930e^{0.0511(PTSF)},\ R^2 = 0.86 \tag{19}$$



(a) Traffic density with PTSF



(b) PTSF with follower density

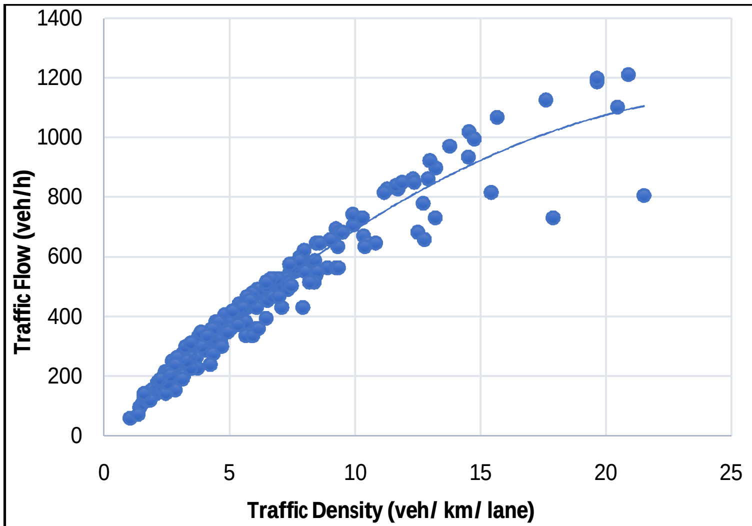
Figure 6. PTSF-density and follower density-PTSF relationships on two-lane highways

Figure (6) shows that both density and follower density increase when PTSF increases. However, the relationships between flow rate with density and follower density are shown in Figure (7) and represented in the following equations:

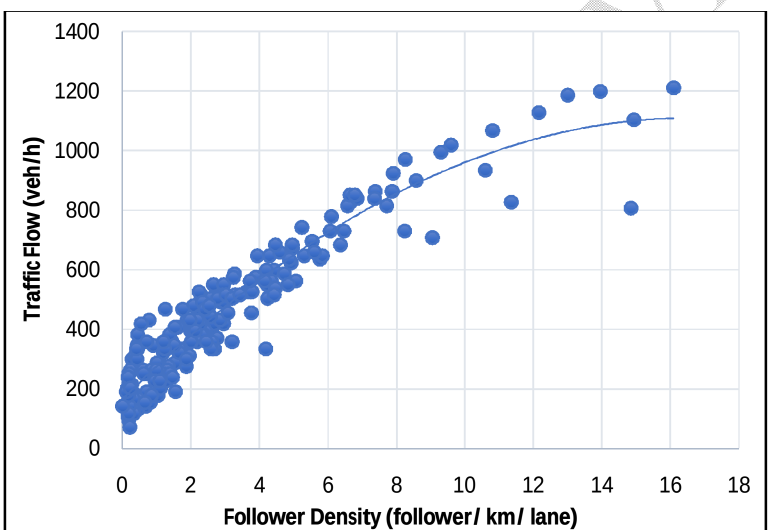
$$traffic\ flow = 83.234(density) - 1.455(density)^2,\ R^2 = 0.95 \quad (20)$$

$$traffic\ flow = 167.338 + 113.564(follower\ density) - 3.419(follower\ density)^2,\ R^2 = 0.90 \quad (21)$$

Figure (7) shows that as the traffic flow increases, density and follower density also increase.



(a) Traffic flow-density



(b) Traffic flow–follower density

Figure 7. Traffic flow with density and follower density relationships on two-lane highways

6 Conclusions and Recommendations

The following are the conclusions drawn from the data analysis, within the constraints of the researched sites:

1. The slopes of the regression lines for the speed-flow rate relationship behave differently, for low flow rate, the HCM-2000 procedures tend to overestimate ATS with the amount of $0.0085V_p$, while, for moderate to high flow rate, the HCM-2000 procedure tends to underestimate ATS with the amount of $0.0025V_p$.
2. For PTSF, HCM-2000 procedures tend to overestimate PTSF for two-lane highways in northern Iraq by about 35%. Moreover, PTSF increases with the rise in the opposing flow rate.

3. ATS decreases as PTSF, density, and follower density increase. PTSF increases with an increase in density and follower density. Density and follower density increase with the rise in traffic flow.
4. It is recommended to study the influence of different percentages of no-passing zones on ATS and PTSF relationships and also find the passing maneuvers at different oncoming gaps which is not considered in this study.

References

Abdul-Mawjoud, A.A., (2007). Development of traffic flow models for two-lane rural highways. *Ph.D. thesis, Department of Highway and Transportation Engineering, College of Engineering,* Al-Mustansiriya University.

Akcelik, R., (2002). Speed-flow models for uninterrupted traffic facilities. Technical report, Akcelik and Associates Pty Ltd, Melbourne, Australia.

Al-Kaisy, A., Jafari, A., Washburn, S., Lutinnen, T., and Dowling, R. (2018). Performance measures on two-lane highways: Survey of practice. Transportation Research Record Journal of the Transportation Research Board.

Al-Zerjawi, A.K., Al-Jameel, H.A., and Zagroot, S.A., (2020). Traffic characteristics of two-way two-lane (TWTL) highway in Iraq: Al-Mishkhab road as a case study. IOP Conf. Series: Materials Science and Engineering 888, 012030.

Casey, P.W. and Tindall, J.I., (1966). The effect of the directional distributions on the capacity of two-lane two-way roads. *Proceeding 3rd Australian Road Research Board Conference,* 3 (1).

Central Road Research Institute, (1982). Road User Cost Study in India, New Delhi: CRRI, India.

Harwood, D.W., May, A.D., Anderson, I.B., Leiman, L., and Archilla, A.R., (1999). Capacity and quality of service of two-lane highways. *Final Report, NCHRP Project 3-55 (3),* Midwest Research Institute.

Ibrahim, M.N., Puan, O.C., and Mustaffar, M., (2019). Measurement of percent time spent following on two-lane highways: An exploration of spot and space-based methodologies, GEOTROPIKA, Materials Science and Engineering 527, IOP Publishing.

Jain, M., Gore,N., Arkatkar., S., and Easa, S., (2021). Developing level of service criteria for two-lane rural roads with grades under mixed traffic conditions. Journal of Transportation Engineering, Part A: Systems/ Volume 147, Issue 5.

Krumins, I.V., (1981). Capacity and Level of Service of Two-Lane Rural Highways in Alberta, Ph.D. Thesis, Department of Civil Engineering, University of Calgary.

Leon, L.V., Shafie, S.A.M., and Goh, W.C., (2019). Percent time spent following model for single carriageway road, Jurnal Teknologi, 81:6, pp. 159-167.

Luttinen, R.T., (2000). Level of service on Finish two-lane highways. Fourth International Symposium on Highway Capacity Proceedings, Transportation Research Circular E-C018, Transportation Research Board, Washington, D.C.

Luttinen, R.T., (2001a). Percent time spent following as a performance measure for two-lane highways. Transportation Research Board, 80th Annual Meeting, Washington, D.C.

Luttinen, R.T. (2001b). Traffic flow on the two-lane highways-An overview. TL Research Report 1/2001, TL Consulting Engineers, Ltd., Lahti.

Mathew T., Joshi G., Velaga N., and Arkatkar S., (2020). A New Model to Evaluate Percent-Time-Spent-Following on Two-Lane Highways. Transportation Research. vol 45, pp 377-387.

McLean, J.R., (1989). Two-lane highway traffic operations -Theory and practice. Gordon and Breach Science Publisher, New York.

Polus, A., Livneh, M. and Frisher, B., (2000). Passing behavior on two-lane rural highways. Transportation Research Record No.1701, Transportation Research Board, Washington, D.C.

Roy, N., Roy, R., Talukdar, H., and Saha, P., (2017). Effect of mixed traffic on the capacity of two-lane Roads: A case study on Indian highways, Procedia Engineering 187, pp. 53 – 58.

Transportation Research Board, (1985). Highway Capacity Manual, National Research Council, (HCM-1985), special report 209, Washington, D.C.

Transportation Research Board, (2000). Highway Capacity Manual, National Research Council, (HCM-2000), Washington, D.C.

Transportation Research Board, (2010). Highway Capacity Manual, National Research Council, (HCM-2010), Washington, D.C.

Underwood, R.T, (1962). Some aspects of the theory of traffic flow. Australian Road Research, Volume 1, No.2.

Van As, C., (2004). The development of an analysis method for the determination of the level of service of two-lane undivided highways in South Africa. Project Summary, South African National Roads Agency Limited.

Walker, W.P., (1957). Speed and travel time measurements in urban areas. Highway Research Board Bulletin, 156.