Modeling Follower Density on Two-Lane Rural Highways

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Introduction

Two-lane highway operations are characterized by passing maneuvers, formation of platoons within the traffic stream, and delay experienced by trailing vehicles while unable to pass lead vehicles. For increased passing demand, passing capacity decreases due to limited passing opportunities. Quality of service becomes unacceptable even for lower volume-to-capacity ratio. Hence, use of volume-to-capacity ratio may not be a good performance measure for two-lane highway analysis.

The HCM 2010 manual uses Percent-Time Spent Following (PTSF), Average Travel Speed (ATS), and Percent Free-flow Speed (PFFS) measures to assess two-lane highways operations. The PTSF measure is difficult to measure in the field. Lack of field validation and difficulty in obtaining PTSF measure in the field led to the development of alternative performance measures for two-lane highway operations. The Oregon Department of Transportation (ODOT) has conducted studies to develop alternative performance measures for two-lane highway analysis[1]. The studies were based on the framework adopted for empirical investigation of two-lane rural highway performance indicators in Montana (*Al-Kaisy and Karjala, 2008*). A preliminary study showed promising measures with limited data. However, the study did not provide any LOS thresholds based on alternative performance measure. Hence, an extension of the study was necessary using expanded datasets.

Objectives

The primary objectives of the study are to:

- Develop and select alternative performance measures for two-lane rural highway analysis
- Refine Level-of-Service(LOS) thresholds based on the selected measure(s)

Study Outline

The study identified performance indicators and platooning variables that influence operations of two-lane highways. Data collection and processing efforts provided required inputs to the model development. After model validation, follower density LOS thresholds were formulated for the identified two-lane highways classes.

Two Lane Highway Classes

The HCM 2010 two-lane highways methodology classified rural highways into three classes. The primary reason to establish the classification was to account for wide range of functionality and driver behavior. The present study also tries to develop models for different classes of rural highways. As per the HCM, arterials are considered to be Class I highways, and most collectors

[1] Modeling Performance Indicators on Two-Lane Rural Highways: The Oregon Experience (ODOT 2010 Study)

and local roads are considered to be Class II. Class III highways are a special case and may be any functional class. Definitions of the three classes are (HCM, 2010):

Class I two-lane highways are highways where motorists expect to travel at relatively high speeds. Two-lane highways that are major intercity routes, primary connectors of major traffic generators, daily commuter routes, or major links in state or national highway networks are generally assigned to Class I. These facilities serve mostly long-distance trips or provide the connections between facilities that serve long-distance trips. Rural Principal Arterials (Functional Class 02 highways) mostly act as Class I highways. Coos Bay-Roseburg Highway-OR 42 (No. 35) is an example of a Class I highway.

Class II two-lane highways are highways where motorists do not necessarily expect to travel at high speeds. Two-lane highways functioning as access routes to Class I facilities, serving as scenic or recreational routes (and not as primary arterials), or passing through rugged terrain (where high-speed operation would be impossible) are assigned to Class II. Class II facilities most often serve relatively short trips, the beginning or ending portions of longer trips, or trips for which sightseeing plays a significant role. Rural Minor Arterials (Functional Class 06 highways) and Rural Major Collectors (Functional Class 07) mostly act as Class II highways. For instance, West Diamond Lake Hwy- OR 230 (No. 233) that connects Crater Lake Hwy (OR 62) and Diamond Lake Hwy (OR 138) primarily serves recreational trips and passes through undeveloped, rugged terrain.

Class III two-lane highways are special cases serving moderately developed areas. They may be portions of a Class I or Class II highway that pass through small towns, unincorporated communities, or developed recreational areas. On such segments, local traffic often mixes with through traffic, and the density of unsignalized roadside access points is noticeably higher than in a purely rural area. Class III highways may also be longer segments passing through more spread-out recreational areas, also with increased roadside densities. Such segments are often accompanied by reduced speed limits that reflect the higher activity level. Any signalized intersections in these areas convert the section to an urban street and this method no longer applies. Some example sections:

- Gearhart to Warrenton section on Oregon Coast Hwy-US 101 (No. 9)
- Detroit city section on N Santiam Hwy-OR 22 (No. 162)
- Richland city section on Baker – Copperfield Highway-OR 86 (No. 12)

The rural US 101 section from Gearhart to Warrenton is a spread-out recreational area with substantial development along the highway. The Detroit and Richland sections of the highways pass through small towns having speed restrictions, significant road side developments and unsignalized access points.

Adopted Performance Measures

The following performance measures were adopted for this study.

- Average travel speed (ATS)

- ATS as a percent of free-flow speed (PFFS),
- Percent followers (PTfollowers), and
- Follower density (FLdensity)

Percent followers represent the percentage of vehicles with short headways in the traffic stream. This performance indicator can easily be measured in the field by using a headway cutoff value of 3.0 seconds as recommended by the HCM 2010 manual. Follower density is the number of followers in a directional traffic stream over a unit length. Follower density measure considers the effect of both traffic level and speed on the performance. Generally, density is difficult to directly measure in the field. But, it can be estimated at point locations from volume and speed measurements using outputs from traffic detectors.

Data Collection & Analysis

Data collection sites were selected based on geographic setting, traffic volumes, and terrain. All sites were located in rural areas on roughly straight segments, and far from the influence of traffic signals and driveways. In total, data is collected at 168 sites by using automatic traffic recorders. Two data sets were collected at each study site, one in each direction of travel.

For each vehicle, data on vehicle class, speed (mph), headway (seconds), percentage of no passing zone, terrain (level, rolling, or mountainous), and functional classification (ODOT highway functional classification; 2= Rural Principal Arterial; 6= Rural Minor Arterial; and 7= Rural Major Collector) was collected. All sites operate as two-lane two-way traffic and traffic data was from year 2009 to 2013.

Data from automatic traffic recorders were processed to measure various performance indicators and platooning variables. For each direction of travel, vehicle counts were aggregated to hourly rates. The percentage of heavy vehicles was found from vehicle classification provided in the recorder output. Free-flow speed was calculated in this analysis by averaging the speed of all vehicles traveling with headways greater than 8.0 seconds (*Al-Kaisy and Karjala, 2008*) . Percent followers were calculated using headways less than 3.0 seconds (*HCM, 2010*). Follower density (veh/mile/lane) is the number of followers (vph) divided by their average travel speed (mph). Similar calculations were performed for each hour at all sites.

Study Methodology

The study segregated highway sections into Class I, II, and III highways based on HCM definition. Rural principal arterial mostly acts as Class I Highways, rural minor arterials and rural major collectors are Class II highways and some portions of Class I and Class II highways are Class III highways. Once the raw data was processed, regression models were developed between performance indicators and other explanatory variables for each class of rural highways. A part of data set was used to validate these models. After the model validation, LOS thresholds were developed.

Model Development

Model development is aimed at examining the level of association between performance indicators on two-lane highways and its major contributory factors. Scattered plot between the performance indicators and platooning variables reveal the trends and patterns existed in the data. As traffic flow and opposing volume increases, follower density increases as shown in Figure 1. Similarly, increase in follower density reduces average travel speed. Geographic distribution of follower density varies by region (Figure 2). Follower density increases as terrain changes from level to mountainous (Figure 3). Follower densities on Class II highways is more than Class I highways (Figure 4).

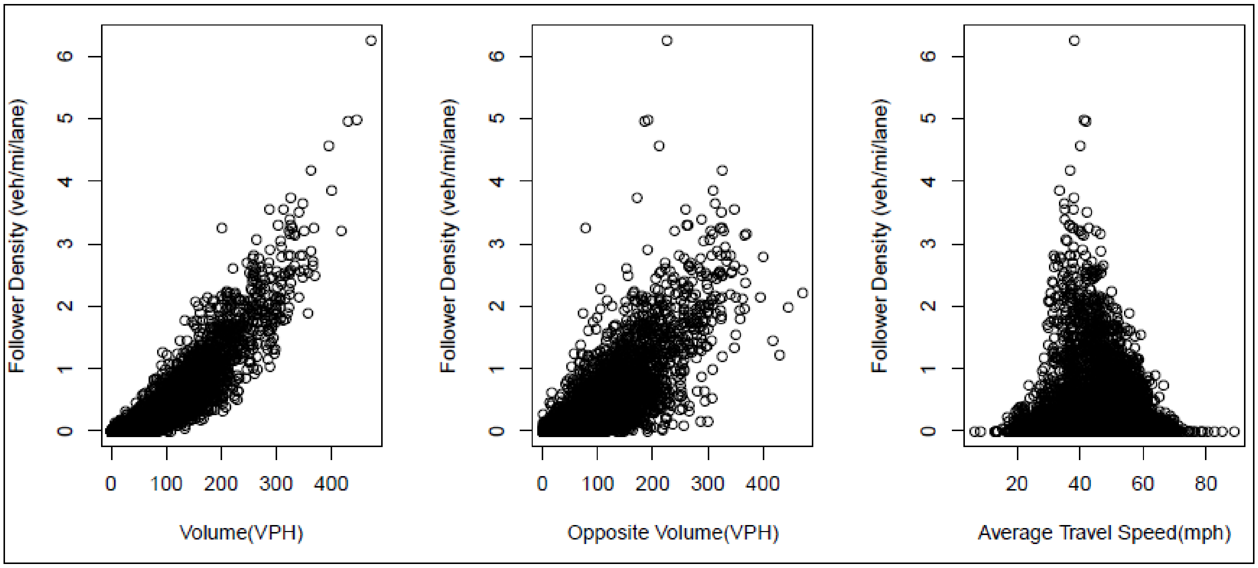

Figure 1. Follower Density versus Explanatory Variables

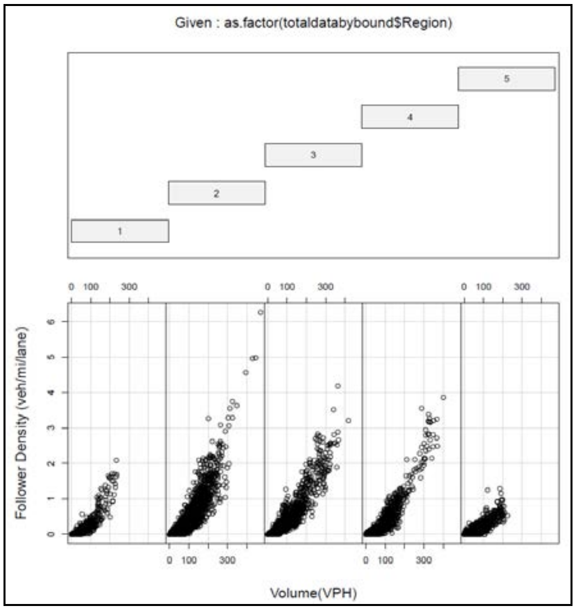

Figure 2. Follower Density by ODOT Region

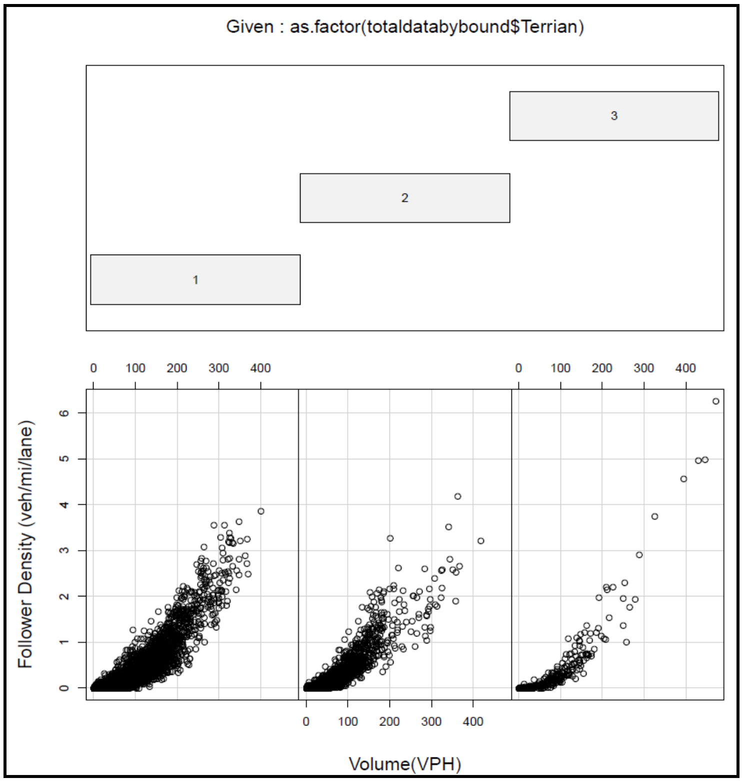

Figure 3. Variation of Follower Density by Terrain (1-level; 2-rolling; 3-mountainous)

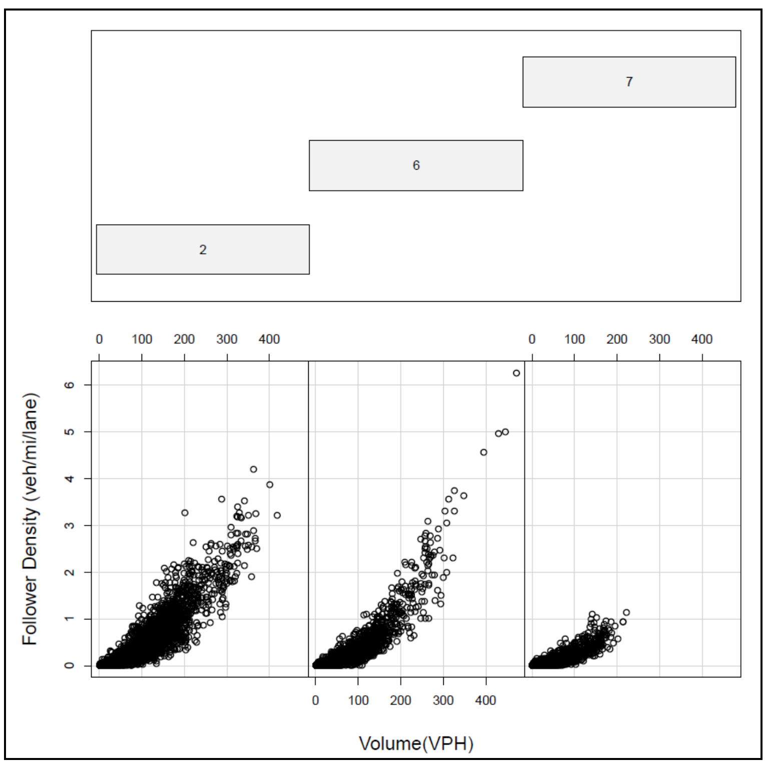

Figure 4. Follower Densities by Rural Highway Functional Classification (2-Rural Principal Arterial; 6-Rural Minor Arterial; 7-Rural Major Collector)

Model Form

The following dependent variables (performance indicators) are considered for the modeling:

- Average travel speed (ATS) in mph,
- ATS as a percent of free-flow speed (PFFS) in %,
- Percent followers (PTfollowers) in %, and
- Follower density (FLdensity) in veh/mile/lane.

Independent variables (explanatory or platooning variables) considered are:

- Traffic flow in the direction of travel (veh/h),
- Opposing traffic flow (veh/h),
- Percent heavy vehicles (%),
- Percent no-passing zones (%),
- RTerrain (dummy variable; 1 = Rolling Terrain, 0 = Otherwise) , and
- MTerrain (dummy variable; 1 = Mountainous Terrain, 0 = Otherwise).

The general form of the regression model is:

$$Y = \beta_0 + \beta_1 \times X_1 + \beta_2 \times X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + \beta n \times X_n$$

Where

Y = Dependent variable

$X_1, X_2, \ldots\ldots X_n$ = Independent or Explanatory Variables

β_0 = Constant; β_1 , β_2 , β_3 = Model coefficients corresponds $X_1, X_2, \ldots\ldots X_n$

Models by Highway Functional Class

Regression modeling and corresponding statistical analysis was performed using the code written in the R programming language. Follower density and all other explanatory variables were calculated using R code. The code also facilitated model selection, development and validation. Based upon the statistical analysis, follower density is chosen as the performance indicator. The model fitted between follower density (veh/mile/lane) as the dependent variable, and traffic flow (vph), opposing flow (vph), percent of heavy vehicles (%), percentage no passing (%), RTerrain, and MTerrian as the independent variables, has the highest R^2 value and statistical significance. Table 6 lists follower density models by highway functional class.

Table 1. Follower Density Models by Rural Functional Classification

Class	Model Form	R^2
I	Follower Density = -0.1917 + 0.005953 (Traffic Volume) + 0.0005167 (Opposing Volume) + 0.0006739 (% Heavy Vehicles) + 0.0002392 (% No Passing) + 0.05248 (Rolling Terrain)	0.81
II	Follower Density = -0.1784 + 0.006189 (Traffic Volume) - 0.0001607 (Opposing Volume) + 0.0006163 (% Heavy Vehicles) + 0.0006055 (% No Passing) + 0.0168 (Rolling Terrain) + 0.03994 (Mountainous Terrain)	0.75
III	Follower Density = -0.04062 + 0.003244 (Traffic Volume) - 0.0003219 (Opposing Volume) + 0.0001127 (% Heavy Vehicles) + 0.0001877 (% No Passing) - 0.007543 (Rolling Terrain) - 0.01995 (Mountainous Terrain)	0.74

After model development, model validation was performed. Next section presents validation and model consistency checking efforts.

Model Validation

Developed model was validated by using data sets from 56 sites. These sites were a part of the original data collection efforts and were separated based on AADT, terrain, and geographic region to cover all possible conditions. Hourly data from all sites were tested with the developed model and comparison is made between observed follower densities and predicted follower densities. The developed models were also compared with the similar study done in the State of Montana (*Al-Kaisy and Karjala, 2008*). The Montana models were shown in Figure 5.

Performance Indicator	Linear Regression Model	R^2	Multiple R
Follower density (veh/mi)	Follower Density = 0.01041 (volume in vph) – 0.00022 (opposing volume in vph) – 0.03057 (% heavy vehicles) + 0.00500 (% no-passing zones) + 0.11670 (standard deviation of free-flow speed in mph)	0.96	0.98
% followers	% Followers = 0.03380 (volume in vph) + 0.00607 (opposing volume in vph) – 0.16062 (% heavy vehicles) + 0.10894 (% no-passing zones) + 2.12739 (standard deviation of free-flow speed in mph)	0.62	0.79

Source: *Al-Kaisy and Karjala, 2008*

Figure 5. Montana Study Models

Figure 6 shows the linear relationship between predicted follower density and observed follower density. However, the relationship between follower densities from Montana study and observed follower densities did not show a liner trend (Figure 7). Table 2 lists relationships between model and observed follower densities.

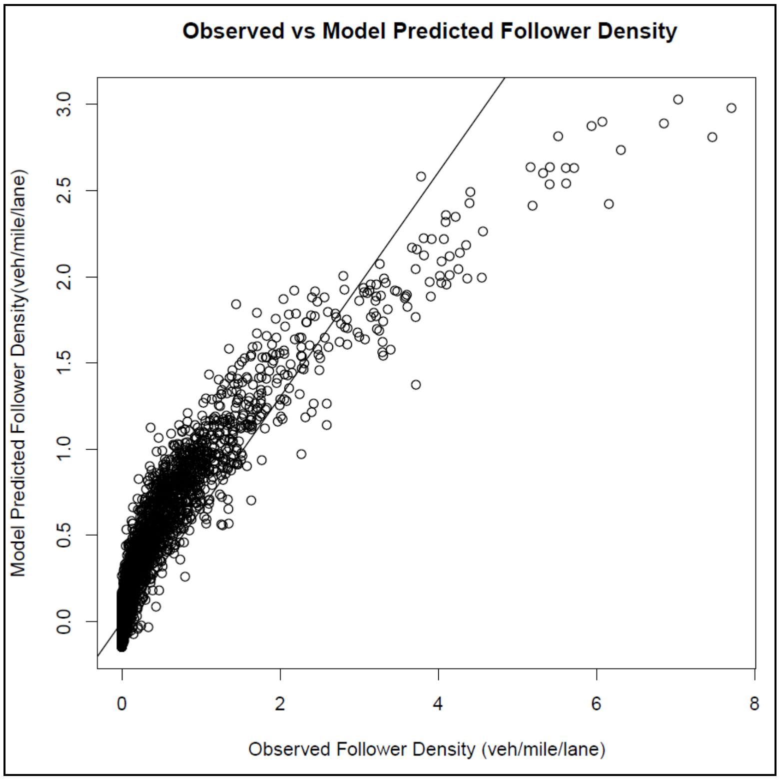

Figure 6. Observed Follower Density versus Predicted Follower Density

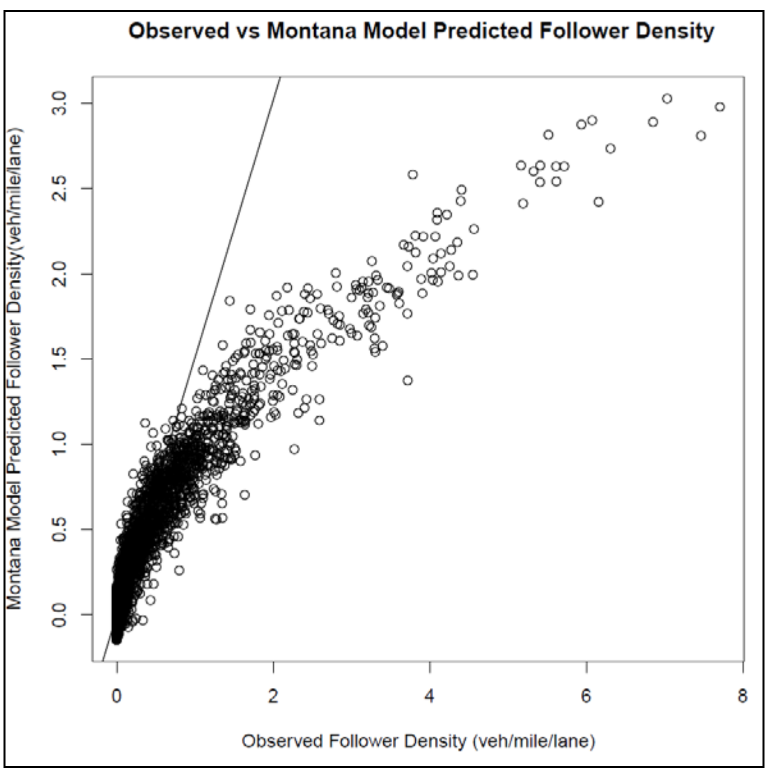

Figure 7. Observed Follower Density versus Follower Density from Montana Study

Table 2. Relationship between Model Follower Density and Observed Follower Density

Item	Model	R^2
ODOT Model vs Observed	Model Follower Density = 0.6514 (Observed Follower Density)	0.85
Montana Study vs Observed	Montana Study Follower Density = 1.5093 (Observed Follower Density)	0.57

Both the developed model and the Montana study model were compared against the error in estimating follower densities. Errors for developed model are less compared to Montana study models on class I highways (Figure 8). However, the Montana model error becomes smaller as the follower density increases. Similar trend was observed for Class II and Class III highways. This study used a follower density difference of ± 0.5 vehicle/mile/lane as the acceptable range; a difference greater than + 0.5 vehicle/mile/lane was labeled as over-estimated, and less than -0.5 vehicle/mile/lane was treated as under-estimated. Data on percent of acceptable, under-estimated and over-estimated follower densities were used for models comparison. Error distribution plots, Figures 9 to 11, show Montana study model over predicting the follower densities. On an average 90 percent of observations have acceptable range of error when using the developed models. However, only 30 percent of observations show acceptable range of error with Montana study model.

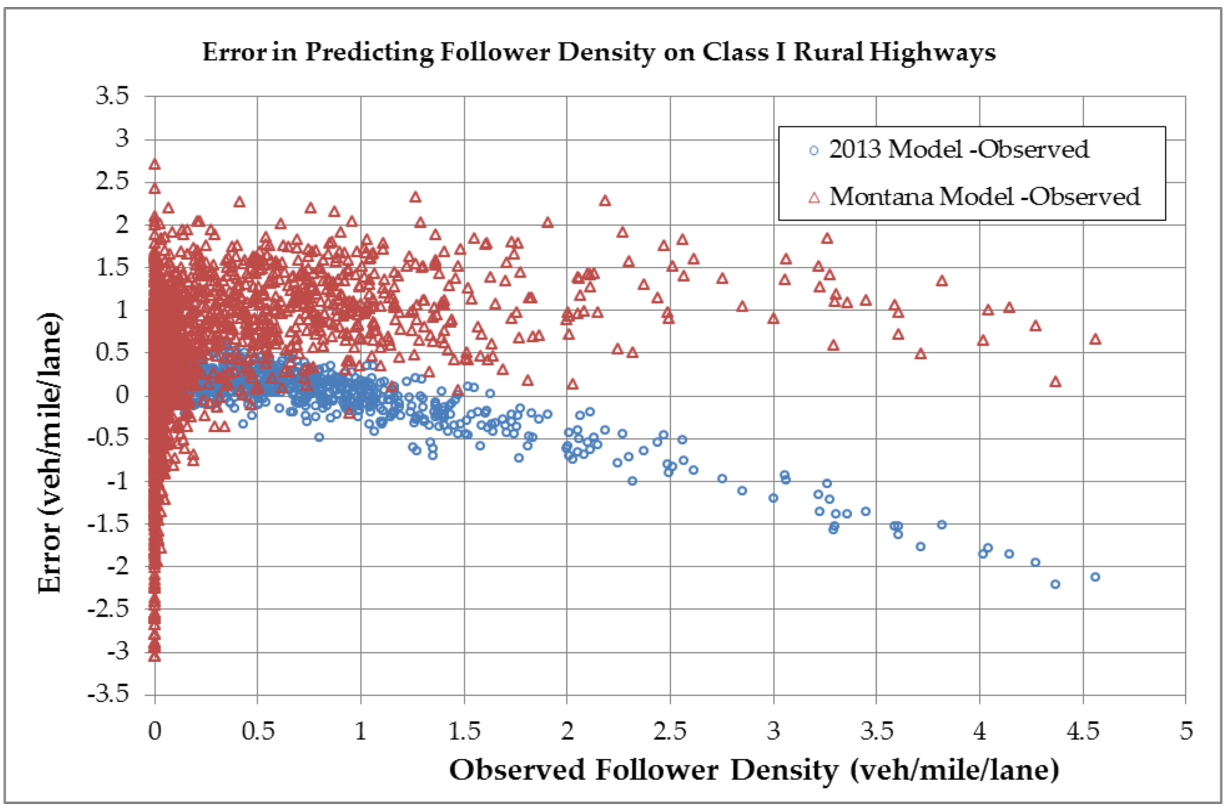

Figure 8. Error between Predicted and Observed Follower Densities for Class I Highways

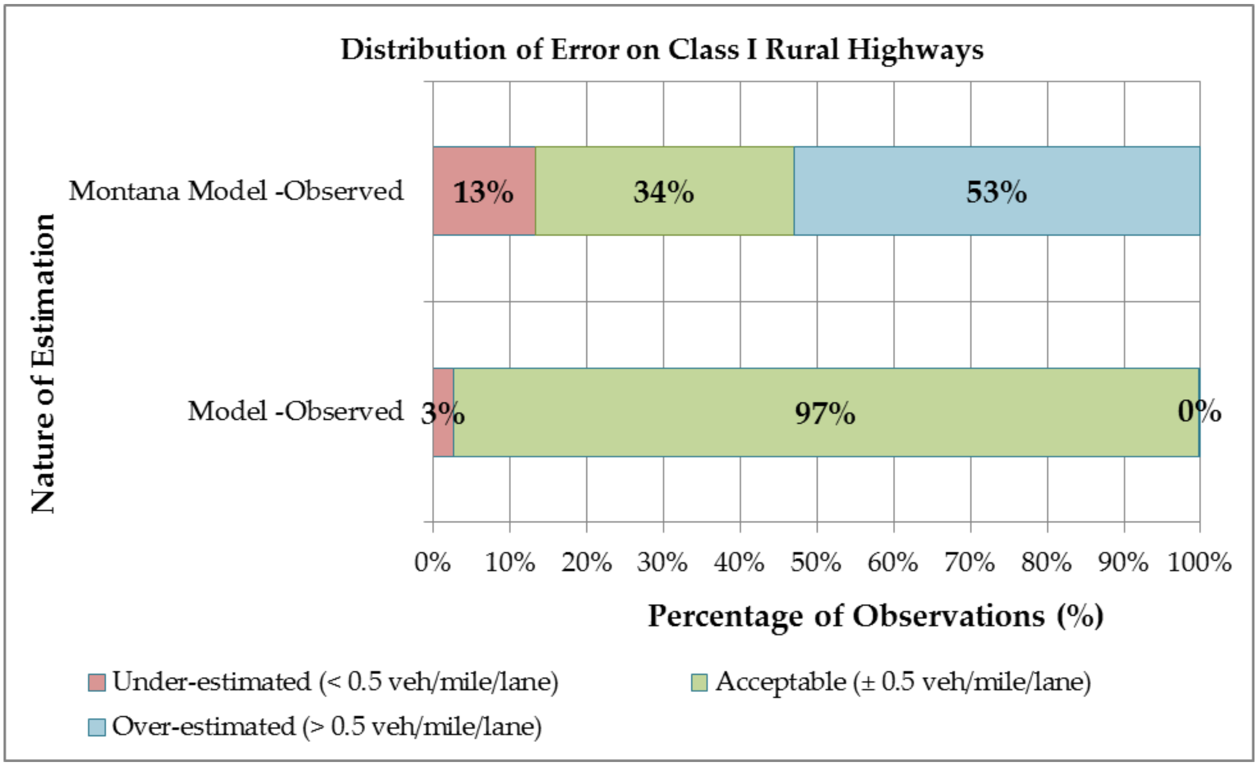

Figure 9. Comparison of Developed Model and Montana Model for Class I Highways

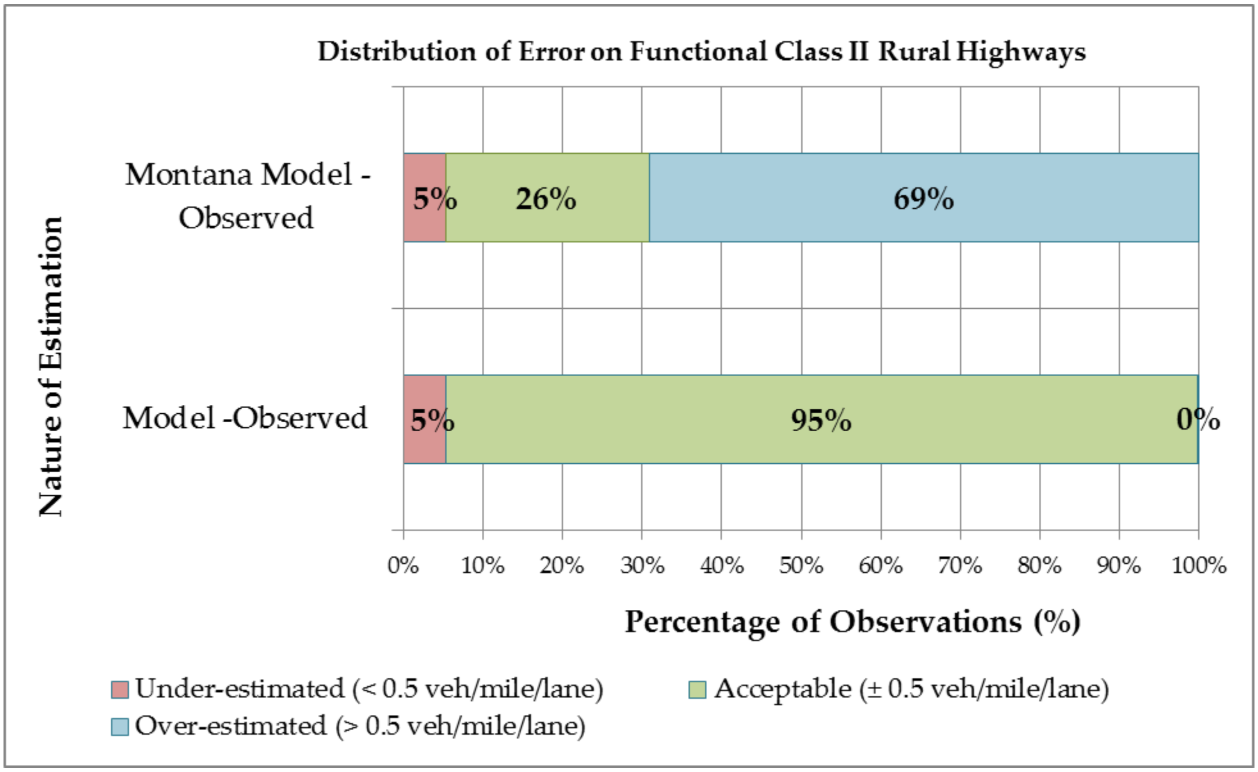

Figure 10. Comparison of Developed Model and Montana Model for Class II Highways

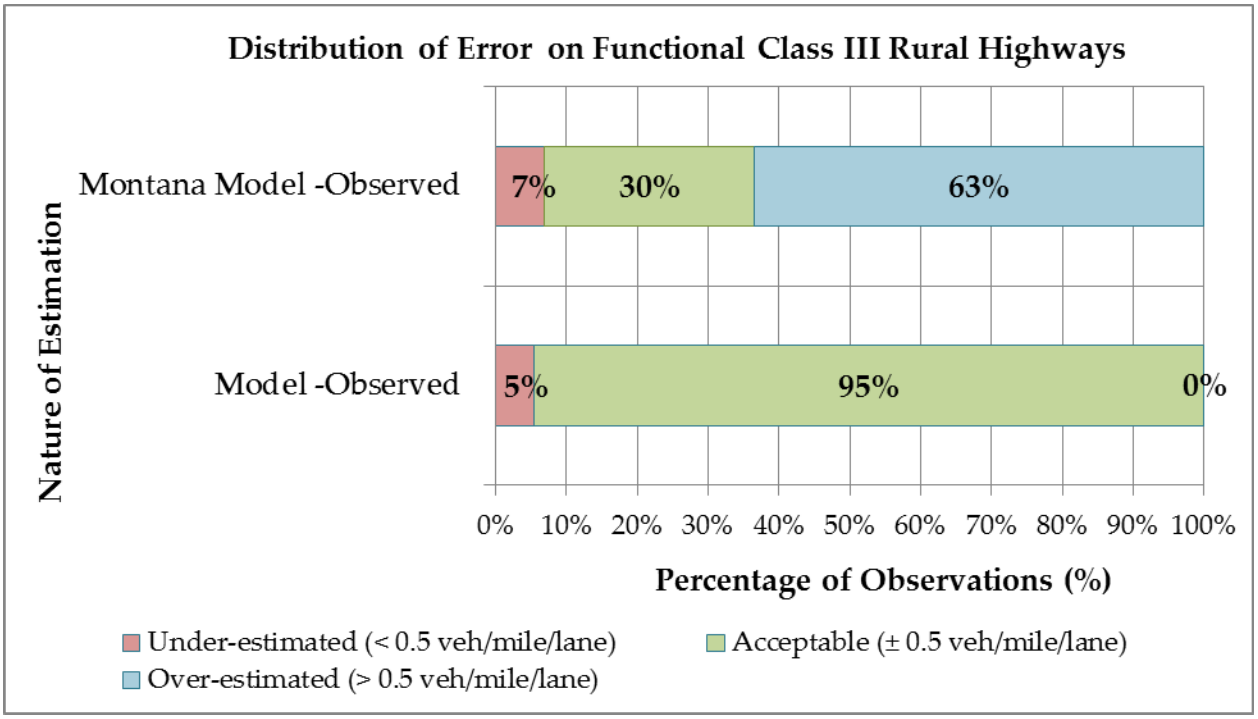

Figure 11. Comparison of Developed Model and Montana Model for Class III Highways

Validation clearly showed follower density models have the potential to be used as an alternative performance measure on two-lane rural highways.

Development of Follower Density Thresholds

Follower density acts as a surrogate measure to assess operations of rural two-lane highways. To leverage the potential of follower density measure, development of follower density thresholds corresponding to each LOS category was necessary. The follower density models helped to develop thresholds at each LOS category by two-lane highway class. According to the HCM 2010 manual, LOS on Class I two-lane highways considers both ATS and PTSF measures. On Class II highways, PTSF governs LOS. On Class III highways Percent of Free-flow Speed (PFFS) is used to define LOS. The HCM 2010 LOS criteria for two-lane highways are shown in Table 3.

Table 3. LOS Criteria for Two-Lane Highways

LOS	Class I Highways		Class II Highways	Class III Highways
	ATS (mi/h)	PTSF (%)	PTSF (%)	PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50–55	>35–50	>40–55	>83.3–91.7
C	>45–50	>50–65	>55–70	>75.0–83.3
D	>40–45	>65–80	>70–85	>66.7–75.0
E	≤40	>80	>85	≤66.7

Source: HCM, 2010, Exhibit 15-3

Both ATS and PFFS measures are obtainable from field data. However, PTSF is difficult to obtain from field. This study uses PTSF LOS boundaries to define follower density thresholds. The procedure to determine the thresholds as follows:

- Step 1. Use the relationship between PTSF and volume given in the HCM manual (HCM 2010, Equation 15-10) to develop corresponding volumes at each LOS boundary
- Step 2. Develop relationship between volume and follower density from data used for model development
- Step 3. With the help of the boundary volumes found in the step 1, designate the follower density thresholds using the relationship obtained from the step 2.

LOS Criteria for Class I Rural Two-Lane Highways

Step 1

According to the HCM (2010), base PTSF is calculated as: $BPTSF_d = 100\left[1 - \exp\left(a v_d^b\right)\right]$

Where

$BPTSF_d$ is base percent time-spent-following in the analysis direction,

V_d is the demand flow rate in the analysis direction, and

a and b are constants.

PTSF ranges as per the HCM (2010) LOS criteria were taken from Table 3. For a given PTSF value at each LOS category, possible volume ranges were calculated (see Table 4).

Table 4. Volume Range at each LOS Category for Class I Rural Two-Lane Highways

Opposing Volume (veh/hr)	a	b	LOS A		LOS B		LOS C		LOS D	
			PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)
200	-0.0014	0.973	35	361	50	589	65	902	80	1398
400	-0.0022	0.923	35	305	50	510	65	799	80	1269
600	-0.0033	0.87	35	271	50	468	65	753	80	1230
800	-0.0045	0.833	35	239	50	423	65	697	80	1163
1000	-0.0049	0.829	35	222	50	393	65	649	80	1086
1200	-0.0054	0.825	35	202	50	360	65	595	80	998
1400	-0.0058	0.821	35	190	50	340	65	563	80	947
1600	-0.0062	0.817	35	180	50	322	65	535	80	902

Step 2

For the collected data, scattered diagram between volume and follower density showed an increasing trend of follower density with the volume (Figure 14). Linear relationship, *follower density = 0.0064 (volume) - 0.138* ($R^2 = 0.81$), was found to be statistically significant.

Step 3

Substituting volume ranges from Table 4 in the above mentioned model (in step 2), follower density ranges were obtained (Table 5).

Table 5. Follower Density Ranges for a given LOS Category for Class I Two-Lane Highways

Opposing Volume (veh/hr)	LOS A		LOS B		LOS C		LOS D	
	VOL	FD	VOL	FD	VOL	FD	VOL	FD
200	361	2.2	589	3.6	902	5.6	1398	8.8
400	305	1.8	510	3.1	799	5.0	1269	8.0
600	271	1.6	468	2.9	753	4.7	1230	7.7
800	239	1.4	423	2.6	697	4.3	1163	7.3
1000	222	1.3	393	2.4	649	4.0	1086	6.8
1200	202	1.2	360	2.2	595	3.7	998	6.2
1400	190	1.1	340	2.0	563	3.5	947	5.9
1600	180	1.0	322	1.9	535	3.3	902	5.6

Note: VOL stands for demand flow rate in veh/hr; FD stands for follower density in veh/mile/lane

The follower densities (in Table 5) are consolidated to get final follower density thresholds as shown in Table 6.

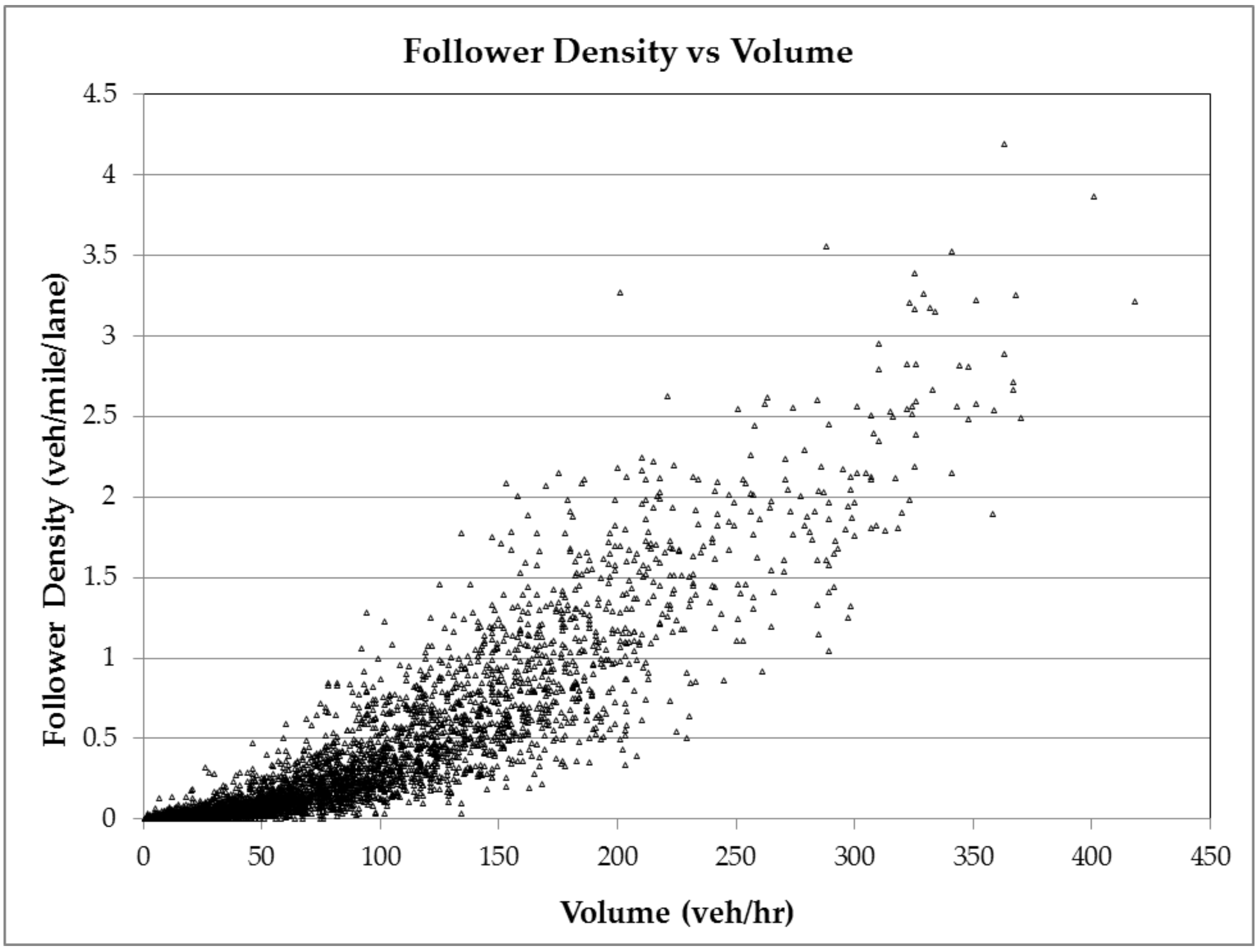

Figure 12. Scattered Plot between Follower Density and Volume on Class I Highways

Table 6. LOS Criteria for Class I Highways (Rural Principal Arterials)

HCM 2010, PTSF Range	HCM 2010, LOS	Suggested Follower Density (veh/mile/lane)
<= 35	A	<= 2.0
> 35 - 50	B	> 2.0 - 3.5
> 50 - 65	C	> 3.5 - 6.0
> 65 - 80	D	> 6.0 - 9.0
> 80	E	> 9.0

LOS Criteria for Class II Rural Two-Lane Highways

Step 1

PTSF values from Table 3 were used for Class II two-lane highways to get the LOS thresholds. For a given PTSF value to each LOS category, corresponding range of possible volumes was calculated (Table 7).

Step 2

Volume and follower density scatter diagram showed that follower density increases with the volume (Figure 15). Linear relationship, *follower density = 0.006 (volume) - 0.124* (R^2 = 0.74), was found to be statistically significant.

Step 3

Using the above relationship, follower density ranges were developed (see Table 8). Follower density ranges were given in the Table 9.

Table 7. Volume Range at each LOS Category for Class II Rural Two-Lane Highways

Opposing Volume (veh/hr)	a	b	LOS A		LOS B		LOS C		LOS D	
			PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)	PTSF (%)	VOL (veh/hr)
200	-0.0014	0.973	40	430	55	681	70	1038	85	1656
400	-0.0022	0.923	40	366	55	594	70	927	85	1516
600	-0.0033	0.870	40	329	55	550	70	881	85	1486
800	-0.0045	0.833	40	294	55	502	70	821	85	1417
1000	-0.0049	0.829	40	272	55	466	70	765	85	1324
1200	-0.0054	0.825	40	249	55	427	70	702	85	1219
1400	-0.0058	0.821	40	234	55	403	70	665	85	1156
1600	-0.0062	0.817	40	222	55	383	70	633	85	1103

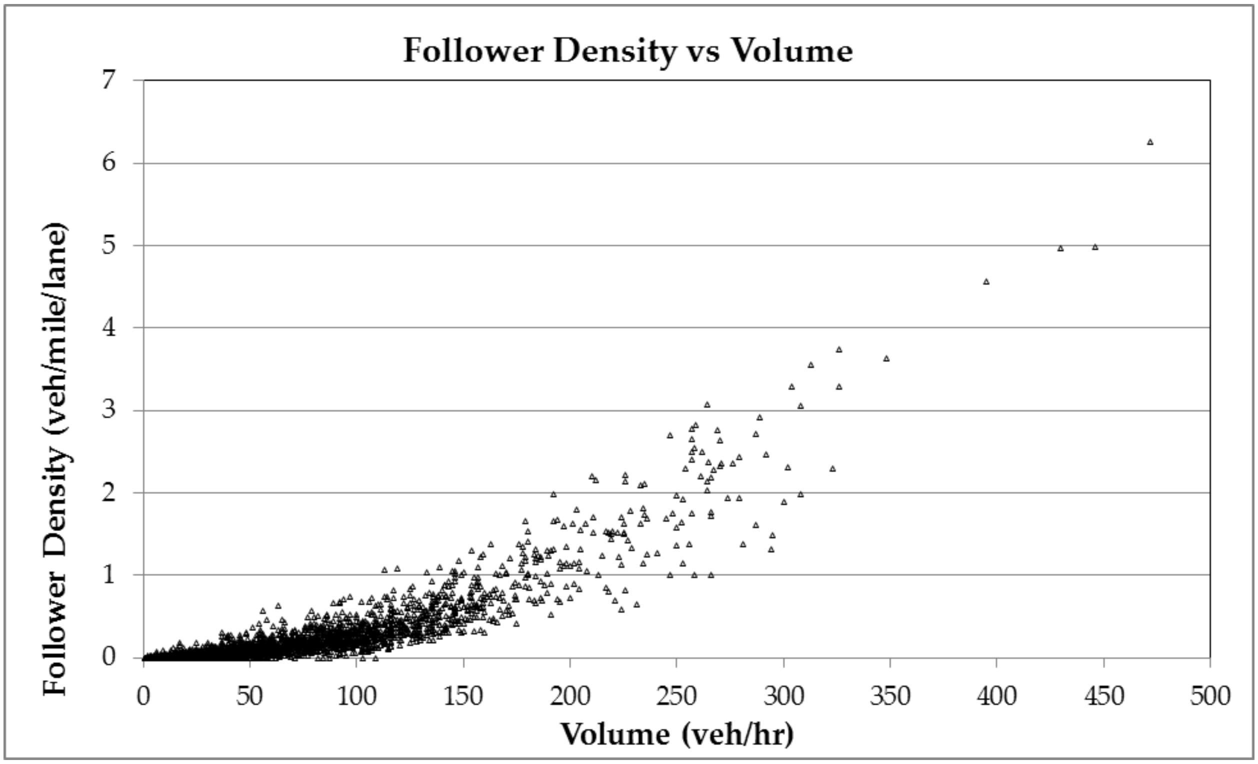

Figure 13. Scattered Plot between Follower Density and Volume on Class II Highways

Table 8. Follower Density Ranges for a given LOS Category for Class II Two-Lane Highways

Opposing Volume (veh/hr)	a	b	LOS A		LOS B		LOS C		LOS D	
			VOL (veh/hr)	FD	VOL (veh/hr)	FD	VOL (veh/hr)	FD	VOL (veh/hr)	FD
200	-0.0014	0.973	430	2.5	681	4.0	1038	6.1	1656	9.8
400	-0.0022	0.923	366	2.1	594	3.4	927	5.4	1516	9.0
600	-0.0033	0.870	329	1.9	550	3.2	881	5.2	1486	8.8
800	-0.0045	0.833	294	1.6	502	2.9	821	4.8	1417	8.4
1000	-0.0049	0.829	272	1.5	466	2.7	765	4.5	1324	7.8
1200	-0.0054	0.825	249	1.4	427	2.4	702	4.1	1219	7.2
1400	-0.0058	0.821	234	1.3	403	2.3	665	3.9	1156	6.8
1600	-0.0062	0.817	222	1.2	383	2.2	633	3.7	1103	6.5

Note: VOL stands for demand flow rate in veh/hr; FD stands for follower density in veh/mile/lane

Table 9. LOS Criteria for Class II Highways (Rural Minor Arterials)

HCM 2010, PTSF Range	HCM 2010, LOS	Follower Density (veh/mile/lane)
<= 40	A	< = 2.5
> 40 - 55	B	> 2.5 - 4.0
> 55 - 70	C	> 4.0 - 6.5
> 70 - 85	D	> 6.5 - 10.0
> 85	E	> 10.0

Sample size from Class III highways was very limited. In addition, Class III highways use PFFS as a LOS measure that can be obtained from field data. Hence, follower density thresholds were not developed for Class III highways. Until refinement, users are advised to use the HCM 2010 methodology and LOS criteria for rural major collector highways.

Summary

The study adopted alternative performance measures to analyze operations on two-lane rural highways. Performance indicators like average travel speed, percent followers, and follower density were tested on data collected from 168 rural highway sites. Datasets covers rural principal arterial, rural minor arterials, and rural major collector highways class. These highway classes are re-designated as per the HCM (2010) definition of class I, class II, and class III two-lane highways.

For each class of two-lane highways, regression models were developed between performance indicators as dependent variables, and the platooning variables, such as traffic flow in the direction of travel, opposing traffic flow, percent heavy vehicles, percent no-passing zones, and terrain as independent variables. Out of various combinations, the model with follower density versus traffic flow, opposing volume, percent of heavy vehicles, percent no passing zones and terrain yields better statistical significance. Model forms by two-lane highway class are shown in Table 10.

Later, data from 58 sites were used to validate the model. A follower density difference of ± 0.5 vehicle/mile/lane was used as the acceptable range of error between model and observations. Data on percent of acceptable, under-estimated and over-estimated observations facilitated models comparison. On an average, 95 percent of observations had an acceptable range of error with the developed models. Model from Montana study is over predicting the follower densities with only 30 percent of observations showing acceptable range of error.

The study also outlined a procedure to develop follower density thresholds. The HCM 2010 manual PTSF boundaries related to Class I and II two-lane highways were used to designate follower density thresholds.

Table 10. Follower Density Models by Rural Two-Lane Highway Functional Class

Functional Class	Model Form	R^2
Class I Highways	Follower Density = -0.1917 + 0.005953 (Traffic Volume) + 0.0005167 (Opposing Volume) + 0.0006739 (% Heavy Vehicles) + 0.0002392 (% No Passing) + 0.05248 (Rolling Terrain)	0.81
Class II Highways	Follower Density = -0.1784 + 0.006189 (Traffic Volume) - 0.0001607 (Opposing Volume) + 0.0006163 (%Heavy Vehicles) + 0.0006055 (% No Passing) + 0.0168 (Rolling Terrain) + 0.03994 (Mountainous Terrain)	0.75
Class III Highways	Follower Density = -0.04062 + 0.003244 (Traffic Volume) - 0.0003219 (Opposing Volume) + 0.0001127 (%Heavy Vehicles) + 0.0001877 (% No Passing) - 0.007543 (Rolling Terrain) - 0.01995 (Mountainous Terrain)	0.74

The study did not set up follower density boundaries for class III highways due to limited sample size. Until further refinement, use of HCM 2010 methodology for class III highways is recommended. New LOS criteria for two-lane rural highways are (except for class III two-lane highways) shown in Table 11.

Table 11. LOS Criteria by Rural Two-Lane Highway Functional Class

LOS	Class I Highways	Class II Highways
	Follower Density (veh/mile/lane)	Follower Density (veh/mile/lane)
A	<= 2.0	<= 2.5
B	> 2.0 - 3.5	> 2.5 - 4.0
C	> 3.5 - 6.0	> 4.0 - 6.5
D	> 6.0 - 9.0	> 6.5 - 10.0
E	> 9.0	> 10.0

Scope for Future Work

Follower density models can be used as a two-lane highways network analysis tool. Using the models and readily available data from HERS (Highway Economic Requirement Systems), follower densities (thereby LOS) can be mapped on each highway network section. Percent miles by LOS category will play a key role in strategic investment, operations and maintenance decisions. However Class III highway models need refinement by obtaining more data. In addition, data expansion to sites with higher directional and opposite traffic flows, and sites located in the mountainous terrain may enhance modelling outcomes.

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Appendix A: VMT and Mileage Guidelines by Functional Class

Table 3-5: VMT and Mileage Guidelines by Functional Classifications - Arterials

	Arterials			
	Interstate	Other Freeways & Expressway	Other Principal Arterial	Minor Arterial
Typical Characteristics				
Lane Width	12 feet	11 - 12 feet	11 - 12 feet	10 feet - 12 feet
Inside Shoulder Width	4 feet - 12 feet	0 feet - 6 feet	0 feet	0 feet
Outside Shoulder Width	10 feet - 12 feet	8 feet - 12 feet	8 feet - 12 feet	4 feet - 8 feet
AADT[1] (Rural)	12,000 - 34,000	4,000 - 18,500[2]	2,000 - 8,500[2]	1,500 - 6,000
AADT[1] (Urban)	35,000 - 129,000	13,000 - 55,000[2]	7,000 – 27,000[2]	3,000 - 14,000
Divided/Undivided	Divided	Undivided/Divided	Undivided/Divided	Undivided
Access	Fully Controlled	Partially/Fully Controlled	Partially/Uncontrolled	Uncontrolled
Mileage/VMT Extent (Percentage Ranges)[1]				
Rural System				
Mileage Extent for Rural States[2]	1% - 3%	0% - 2%	2% - 6%	2% - 6%
Mileage Extent for Urban States	1% - 2%	0% - 2%	2% - 5%	3% - 7%
Mileage Extent for All States	1% - 2%	0% - 2%	2% - 6%	3% - 7%
VMT Extent for Rural States[2]	18% - 38%	0% - 7%	15% - 31%	9% - 20%
VMT Extent for Urban States	18% - 34%	0% - 8%	12% - 29%	12% - 19%
VMT Extent for All States	20% - 38%	0% - 8%	14% - 30%	11% - 20%
Urban System				
Mileage Extent for Rural States[2]	1% - 3%	0% - 2%	4% - 9%	7% - 14%
Mileage Extent for Urban States	1% - 2%	0% - 2%	4% - 5%	7% - 12%
Mileage Extent for All States	1% - 3%	0% - 2%	4% - 5%	7% - 114%
VMT Extent for Rural States[2]	17% - 31%	0% - 12%	16% - 33%	14% - 27%
VMT Extent for Urban States	17% - 30%	3% - 18%	17% - 29%	15% - 22%
VMT Extent for All States	17% - 31%	0% - 17%	16% - 31%	14% - 25%
Qualitative Description (Urban)	• Serve major activity centers, highest traffic volume corridors, and longest trip demands • Carry high proportion of total urban travel on minimum of mileage • Interconnect and provide continuity for major rural corridors to accommodate trips entering and leaving urban area and movements through the urban area • Serve demand for intra-area travel between the central business district and outlying residential areas			• Interconnect with and augment the principal arterials • Serve trips of moderate length at a somewhat lower level of travel mobility than principal arterials • Distribute traffic to smaller geographic areas than those served by principal arterials • Provide more land access than principal arterials without penetrating identifiable neighborhoods • Provide urban connections for rural collectors
Qualitative Description (Rural)	• Serve corridor movements having trip length and travel density characteristics indicative of substantial statewide or interstate travel • Serve all or nearly all urbanized areas and a large majority of urban clusters areas with 25,000 and over population • Provide an integrated network of continuous routes without stub connections (dead ends)			• Link cities and larger towns (and other major destinations such as resorts capable of attracting travel over long distances) and form an integrated network providing interstate and inter-county service • Spaced at intervals, consistent with population density, so that all developed areas within the State are within a reasonable distance of an arterial roadway Provide service to corridors with trip lengths and travel density greater than those served by rural collectors and local roads and with relatively high travel speeds and minimum interference to through movement

1- Ranges in this table are derived from 2011 HPMS data.

2- For this table, Rural States are defined as those with a maximum of 75 percent of their population in urban centers.

Source: FHWA, 2013

Figure A1. VMT and Mileage Guidelines for Arterial Highways

Table 3-6: VMT and Mileage Guidelines by Functional Classifications – Collectors and Locals

	Collectors		Local
	Major Collector[2]	Minor Collector[2]	
Typical Characteristics			
Lane Width	10 feet - 12 feet	10 - 11 feet	8 feet - 10 feet
Inside Shoulder Width	0 feet	0 feet	0 feet
Outside Shoulder Width	1 feet - 6 feet	1 feet - 4 feet	0 feet - 2 feet
AADT[1] (Rural)	300 - 2,600	150 - 1,110	15 - 400
AADT[1] (Urban)	1,100 - 6,300[2]		80 - 700
Divided/Undivided	Undivided	Undivided	Undivided
Access	Uncontrolled	Uncontrolled	Uncontrolled
Mileage/VMT Extent (Percentage Ranges)[1]			
Rural System			
Mileage Extent for Rural States[3]	8% - 19%	3% - 15%	62% - 74%
Mileage Extent for Urban States	10% - 17%	5% - 13%	66% - 74%
Mileage Extent for All States	9% - 19%	4% - 15%	64% - 75%
VMT Extent for Rural States[3]	10% - 23%	1% - 8%	8% - 23%
VMT Extent for Urban States	12% - 24%	3% - 10%	7% - 20%
VMT Extent for All States	12% - 23%	2% - 9%	8% - 23%
Urban System			
Mileage Extent for Rural States[3]	3% - 16%	3% - 16%[2]	62% - 74%
Mileage Extent for Urban States	7% - 13%	7% - 13%[2]	67% - 76%
Mileage Extent for All States	7% - 15%	7% - 15%[2]	63% - 75%
VMT Extent for Rural States[3]	2% - 13%	2% - 12%[2]	9% - 25%
VMT Extent for Urban States	7% - 13%	7% - 13%[2]	6% - 24%
VMT Extent for All States	5% - 13%	5% - 13%[2]	6% - 25%
Qualitative Description (Urban)	• Serve both land access and traffic circulation in higher density residential, and commercial/industrial areas • Penetrate residential neighborhoods, often for significant distances • Distribute and channel trips between local streets and arterials, usually over a distance of greater than three-quarters of a mile	• Serve both land access and traffic circulation in lower density residential, and commercial/industrial areas • Penetrate residential neighborhoods, often only for a short distance • Distribute and channel trips between local streets and arterials, usually over a distance of less than three-quarters of a mile	• Provide direct access to adjacent land • Provide access to higher systems • Carry no through traffic movement
Qualitative Description (Rural)	• Provide service to any county seat not on an arterial route, to the larger towns not directly served by the higher systems, and to other traffic generators of equivalent intra-county importance such as consolidated schools, shipping points, county parks, important mining and agricultural areas • Link these places with nearby larger towns and cities or with arterial routes • Serve the most important intra-county travel corridors	• Be spaced at intervals, consistent with population density, to collect traffic from local roads and bring all developed areas within reasonable distance of a minor collector • Provide service to smaller communities not served by a higher class facility • Link locally important traffic generators with their rural hinterlands	• Serve primarily to provide access to adjacent land • Provide service to travel over short distances as compared to higher classification categories • Constitute the mileage not classified as part of the arterial and collectors systems

1- Ranges in this table are derived from 2011 HPMS data.

2- Information for Urban Major and Minor Collectors is approximate, based on a small number of States reporting.

3- For this table, Rural States are defined as those with a maximum of 75 percent of their population in urban centers.

Source: FHWA, 2013

Figure A2. VMT and Mileage Guidelines for Collectors and Locals Highways