Modeling Performance Indicators on Two-Lane Rural Highways:

The Oregon Experience

Facility Analysis and Simulation Team
Transportation Development Division
Oregon Department of Transportation

December 2010

Table of Contents

TABLE OF CONTENTS ..... **II**

TABLE OF FIGURES ..... **III**

TABLE OF TABLES ..... **III**

1 INTRODUCTION **1**

1.1 LITERATURE REVIEW 1
1.1.1 Highway Capacity Manual (HCM) method *1*
1.1.2 Luttinen *1*
1.1.3 Morrall and Werner *2*
1.1.4 Brilon and Weiser *2*
1.1.5 Christo van As *2*
1.1.6 Romana and Pérez *2*
1.1.7 Ahmed Al-Kaisy and Sarah Karjala *3*
1.2 PROBLEM DEFINITION 3
1.3 STUDY OBJECTIVES 3
1.4 STUDY METHODOLOGY 4

2 ADOPTED MEASURES OF PERFORMANCE **4**

2.1 AVERAGE TRAVEL SPEED (ATS) 4
2.2 AVERAGE TRAVEL SPEED OF PASSENGER CARS (ATSPC) 4
2.3 AVERAGE TRAVEL SPEED AS PERCENTAGE OF FREE-FLOW SPEED 4
2.4 AVERAGE TRAVEL SPEED OF PASSENGER CARS AS PERCENTAGE OF FREE-FLOW SPEED OF PASSENGER CARS (ATSPC/ FFSPC) 5
2.5 PERCENT FOLLOWERS 5
2.6 FOLLOWER DENSITY 5

3 DATA COLLECTION & ANALYSIS **6**

4 MODEL DEVELOPMENT **6**

4.1 DATA ANALYSIS RESULTS 6
4.2 MODEL FORM 12
4.3 MODEL 12
4.4 PERFORMANCE OF MONTANA STUDY 14

5 MODEL VALIDATION **15**

5.1 DATA COLLECTION 15
5.2 DATA ANALYSIS 15
5.3 MODEL COMPARISON 18

6 SUMMARY **18**

7 SCOPE FOR FUTURE WORK **19**

APPENDIX A -DESCRIPTION OF DATA COLLECTION SITES **20**

Table of Figures

Figure 1 Variation of speeds with Volume (VPH) and % Heavy Vehicles (%) 7
Figure 2 Variation of ratio ATS/FFS with Volume (VPH) and % Heavy Vehicles (%) 7
Figure 3 Variation of percent followers with Volume (VPH) and % Heavy Vehicles (%) 8
Figure 4 Variation of follower densities with Volume (VPH) and % Heavy Vehicles (%) 8
Figure 5 Traffic flow and % followers 9
Figure 6 Percent Followers and Average Followers Travel Speed 9
Figure 7 Followers Density and Percent Followers 10
Figure 8 Followers Density and Followers Average Travel Speed 10
Figure 9 Variation of follower density with volume and opposing volume 11
Figure 10 Variation of follower density with volume and opposing volume 11
Figure 11 Montana Study and Observed Follower Density 14
Figure 12 Error between Montana Study Follower Density and Observed Follower Density 15
Figure 13 Residuals plot of predicted follower density and observed follower density 16
Figure 14 Observed follower density and predicted follower density 17
Figure 15 Error Variation among the Models 18

Table of Tables

Table 1 Fitted models for various performance indicators 13
Table 2 Regression model between predicted follower density and observed follower density . 17
Table A1 Sites used for model development 20
Table A2 Sites used for model validation 20

1 Introduction

Two-lane rural roads exhibit high level of interactions between vehicles traveling in the same and opposite directions. Traffic volume in both directions, configuration of highway geometry, terrain, grades, and presence of heavy vehicles intensifies this interaction. Drivers look for opportunities to pass slower vehicles in order to maintain free flow speeds. Limited passing opportunities may lead to an increase in crash rates as evidenced from crash reports. Also, higher interactions between vehicles forms platoons. In order to study the operational characteristics of two-lane highways, one needs to analyze platoons. The following section briefly describes some common approaches to studying two-lane rural highways

1.1 Literature Review

Several studies have proposed or reported on the use of performance measures on two-lane highways, including those used by the HCM.

1.1.1 Highway Capacity Manual (HCM) method

The 2000 Highway Capacity Manual (HCM) evaluates two-lane highway performance using both average travel speed (ATS) and percent time spent following (PTSF) as performance indicators. The PTSF[1] is defined as "the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of an inability to pass". But, PTSF is very difficult to measure in the field. The HCM recommends use of a surrogate measure, percent followers, defined as the percentage of vehicles in the traffic stream with time headways smaller than 3 sec.

1.1.2 Luttinen[2]

Luttinen reported a study by Normann[3] who suggested the following performance measures on two-lane highways:

- Proportion of headways less than 9 s,
- Ratio of actual passings to desired passings,
- Average number of passings per vehicle, and
- Speed differences between successive vehicles.

---

[1] Highway Capacity Manual. TRB, National Research Council, Washington, D.C., 2000.

[2] Luttinen, R. T. Percent Time-Spent-Following as Performance Measure for Two-Lane Highways. In Transportation Research Record: Journal of the Transportation Research Board, No. 1776, TRB, National Research Council, Washington, D.C., 2001, pp. 52–59.

[3] Normann, O. K. Results of Highway Capacity Studies. Public Roads,Vol. 23, No. 4, June 1942, pp. 57–81.

1.1.3 Morrall and Werner[4]

Morrall and Werner proposed 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 LOS on two-lane highways. According to the study, the number of passings achieved is the total number of passings for a given two-lane highway, and 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.

1.1.4 Brilon and Weiser[5]

Brilon and Weiser reported the use of average speed of passenger cars over a longer stretch of highway, averaged over both directions, as a major performance measure on two-lane highways.

1.1.5 Christo van As[6]

A South African research project was undertaken to investigate 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, found follower density (number of followers per kilometer) a promising measure of performance on two-lane highways. Among other performance measures considered by the same project are follower flow (followers per hour), percent followers, percent speed reduction due to traffic, total queuing delay, and traffic density.

1.1.6 Romana and Pérez[7]

This study suggested a "new LOS scheme" on two-lane highways using the current HCM performance measures, such as average travel speed and percent time spent following.

---

[4]Morrall, J. F., and A. Werner. Measuring Level of Service of Two-Lane Highways by Overtakings. In Transportation Research Record 1287, TRB, National Research Council, Washington D.C., 1990, pp. 62–69.

[5] Brilon, W., and F. Weiser. Two-Lane Rural Highways: The German Experience. In Transportation Research Record: Journal of the TransportationResearch Board, No. 1988, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 38–47.

[6] Van As, C. The Development of an Analysis Method for the Determination of Level of Service on Two-Lane Undivided Highways in South Africa. Project Summary. South African National Roads Agency, Limited, Pretoria, 2003.

[7]Romana, M. G., and I. Pérez. Measures of Effectiveness for Level-of- Service Assessment of Two-Lane Roads: An Alternative Proposal Using a Threshold Speed. In Transportation Research Record: Journal of the Transportation Research Board, No. 1988, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 56–62.

1.1.7 Ahmed Al-Kaisy and Sarah Karjala[8]

Six performance indicators were investigated in this study:

- 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.

Field data was collected from four study sites in the state of Montana. 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***.

This study takes the same performance measures and platooning variables and tries to fit regression models among them based on Oregon data.

1.2 Problem Definition

PTSF, used in current HCM Manual, is based heavily on traffic simulation, which lacks field validation. PTSF is very difficult to measure in the field. HCM estimates of PTSF are far from field observations, according to the studies by Luttinen[9] and Dixon et al[10]. Therefore there is a need for alternative and practically measurable performance measures to study operations on two-lane rural highways.

1.3 Study Objective

The objective of this study is to examine an array of performance measures, proposed by Ahmed Al-Kaisy and Sarah Karjala, in regard to their suitability in describing performance on two-lane rural highways for Oregon conditions.

---

[8] A. Al-Kaisy, and S. Karjala, Indicators of Performance on Two-Lane Rural Highways :Empirical Investigation, Transportation Research Record: Journal of the Transportation Research Board, No. 2071, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 87–97.

[9] Luttinen, R. T. Percent Time-Spent-Following as Performance Measure for Two-Lane Highways. In Transportation Research Record:Journal of the Transportation Research Board, No. 1776, TRB, National Research Council, Washington, D.C., 2001, pp. 52–59.

[10] Dixon, M. P., S. S. K. Sarepali, and K. A. Young. Field Evaluation of Highway Capacity Manual 2000 Analysis Procedures for Two-Lane Highways. In Transportation Research Record: Journal of the Transportation Research Board, No. 1802, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 125–132.

1.4 Study Methodology

The first step in the study is to identify the performance indicators and platooning variables which explain the operations of traffic on rural two-lane highways. Data collection comes next, and requires prior effort in the form of defining site selection criteria, checking the sample size and location, and determining the season and duration of data collection. After collection, data should be processed to obtain the required inputs. Then, a model is formulated, and statistical analysis of data is performed to predict performance measures. Finally, model validation is conducted to check the model accuracy.

2 Adopted Measures of Performance

The following performance measures are adopted for this study.

- Average travel speed (ATS)
- Average travel speed of passenger cars (ATSPC),
- ATS as a percent of free-flow speed (ATS/FFS),
- ATSPC as a percent of free-flow speed of passenger cars (ATSPC/ FFSPC),
- Percent followers (PTfollowers), and
- Follower density (FLdensity)

2.1 Average Travel Speed (ATS)

ATS was used as one of the two performance measures used in the 2000 version of HCM. Average speed does not consider the variations of geometric and other operational characteristics. Although it is easy to measure in the field, ATS alone may not give accurate picture of traffic performance on two-lane rural highways.

2.2 Average Travel Speed of Passenger Cars (ATSPC)

The average travel speed of passenger cars (ATSPC) is currently used in Germany and Finland as a performance indicator. Average travel speed of passenger cars may more accurately describe speed reduction due to traffic because passenger car speeds are more affected by high traffic volumes than are heavy vehicle speeds. This performance indicator has the same limitations and strengths as those for overall ATS discussed earlier.

2.3 Average Travel Speed as Percentage of Free-Flow Speed

Average travel speed as a percentage of free-flow speed (ATS/FFS) is an indicator of the amount of speed reduction due to traffic. If average travel speed is close to free-flow speed, then the interaction among successive vehicles in the traffic stream is small and a high level of service or performance is expected. A lower percentage indicates a higher interaction between vehicles in the traffic

stream and therefore a lower quality of service. ATS as a sole measure of performance is a limitation, although this indicator can easily be measured in the field.

2.4 Average Travel Speed of Passenger Cars as Percentage of Free-Flow Speed of Passenger Cars (ATSPC/ FFSPC)

ATSPC as a percentage of the free-flow speed of passenger cars is similar to the previous performance indicator, except that heavy vehicles are not considered in the speed measurements. The rationale behind this performance indicator is that passenger cars more accurately describe speed reduction due to traffic because their speeds are more affected by high traffic volumes than are heavy vehicle speeds. This performance indicator has the same limitations and strengths as those for ATS/FFS.

2.5 Percent Followers

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 sec as recommended by the HCM. Moreover, the percentage of short headways in the traffic stream is a function mainly of traffic flow level and speed variation. As flow increases, so do 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 concerning highway improvements and upgrades.

2.6 Follower Density

Follower density is the number of followers in a directional traffic stream over a unit length, typically one mile stretch of a highway. The argument behind using this 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. The main advantage of using this performance indicator is that, unlike percent followers, it takes into account the effect of traffic level on performance. Although 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.

3 Data Collection & Analysis

Geographic setting, traffic volumes, and terrain are among the considerations for the selection of study sites. All sites are located in rural areas on roughly straight segments, and far from the influence of traffic signals and driveways. In total, data is collected at 17 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 was recorded on direction of travel, date and time, number of axles, vehicle class, speed (mph), time gap (sec), headway (sec), acceleration (ft/sec^2), and spacing between axles. The 2010 AADT varies from 850 to 8100 vpd, and percent heavy vehicles varies from 5 to of 21%. Except for three sites, all sites are located in level terrain. All sites operate as two-lane two-way traffic. Traffic data was collected over two consecutive two days. Table A1 in the Appendix describes the data collection sites.

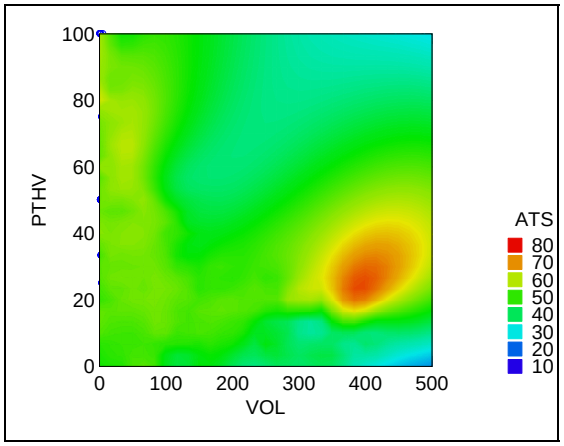
Data from automatic traffic recorders are processed to measure various performance indicators and platooning variables. In the measurement of flow rates for each direction of travel, vehicle counts are aggregated to hourly rates. The percentage of heavy vehicles is found from vehicle classification provided in the recorder output. Free-flow speed is calculated in this analysis by averaging the speed of all vehicles traveling with headways greater than 8 s. Percent followers is calculated using headways less than 3 s. The same headway cutoff value 3 s, is used in determining follower density. Follower density (veh/mil/lane) is calculated as the number of followers (vph) divided by the average follower travel speed (mph). These calculations are performed for each hour at all sites. Site specific hourly data is used to develop site specific models between performance indicators and platooning variables. Later, all site data is aggregated to build the final version of the model.

4 Model Development

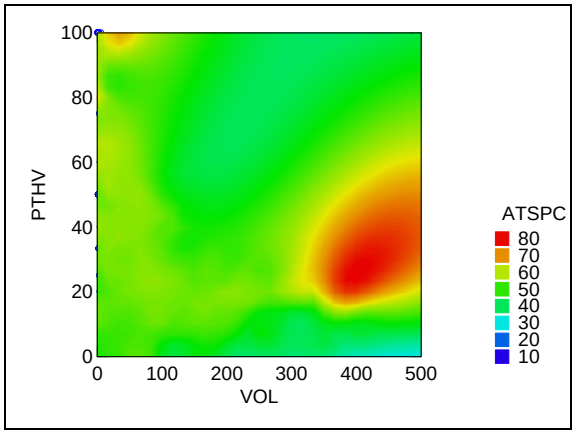
Model development is aimed at examining the level of association between performance indicators on two-lane highways and the "platooning" phenomenon through its major contributory factors.

4.1 Data Analysis Results

The analyses involve graphical examination of relationships along with the use of correlation and regression statistical analyses. Site-specific and across-sites examinations are conducted in this study. The relationship between the proposed performance indicators and platooning variables for all the sites combined is plotted first to explore the trends and patterns.



a) Average Travel Speed(ATS)



b) Average Travel Speed of Passenger Cars

Figure 1 Variation of speeds with Volume (VPH) and % Heavy Vehicles (%)

Although as the volume and % heavy vehicles increases ATS decreases, there is no definite pattern observed among sites, as shown in Figure 1. Higher percent of heavy vehicles are observed for lower volumes during the night off peak periods, where heavy vehicle volume usually dominates the traffic flow. Similar trend is observed for ATSPC. Clearly shown in Figure 2, the ratio between ATS and FFS decreases as the volume and % heavy vehicles increases.

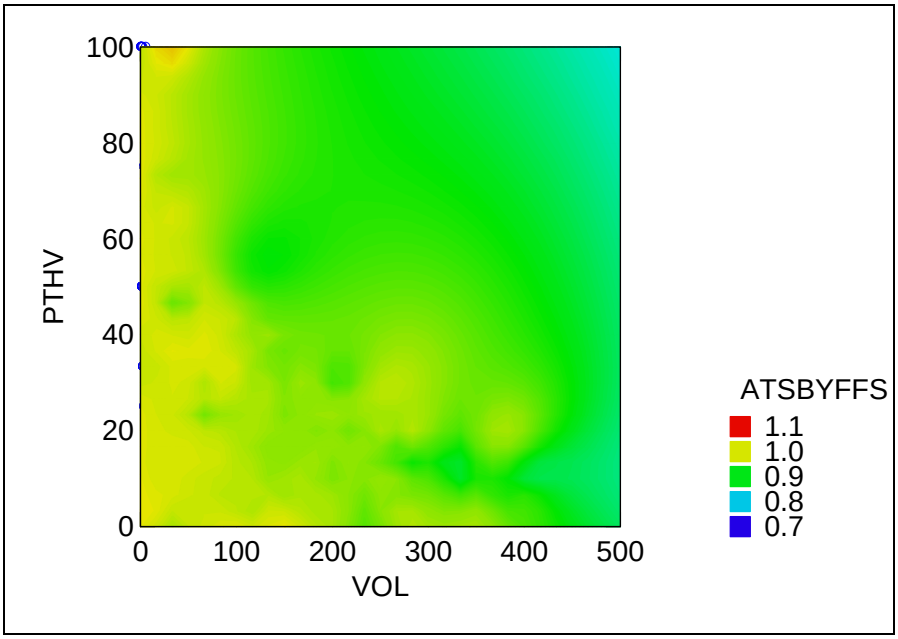


Figure 2 Variation of ratio ATS/FFS with Volume (VPH) and % Heavy Vehicles (%)

Roughly, increases in volume and percent heavy vehicles increases percent vehicles following. This trend is obvious when heavy vehicles are below 25%.

The trends of percent followers with varying VOL and percent heavy vehicles are shown in figure 3.

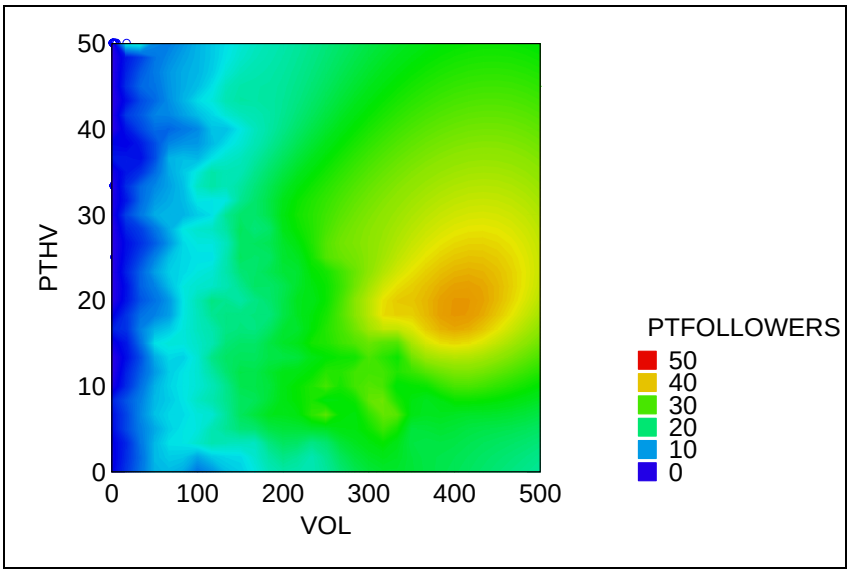


Figure 3 Variation of percent followers with Volume (VPH) and % Heavy Vehicles (%)

Figure 4 shows the bands for follower densities. Follower densities have the value ranging from 0 to 4 vehicles/mile/lane.

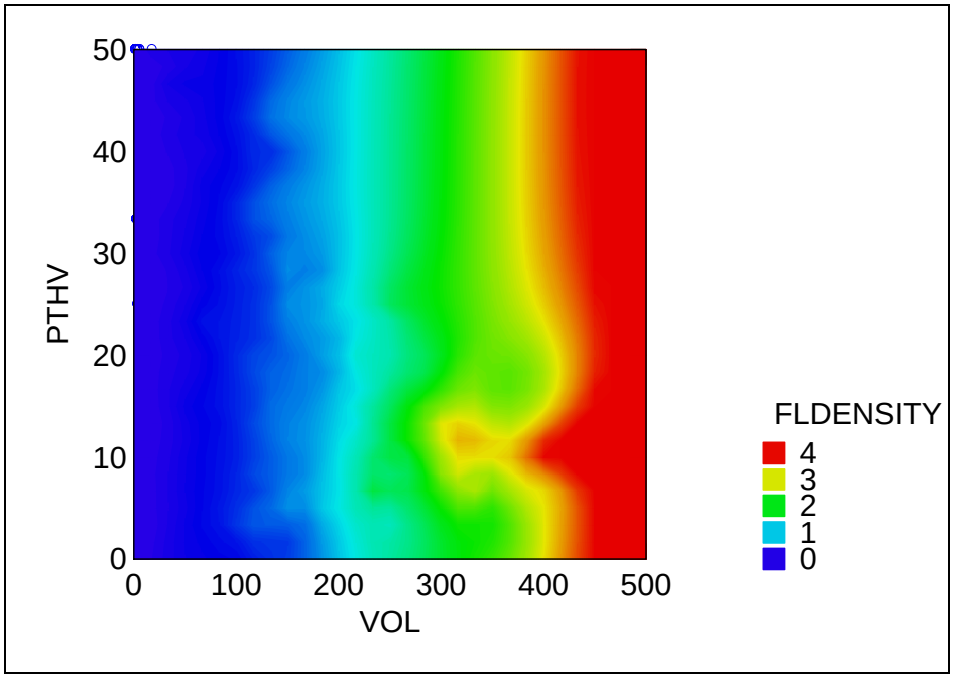


Figure 4 Variation of follower densities with Volume (VPH) and % Heavy Vehicles (%)

As traffic flow increases, average percent followers relatively increases as shown in Figure 5. Similarly, increase in followers reduces average travel speed as shown in Figure 6.

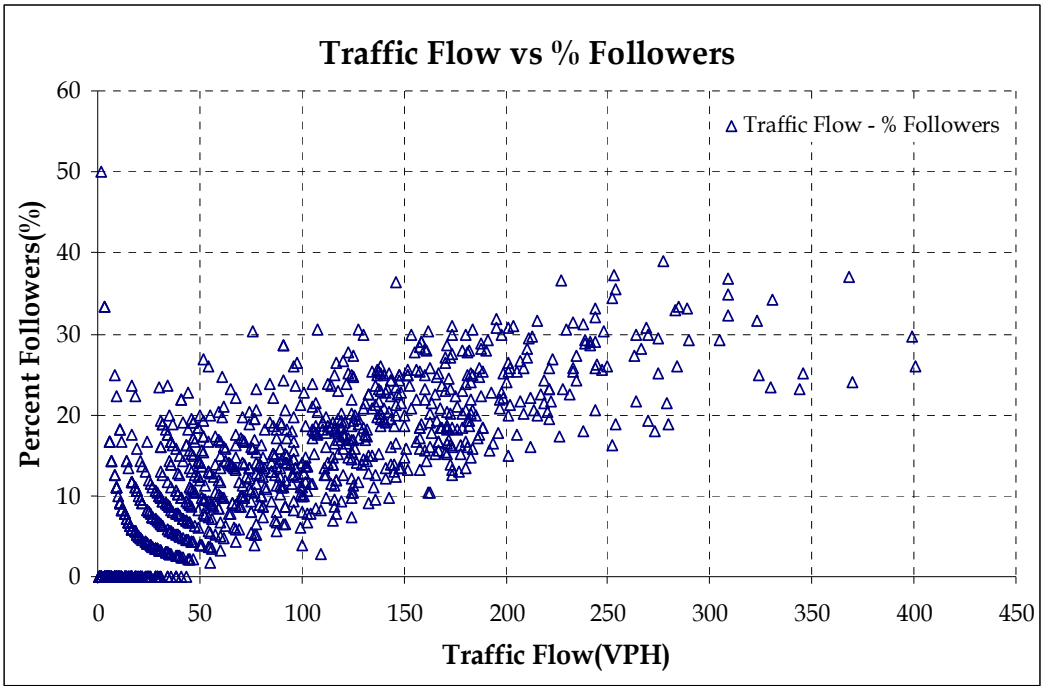


Figure 5 Traffic flow and % followers

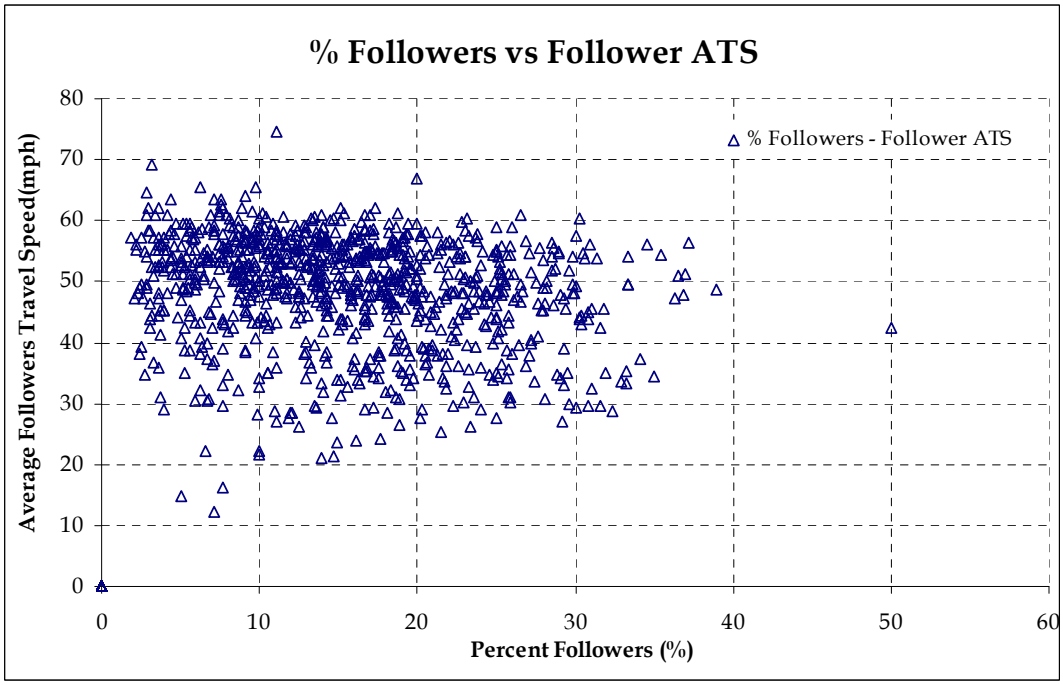


Figure 6 Percent Followers and Average Followers Travel Speed

Figure 7 shows the trend of increasing follower density with increasing percent followers. Figure 8 shows followers average travel speed decreases as the follower density increases.

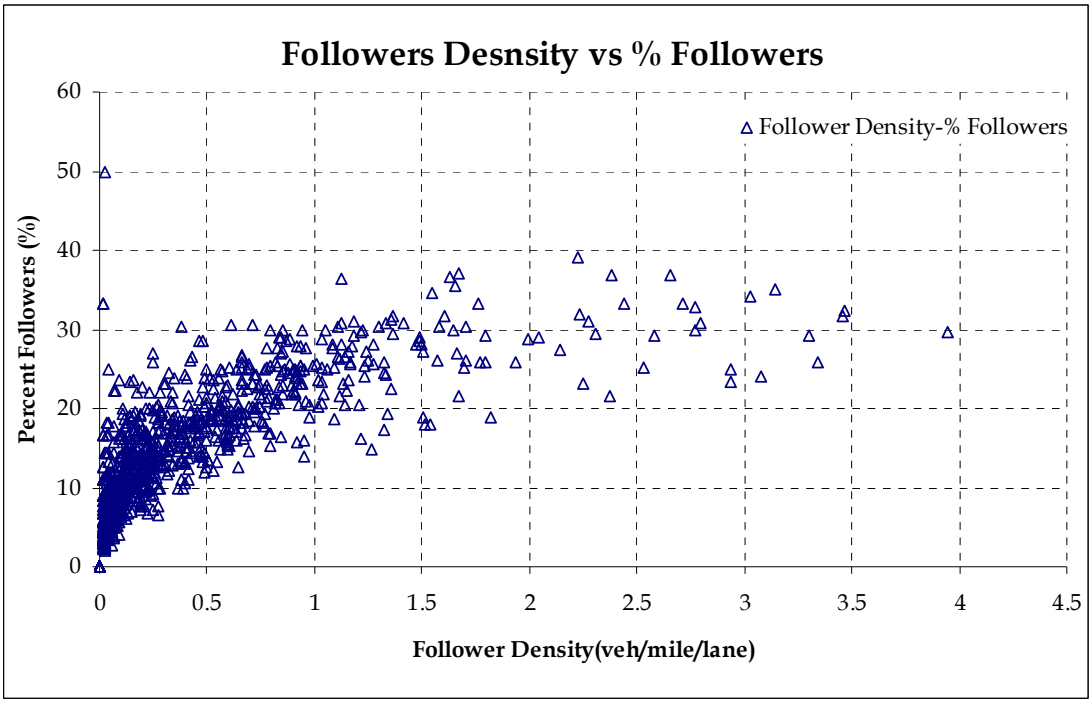


Figure 7 Followers Density and Percent Followers

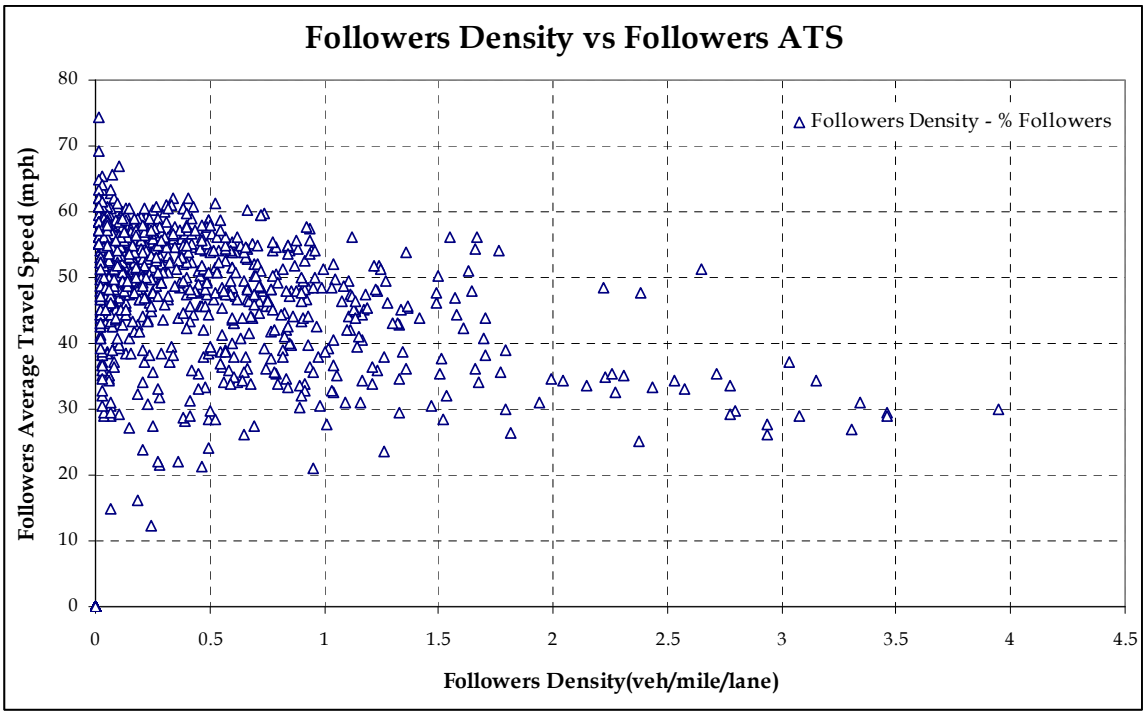


Figure 8 Followers Density and Followers Average Travel Speed

As the volume group and its corresponding opposing volume increases, follower densities increases as distinguished bands, shown in Figure 9.

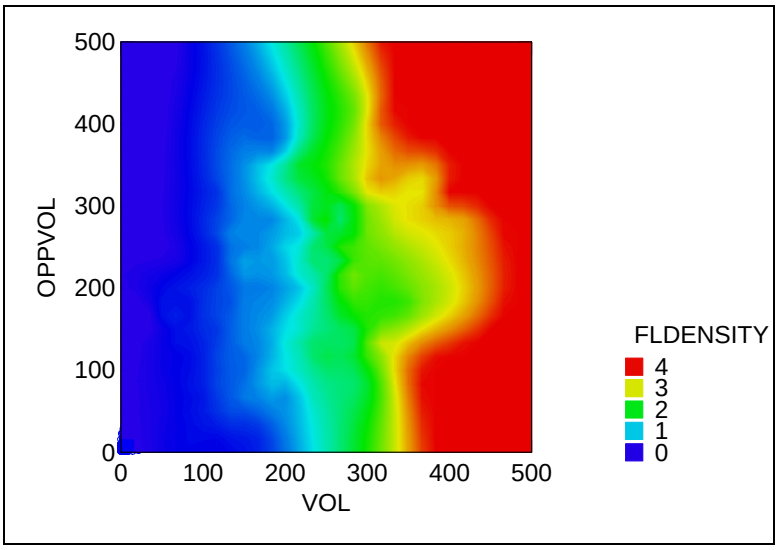


Figure 9 Variation of follower density with volume and opposing volume

Figure 10 shows lower speeds and higher percent followers reflect higher follower densities. Although follower densities show bands, it is very difficult to set LOS intervals based on follower density values for follower ATS and percent followers.

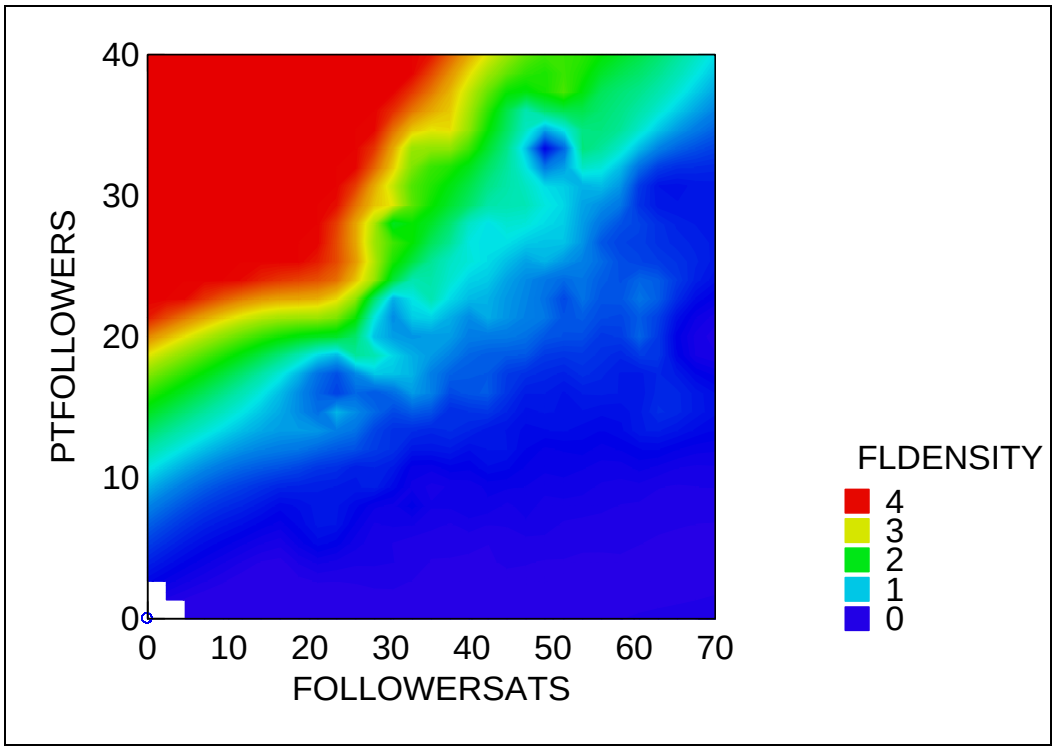


Figure 10 Variation of follower density with volume and opposing volume

4.2 Model Form

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

- Average travel speed (ATS)
- Average travel speed of passenger cars (ATSPC),
- ATS as a percent of free-flow speed (ATS/FFS),
- ATSPC as a percent of free-flow speed of passenger cars (ATSPC/ FFSPC),
- Percent followers (PTfollowers), and
- Follower density (FLdensity)

Independent variables (platooning variables) considered are:

- Traffic flow in the direction of travel,
- Opposing traffic flow,
- Percent heavy vehicles,
- Standard deviation of free flow speeds, and
- Percent no-passing zones.
- Terrain

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 $X_1, X_2, \ldots\ldots X_n$

4.3 Model

Regression modeling and corresponding statistical analysis was performed using code written in the R statistical package. The statistically significant model is given in Table 1.

Table 1 Fitted models for various performance indicators

```
---------------------------------------------------------------------
model for  FL density   vs    VOL  ,  OPPVOL  ,  PTHV  , % No Passing,
and  Terrain
---------------------------------------------------------------------
Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.4823332  0.0256702 -18.790  < 2e-16 ***
totaldata$VOL       0.0067640  0.0001519  44.531  < 2e-16 ***
totaldata$OPPVOL   -0.0006175  0.0001516  -4.074  4.9e-05 ***
totaldata$PTHV      0.0008791  0.0003850   2.283   0.0226 *
totaldata$PtNOPASS  0.0008097  0.0001768   4.580  5.1e-06 ***
totaldata$Terrain   0.2482458  0.0180203  13.776  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2074 on 1266 degrees of freedom
Multiple R-squared: 0.8456,   Adjusted R-squared: 0.845
F-statistic:  1387 on 5 and 1266 DF,  p-value: < 2.2e-16
```

Based upon the statistical analysis, follower density is chosen as the performance indicator. The model fitted between Follower Density (veh/mile/lane) as the independent variable, and Traffic Flow (vph) , Opposing Flow (vph) , Percent of Heavy Vehicles (%) , Percentage No Passing (%), and Terrain as the dependent variables, has the highest R^2 value and statistical significance.

```
Follower Density =
-0.4823332+0.0067640(Traffic Volume)-0.0006175(Opposing Volume)
+0.0008791 (%Heavy Vehicles) +0.0008097 (% No Passing)
+ 0.2482458 (Terrain)
R² = 0.845
Terrain: Either Level or Rolling Type
1 for Level ; and 2- for Rolling
```

The next section deals with model validation and checking the model consistency for varying conditions.

4.4 Performance of Montana Study

The developed model is compared with the similar study done in the State of Montana by Ahmed Al-Kaisy and Sarah Karjala[11]. The Montana Models are shown below.

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

Figure 11 shows the performance of Montana Model when compared to observed follower density. A linear relation does not exist between them. The error between observed and Montana model exceeds 1 vehicle/mile/lane as given in Figure 12.

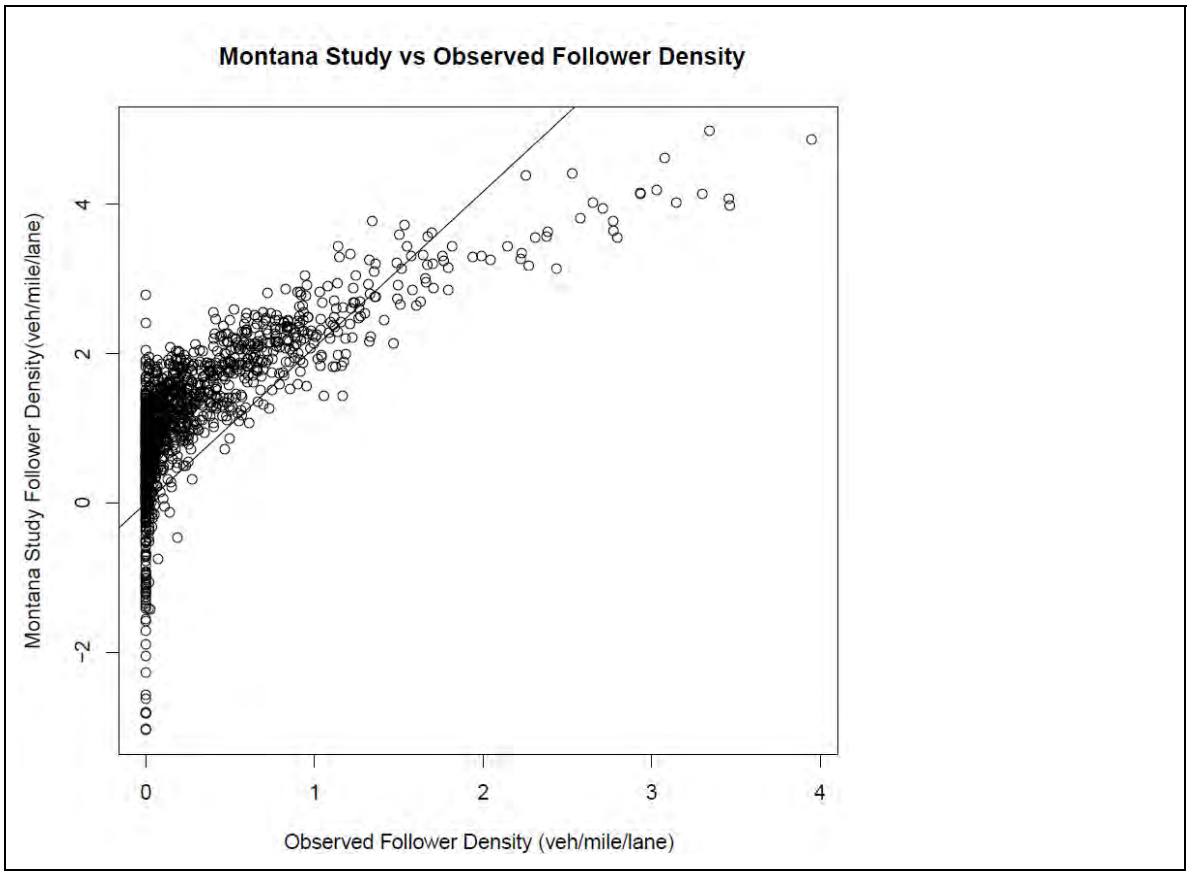


Figure 11 Montana Study and Observed Follower Density

[8]A. Al-Kaisy, and S. Karjala, Indicators of Performance on Two-Lane Rural Highways :Empirical Investigation, Transportation Research Record: Journal of the Transportation Research Board, No. 2071, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 87–97.

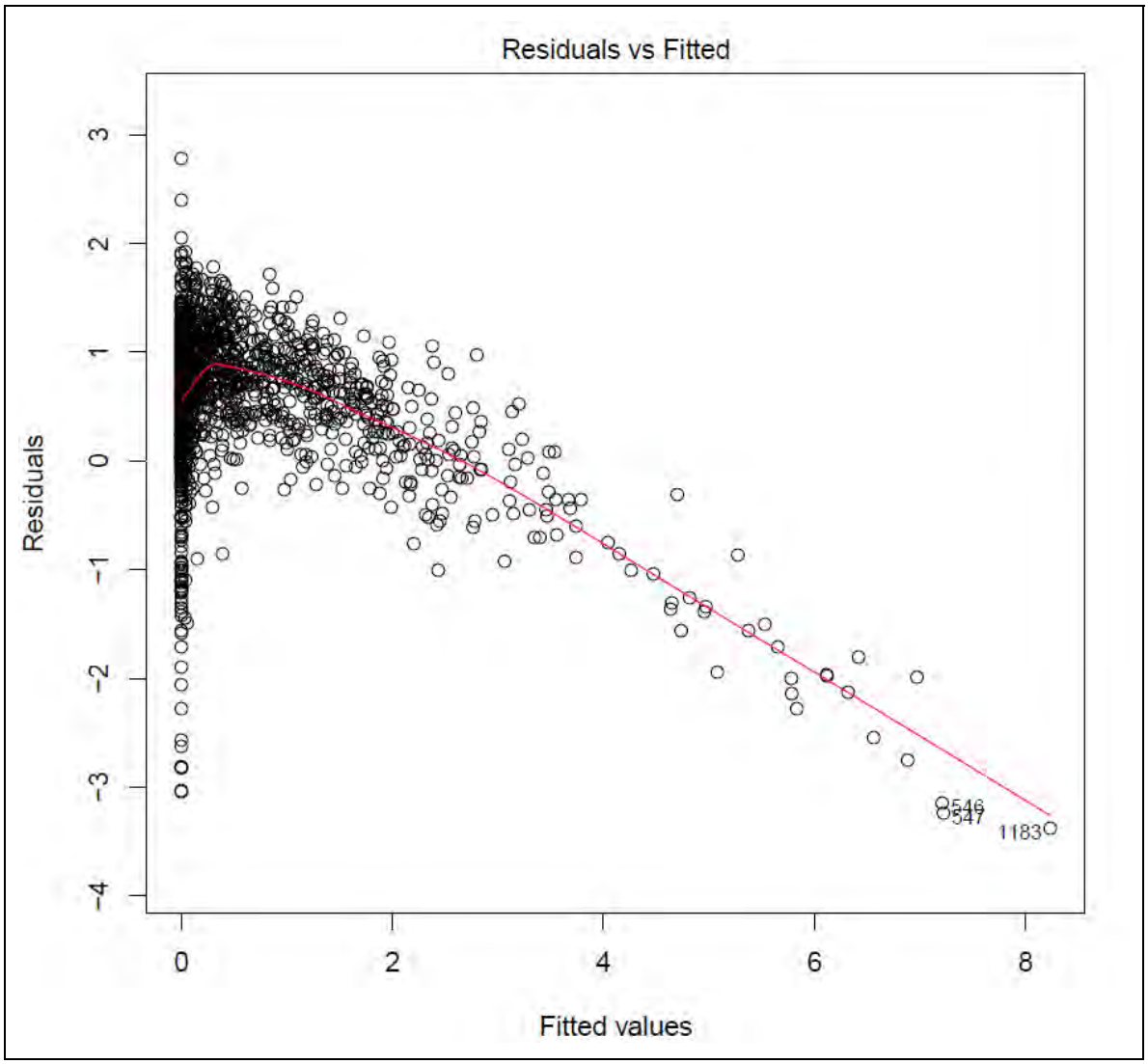


Figure 12 Error between Montana Study Follower Density and Observed Follower Density

5 Model Validation

5.1 Data Collection

The model is validated by using data sets from four sites. These sites are part of the original data collection efforts and are separated based on AADT, terrain, and geographic region to cover all possible conditions. The sites that are considered and their brief description are given in Appendix A, Table A2. Data analysis and preparation of data sets are done according to the procedure mentioned in the section 3.

5.2 Data Analysis

Hourly data from all sites are tested with the developed model and comparison is made between observed field densities and predicted field densities. The error

between observed and predicted densities varies by ± 0.5 veh/mile/lane as shown in Figure 13.

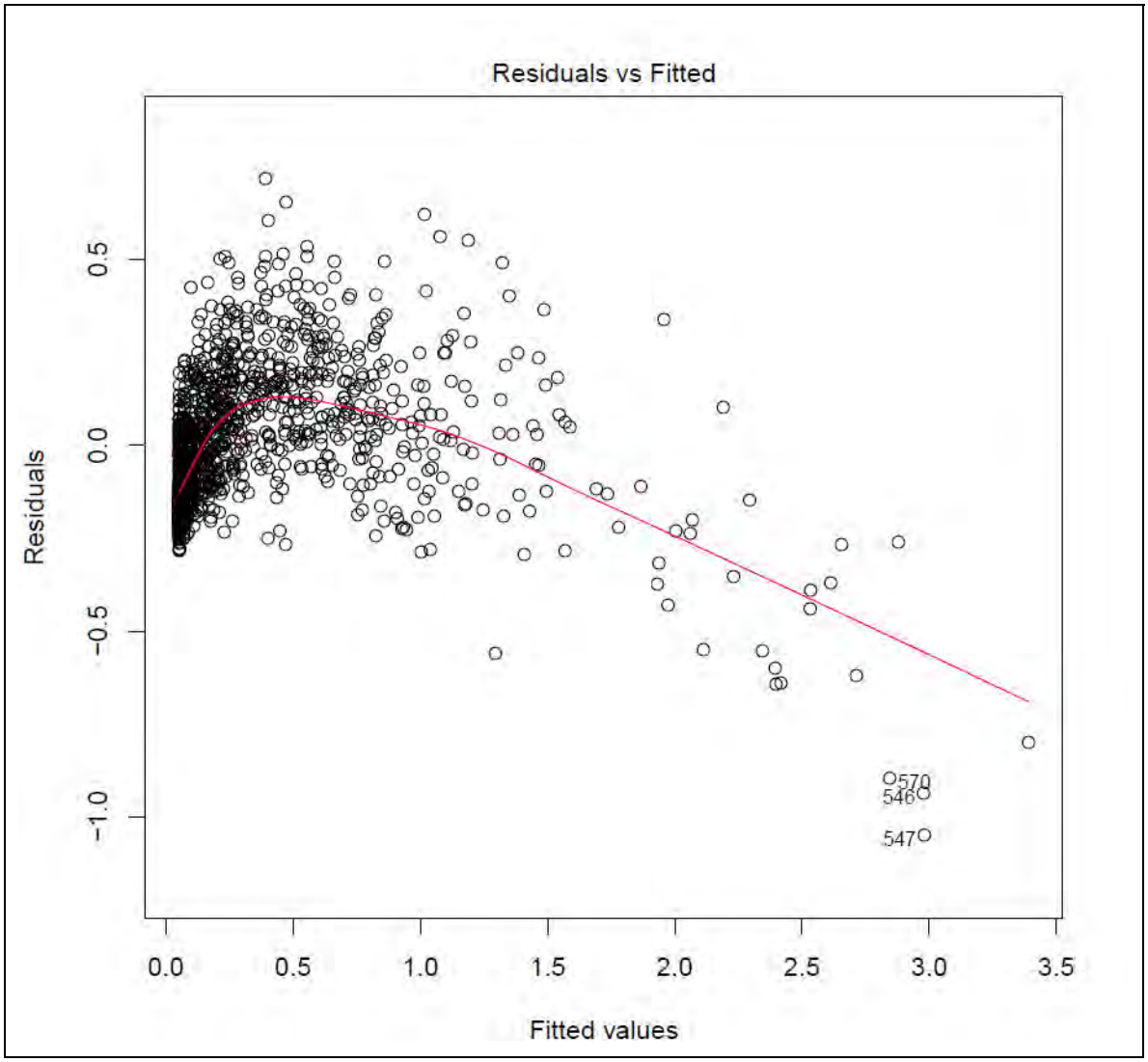


Figure 13 Residuals plot of predicted follower density and observed follower density

A regression model was fitted between the predicted follower density and observed follower densities. A summary of the regression analysis is listed in Table 2 and shown in Figure 14.

Table 2 Regression model between predicted follower density and observed follower density

```
Call:
lm(formula = totaldata$predictedFLdensity ~ totaldata$FLdensity,
    data = totaldata)
Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)         0.051884   0.006334   8.191 6.26e-16 ***
totaldata$FLdensity 0.845617   0.010139  83.404  < 2e-16 ***

Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.1904 on 1270 degrees of freedom
Multiple R-squared: 0.8456,   Adjusted R-squared: 0.8455
F-statistic:  6956 on 1 and 1270 DF,  p-value: < 2.2e-16
```

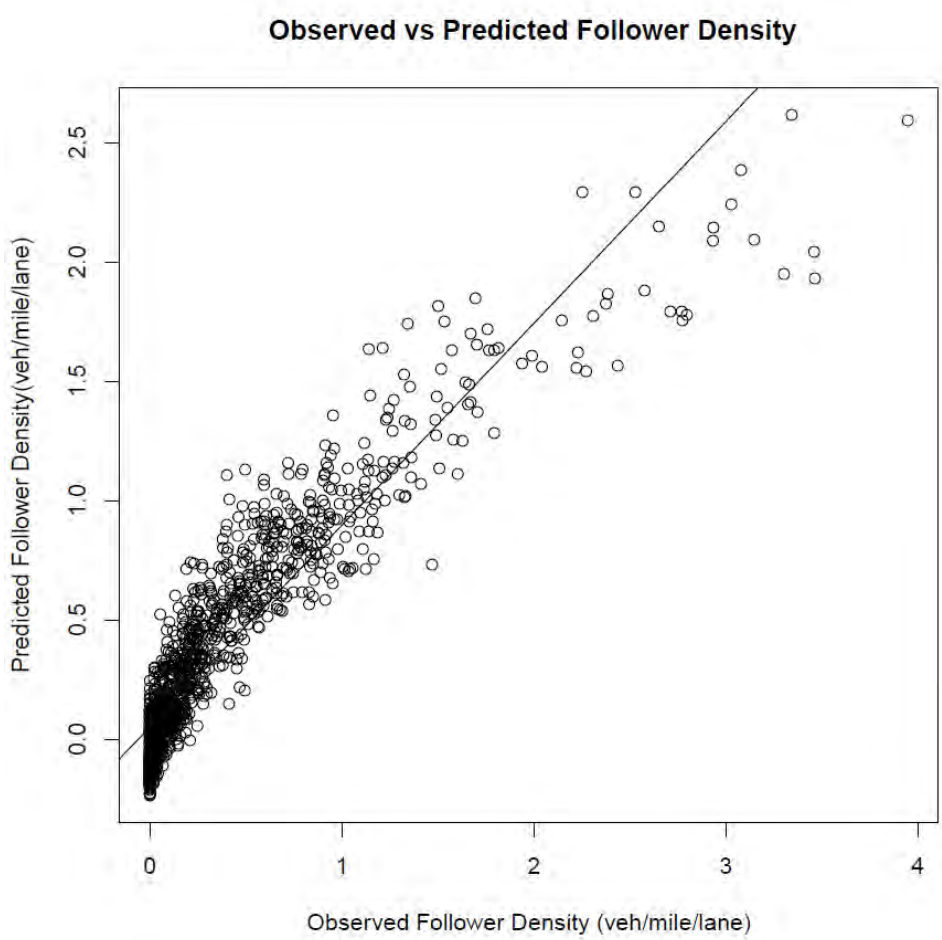


Figure 14 Observed follower density and predicted follower density

5.3 Model Comparison

Both the developed model and the Montana model are compared against the error in estimating follower densities. The error between observed follower densities and developed model estimated follower densities varies between ±0.5 veh/mile/lane. The error varies from + 1.3 veh/mile/lane to -2.7 veh/mile/lane for the Montana model.

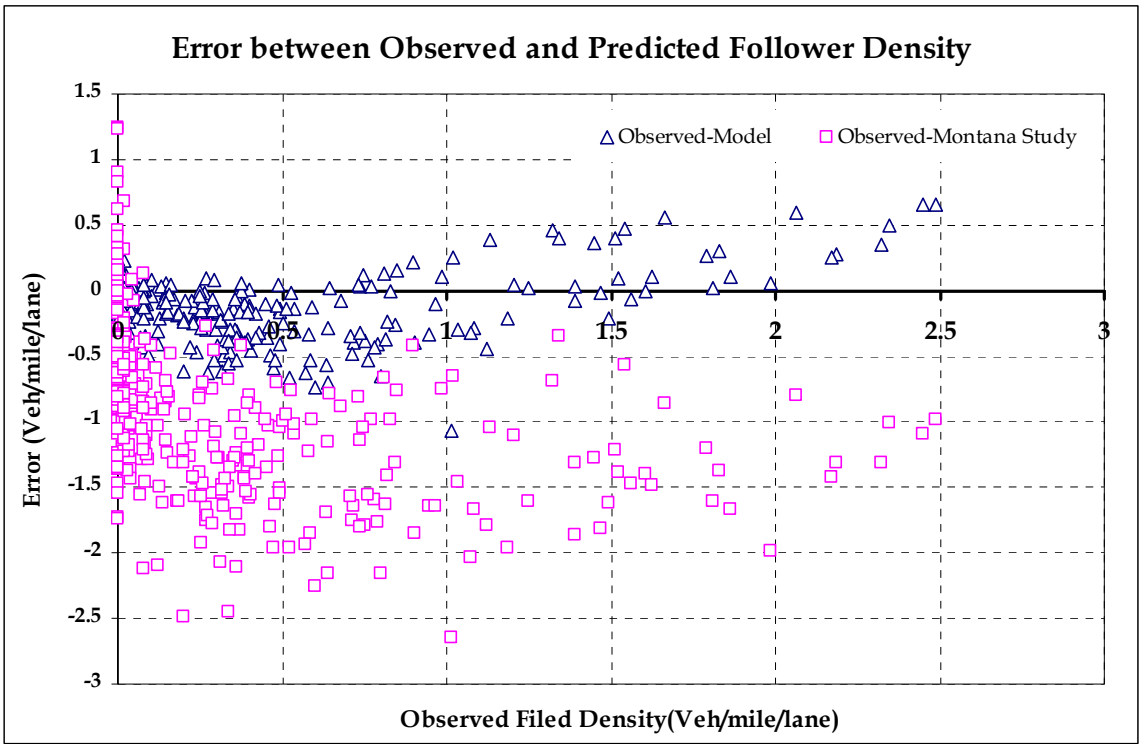


Figure 15 Error Variation among the Models

6 Summary

The difficulty in measuring Percentage Time Spent Following (PTSF) in the field led to the study of alternative performance measures to deal with operations on two-lane rural highways. This study is based on research work done in the state of Montana, expanded to state of Oregon rural two-lane highway conditions. Performance indicators Average travel speed (ATS), Average travel speed of passenger cars (ATSPC), ATS as a percent of free-flow speed (ATS/FFS), ATSPC as a percent of free-flow speed of passenger cars (ATSPC/FFSPC), Percent followers (PTfollowers), and Follower density (FLdensity) are tested on data collected through detectors at 13 sites. Regression models are developed by taking the above mentioned performance indicators as dependent variables, and the platooning variables, such as traffic flow in the direction of travel, opposing traffic flow, percent heavy vehicles, standard deviation of free flow speed, 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. Later, data from 4 sites were used to validate the model. The error between the observed follower density and predicted follower density varies by ± 0.5 veh/mile/lane. The variation of observed follower density with average travel speed and percent followers has groups, but does not have clearly cut boundaries to mark level-of-service zones. Moreover, volume to capacity ratios on two-lane rural roads are small. Observed follower density varies from 0 to 4 veh/mile/lane. A wide spectrum of follower densities may designate more clear cut level of service categories.

```
Follower Density =
-0.4823332+0.0067640(Traffic Volume)-0.0006175(Opposing Volume)
+0.0008791 (%Heavy Vehicles) +0.0008097 (% No Passing)
+ 0.2482458 (Terrain)
R2 = 0.845
Terrain: Either Level or Rolling Type
1 for Level ; and 2- for Rolling
```

7 Scope for Future Work

The model can be refined by obtaining more site data covering a spectrum of geographic areas, higher volumes, and rolling and mountainous sites. Following other vehicles is critical during peak periods, so consideration should be given to further model development using variables calculated in those periods.

Appendix A -Description of Data Collection Sites

Table A1 Sites used for model development

No	TSM Site Id	Hwy_No	BMP	MP (Count Loc)	EMP	Description	AADT	County	FC	% Trucks	Terrain	% No Passing
1	967	8	23.45	23.47	26.20	0.02 mile north of Blue Mt. Station Rd	6400	Umatilla	2	12	L	0%
2	1336	10	22.11	24.59	24.61	0.02 mile west of Good Rd	1800	Union	2	21	L	45%
3	1352	10	65.87	68.46	68.59	0.02 mile west of Crow Creek Rd	3300	Wallowa	2	21	L	90%
4	1610	21	6.46	6.61	9.18	Siskiyou ATR 15-007	1000	Jackson	6	7	L	85%
5	1654	22	45.31	51.37	54.87	0.10 mile east of Woodruff Bridge Rd	1900	Jackson	6	9	L	0%
6	1656	22	57.31	57.81	61.94	0.50 mile east of West Diamond Lake Hwy	850	Jackson	7	9	R	5%
7	3240	140	42.88	43.33	44.83	0.22 mile south of Bonney Rd	6000	Marion	6	5	L	25%
8	3437	160	20.76	22.15	22.96	Marquam ATR 03-013	3900	Marion	6	10	L	35%
9	3449	161	7.59	7.69	9.11	0.10 mile east of Canby-Marquam Rd	6000	Marion	6	9	L	20%
10	3558	171	30.92	39.13	39.23	0.10 mile north of Fish Creek Rd	1400	Clackamas	7	5	L	45%
11	3775	212	0.21	1.45	1.47	0.02 mile west of Bond Road	4400	Linn	6	16	L	55%
12	4074	272	8.64	9.76	11.83	At Johnson Creek, 0.07 mi east of Crystal Dr	2900	Jackson	6	5	L	100%
13	4118	281	3.61	4.16	5.09	0.02 mile south of Portland Dr	8100	Hood River	6	7	R	75%

Table A2 Sites used for model validation

No	TSM Site Id	Hwy_No	BMP	MP (Count Loc)	EMP	Description	AADT	County	FC	% Trucks	Terrain	% No Passing
1	961	8	12.75	16.05	16.07	0.02 mile west of Pambrun Rd	4500	Umatilla	2	12	L	40%
2	2916	71	40.11	41.75	41.85	0.10 mile west of Dooley Mtn Hwy	1000	Baker	6	6	L	100%
3	3565	172	1.55	1.56	3.14	0.10 mile northeast of Judd Rd	5700	Clackamas	6	9	R	35%
4	4059	271	10.68	10.83	15.81	0.15 mile east of Table Rock Road	2500	Jackson	6	9	L	10%