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This is a postprint of an article that originally appeared in [Transportation Research Record](#) on January 2017. The final version can be found at [10.3141/2615-08](#).

Al-Kaisy, Ahmed, Amirhossein Jafari, and Scott Washburn. "Measuring Performance on Two-Lane Highways: Empirical Investigation." *Transportation Research Record: Journal of the Transportation Research Board* 2615, no. 1 (January 2017): 62–72. doi:10.3141/2615-08.

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Measuring Performance on Two-Lane Highways: Empirical Investigation

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November 2016

Word count: 4472 (text) + 5×250 (table) + 6×250 (figure) = 7222 word equivalents

ABSTRACT

This paper presents an empirical investigation into several performance measures for operational analysis on two-lane highways. The performance measures investigated are average travel speed, average travel speed to free flow speed, percent followers, followers flow, followers density, percent impeded, impeded flow and impeded density. Field data from 16 study sites in the states of Montana, Idaho, Oregon, and North Carolina representing class I, class II, and class III highways were used in this study. The level of association between performance measures and some of the most important traffic variables were examined using graphical and statistical techniques. The traffic variables investigated in this study included combined flow in both directions of travel, proportion of traffic in direction of travel, called in this study as traffic split, percentage of heavy vehicles and speed variance. Study results suggest that speed-related measures have weak associations with traffic variables compared to headway-related measures. Further, compound measures involving headway and traffic flow or density exhibited highest associations with traffic variables. In regards to two-lane highway type, higher associations are exhibited at class I sites compared to class II and class III sites. Performance measures showed highest associations with combined flow and traffic split respectively.

Keywords: *Two-lane highways, operational analysis, performance measures.*

INTRODUCTION

Two-lane two-way highways constitute a large proportion of the highway network in the United States, particularly in rural areas. The unique characteristic that separates two-lane highways from other uninterrupted flow facilities is that passing occurs on the opposing lane of traffic. There should be adequate gap and sight distance in the opposite direction that a passing maneuver could take place. Passing opportunities decrease as flow rate and geometric restrictions increase. Lack of passing opportunities typically results in formation of platoons with trailing vehicles subject to additional delay.

Performance indicators are used to assess operations and the quality of service on two lane highways. They reflect the level of freedom for drivers to select their desired speeds and pass slow moving vehicles. Measuring performance is important for operational analysis and for upgrade and improvement projects. A low Level of Service (LOS) on a section of two-lane highway may be improved by adding a passing lane or expanding the route into a continuous three lane section or a multilane highway.

Operational analysis on two-lane highways in the U.S. is usually conducted using the procedures outlined in the Highway Capacity Manual (HCM) 2010 (1). Average travel speed (ATS) and percent time spent following (PTSF) are used in the HCM for evaluating performance on class I two-lane highways. Class I highways include major intercity routes, daily commuter routes, and major links in state or national highway network. The PTSF is defined as “the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of an inability to pass.” PTSF is also used for class II two-lane highways which involve highways that serve as access routes to class I facilities as well as scenic and recreational routes. On those highways, motorists do not necessarily expect to travel at high speeds. Due to difficulties in measuring the PTSF in field, the HCM recommends a surrogate measure, percent followers, calculated as the percentage of vehicles following other vehicles with headways smaller than 3 seconds. Percent Free Flow Speed (PFFS) is used for evaluating performance on class III highways. It is the ratio of average travel speed to free flow speed. Class III highways are two-lane highways serving moderately developed areas. They may include portions of class I and class II highways that pass through small towns or developed recreational areas.

There are some limitations inherent to the current HCM performance measures. The PTSF is impractical to measure in the field, and it is not compatible with performance measures of other facilities. Moreover, the PTSF cannot describe all flow regimes and it doesn't support other analyses including safety, environmental, reliability and economic analyses. The ATS, on the other hand, does not provide much information about operational conditions. The lack of a benchmark along the performance scale is one limitation of using average travel speed as a sole performance measure as reported by Al-Kaisy and Karjala (2). The PFFS, an indicator of speed reduction due to traffic, can easily be measured in the field and addresses the limitations related to average travel speed; however adding a passing lane will not affect this performance measure as reported by Al-Kaisy and Freedman (3).

Due to the limitations in HCM performance measures mentioned above, the current research attempts to examine several proposed measures for use in the operational analysis on two-lane highways.

BACKGROUND

The HCM 1950 (4) was the first document introducing an analytical method for capacity analysis of two lane highways. Practical capacity, which corresponds to the capacity under

reasonable driving condition, was used in this manual to assess the operating conditions on two-lane highways. Operating speed was the indicator for measuring the practical capacity. The concept of level of service was presented in the second edition of the HCM in 1965 (5). Operating speed and volume to capacity (v/c) ratio were used to estimate the level of service on two-lane highways. In 1985, the HCM introduced percent time delay (PTD) for measuring performance on two-lane highways besides average travel speed (6). It refers to the percentage of time that vehicles are delayed and trapped in platoons due to inability to pass slower vehicles. Delay refers to situations where drivers travel at speeds lower than their desired speeds. Headway threshold of 5 seconds was used to estimate the PTD in the field. The fourth edition of the HCM introduced PTSF which is a similar measure to PTD and refers to the percent of time vehicles are following other vehicles on two-lane highways (7). The percentage of vehicles with headways less than 3 seconds was used as a surrogate measure for PTSF in this edition of the HCM. The most recent edition of the HCM was released in 2010 (1) and introduced a new classification for two-lane highways: classes I, II and III. The percent free flow speed was the new measure introduced in this edition for operational analysis of class III two-lane highways.

Several other performance measures have been proposed in the literature. Overtaking ratio was introduced as a performance measure by Moral and Werner (8). It is defined as the ratio of the number of passing achieved to the number of passing desired. Brilon and Weiser reported on the use of density as a performance measure in Germany (9). Furthermore, average travel speed of passenger cars over a long stretch of the highway has been used in Germany for two lane highways analysis. Van As (10) developed an alternative model for operational analysis of two-lane highways in South Africa. Several performance measures including percent followers, follower flow, follower density, travel speed, percentage speed reduction due to traffic, traffic density and total queuing delay were investigated in his study. Follower flow was defined as the flow rate of vehicles trapped in platoons. A headway threshold of 3.5 seconds was used to identify the platooned vehicles in this study. Follower density refers to the number of followers per unit length of the highway. It is found using the product of percent followers and density. Catabgan and Nakamura (11) evaluated several performance measures for two lane expressways in Japan. Average travel speed, density, percent time spent following, percent followers and follower density were among the performance measures investigated. Follower density showed the highest correlation with flow rate in their study. Percent impeded is another performance measure introduced by Al-Kaisy and Freedman (12). It is defined as the percentage of vehicles trapped in platoons and impeded by slower vehicles. It is calculated as the product of percent followers and the probability of a vehicle being impeded, i.e. forced to travel at a speed lower than the desired speed. The impedance probability is found using the speed distribution of non-platooned vehicles and average speed of platooned vehicles. The study showed that percent impeded had the highest correlation with platooning variables on two-lane highways using data from a passing lane site. In another study by Al-Kaisy and Karjala (2), follower density followed by percent followers exhibited the highest correlation with platooning variables. In Spain, Moreno et al. (13) evaluated several performance measures and reported on follower density and percent followers as the best performance measures. Hashim and Abdel-Wahed (14) conducted the same evaluation for two-lane roads in Egypt. Follower density was found to have the highest correlation with platooning variables. Penmtsa et al. evaluated several performance measures for Indian two lane highways under mixed traffic condition (15). Number of followers as a proportion of capacity (NFPC) was introduced as a new performance measure. Followers were defined as the number of vehicles traveling with a gap less than 2.6 s. The new measure showed a very strong correlation with traffic volume.

RESEARCH MOTIVATION

As discussed earlier, the current performance measures for evaluating level of service on two-lane highways have some limitations. These limitations were the main motive behind this study. Specifically, this study aims at examining the suitability of some proposed performance measures for use in two-lane highway capacity analysis.

STUDY DESIGN

In order to assess the suitability of performance measures, the association between several performance measures and traffic variables were investigated in this research. Traffic variables investigated consisted of combined flow in both directions of travel, heavy vehicle percentage (% HV), traffic split (proportion of traffic in travel direction), speed variance and percent no passing zone. Performance measures used in this investigation include:

- Average Travel Speed (ATS): Average speed of all vehicles traveling in the direction of analysis.
- Average Travel Speed to Free Flow Speed (ATS/FFS): The ratio between the average travel speed of all vehicles to free-flow speed. In this study, average speed of vehicles with headway more than 8 seconds was used to establish the free-flow speed.
- Percent Followers (PF): Percentage of vehicles with headways less than 3 seconds (a surrogate measure used by HCM to estimate PTSF using field data).
- Follower Density (FD): The number of vehicles with headways less than 3 seconds per mile per lane in one direction of travel. This measure is calculated as the traffic density (in one direction) multiplied by percent followers (PF).
- Follower Flow (FF): The hourly rate of vehicles with headways less than 3 seconds that passes a point along a two-lane highway in the analysis direction. This measure is calculated as the flow rate multiplied by percent followers (PF).
- Percent Impeded (PI): Percentage of vehicles impeded by slower-moving vehicles in a directional traffic stream measured at a point. PI is calculated as the probability of desired speeds being greater than the average speed of platoon leaders multiplied by the percent of vehicles with headways less than a pre-specified threshold value. A threshold value of 3 seconds was used in this study (same as PF). For establishing the distribution of desired speeds, vehicles with headway more than 8 seconds were used. Platoon leaders were used as a representative sample of slow moving vehicles.
- Impeded Flow (IF): The hourly rate of vehicles impeded by slow-moving vehicles, i.e. platoon leaders. It is calculated as the product of PI and the hourly rate of traffic flow.
- Impeded Density (ID): Number of vehicles impeded per mile per lane in one direction of travel. It is calculated as the product of PI and traffic density.

As defined above, performance measures are either speed-related (ATS, PFFS), headway related (PF) or composite measures (FD, FF, PI, ID, IF). Traffic variables investigated in this study include:

- Combined flow (veh/hr): The hourly flow rate in both directions of travel.
- Traffic split: The proportion of hourly flow rate in the direction of analysis to combined flow.

- Percent heavy vehicles (% HV): The percentage of heavy vehicles in the direction of analysis.
- Speed variance: The square of standard deviation of all vehicle speeds measured at a specific location in the direction of analysis.
- Percent no passing: The percentage of road by length in which passing is not allowed in the direction of analysis. This percentage was found for 3 miles upstream and downstream of the location being investigated.

STUDY SITES

Sixteen study sites in the states of Montana, Idaho, Oregon and North Carolina were used in this study (four sites in each state). In the selection of study sites, an attempt was made, as much as possible, to include sites with a wide range of traffic conditions away from the influence of intersections or other access points that may have implications on vehicle speeds and headways. Moreover, the study sites were selected on tangent segments outside the effect of extended and/or significant grades, horizontal and vertical curves. All sites are located in rural areas.

A description of the data collected at the 16 study sites is provided in Table 1. According to the HCM 2010, Sites 3 and 7 are major collectors and are considered class II highways while sites 4, and 8 are located in a relatively developed area and as such considered as class III highways. The rest of the sites are located on principal arterials and can be classified as class I. Data for study sites were provided by the Departments of Transportation in the respective states. Per vehicle data including arrival time, spot speed, and vehicle classification was obtained from automatic traffic recorders at study sites. Headways were found using the time stamp of individual vehicle arrivals. Data were aggregated into one hour intervals for use in the analysis.

RESEARCH UNDERLYING HYPOTHESES

In this section, the major hypotheses underlying the relationship between performance measures and traffic variables are discussed.

- I. Combined flow: This is traffic flow in the two directions of travel expressed as an hourly flow rate. As combined flow increases, ATS and ATS/FFS are expected to decrease. On the other hand, all other performance measures (PF, FD, FF, PI, ID, and IF) are expected to increase.
- II. Traffic split: This is the proportion of traffic flow in the analysis direction. The hypotheses here are similar to those of combined flow. As traffic split increases, ATS and ATS/FFS are expected to decrease while all other performance measures (PF, FD, FF, PI, ID, and IF) are expected to increase.
- III. Percent heavy vehicles: Heavy vehicles are generally associated with lower performance and thus lower speeds compared to passenger cars. As heavy vehicle percentage increases, ATS and ATS/FFS are expected to decrease while all other performance measures are expected to increase.

TABLE 1 Description of Field Data at Study Sites

Site Number	Site Name	Dates	Class	Duration of Data Collection (hours)	Total Vehicle Count (veh)	Annual Average Daily Traffic (veh/day)	Speed Limit(mph)	Direction of Analysis	Percent No-Passing Zones
1	ATR 43-MT	July 20, 2014- July 26, 2014	I	168	23,676	4776	60	South-bound	93
2	ATR 132-MT	July 9, 2014- July 24, 2014	I	384	31,653	2831	70, 60 (trucks)	West-bound	56
3	ATR 28 -MT	July 16, 2015 - July 30, 2015	II	360	24,311	2939	70, 60(trucks)	North-bound	40
4	ATR 73 -MT	July 16, 2015 - July 30, 2015	III	360	47,052	3601	60	North-bound	66
5	ATR 47-ID	June 16, 2015 - June 30, 2015	I	360	62,643	6799	60	West-bound	33
6	ATR 44-ID	June 15, 2015 - June 30, 2015	I	384	49,737	5206	65	North-bound	13
7	ATR 147-ID	September 12,2015-September 20,2015	II	216	8,727	1582	50	North-bound	86
8	ATR 126-ID	September 12,2015-September 20,2015	III	216	33,300	6391	45	South-bound	30
9	Site 1-NC	June 8, 2015-June 16, 2015	I	185	91,790	9600	55	South-bound	37
10	Site 3-NC	June 15, 2015-June 23, 2015	I	172	50,334	3300	55	East-bound	3
11	Site 4-NC	June 9, 2015-June 17, 2015	I	188	93,700	2700	55	North-bound	68
12	Site 7-NC	June 8, 2015-June 16, 2015	I	171	88,082	7700	55	North-bound	30
13	Site 2-OR	July 9, 2015-July 12 2015	I	48	21,932	3900	55	South-bound	17
14	Site 11-OR	May 28,2015-May 31,2015	I	48	19,657	5000	55	East-bound	50
15	Site 13-OR	June 4, 2015-June 7, 2015	I	48	12,596	2700	55	South-bound	30
16	Site 17-OR	June 11 2015-June 14, 2015	I	48	26,757	4900	55	South-bound	55

- IV. Speed variance: Similar to percent heavy vehicles, this variable is not generally perceived as being related to traffic level, however, it may well be associated with the level of platooning in the traffic stream. The relationship between speed variance and performance measures may not be as straightforward as with the other three traffic variables. On one hand, high speed variance could mean faster formation of platoons due to faster vehicles quickly catching up with slower vehicles forming platoons (a.k.a. bunches, groupings, etc.). On the other hand, a traffic stream consisting of high percentage of platooned vehicles may exhibit more uniformity in speeds due to following vehicles roughly traveling at speeds of platoon leaders (thus smaller speed variance). Therefore, the validity of either hypothesis may well be a function of traffic level and passing opportunities.

STUDY RESULTS

To investigate the relationship between performance measures and traffic variables, a graphical examination of the relationships between the two was conducted first. This step is expected to reveal some of the patterns and trends that underlie those relationships. Then correlation and regression analyses were conducted to assess the level of association between performance measures and traffic variables.

Preliminary Analysis (Graphical Examination)

As was mentioned earlier, data were collected from 16 different sites: of which 12 are class I, two class II and two class III sites. In this analysis, sites ATR 47, ATR 147 and ATR 73 were chosen to represent class 1, class 2 and class 3 two-lane highways, respectively. Figure 1 shows the relationship between the eight performance measures investigated in this study and combined flow at the three study sites. In general, all relationships are consistent with the research hypotheses discussed earlier particularly those related to PF, FD, FF, PI, ID, and IF. The trends for the speed-related performance measures (ATS and ATS/FFS) generally show lower sensitivity between those measures and combined flow. It is also important to notice that ATS/FFS exhibited very little sensitivity (if any) on class I highways and a relatively higher sensitivity on class II and III, respectively.

A similar set of graphs showing the relationship between the performance measures and traffic split is shown in Figure 2. With the exception of ATS at class I and class II study sites, all relationships exhibited trends that are in agreement with the research hypotheses. ATS shows almost no sensitivity whatsoever to traffic split at sites ATR47 and ATR 147.

Figure 3 shows the relationships between performance measures and speed variance. In regards to speed-related measures, all relationships showed decline in the two performance measures as speed variance increases, with the exception of ATS/FFS at class I study site. As for headway-related and composite measures, all relationships at class I and class III sites (ATR 47 and ATR 73) showed decline in performance measures with the increase in speed variance. The relationships at class II study site (ATR 147) showed trends that are inconsistent with those at the other two study sites. Specifically, performance measures showed almost no sensitivity to speed variance for the most part. It is important to remember that traffic level at this study site is notably lower than that at the other study sites as shown in Table 1.

Figure 4 shows the relationships between performance measures and percentage of heavy vehicles. Overall, the majority of relationships showed very little to no sensitivity of

performance measures to the percent of heavy vehicles. The only exception are those relationships at site ATR 73 (class III) where headway-related and composite measures (PF, FD, FF, PI, ID, and IF) showed noticeable decline with the increase in heavy vehicle percentage.

FIGURE 1 Scatterplots of performance measures vs combined flow.

FIGURE 2 Scatterplots of performance measures vs traffic split.

FIGURE 3 Scatterplots of performance measures vs speed variance.

FIGURE 4 Scatterplots of performance measures vs percent heavy vehicles.

To gain a closer insight into the suitability of performance measures on different types of two-lane highways, three levels of analysis (data aggregation) were used in this study. The first level utilized combined data from all study sites in the analysis. The second level of analysis utilized data aggregated across sites of the same highway class (class I, II or III). The third level involved separate analyses using data from individual study sites.

The relationship between performance measures and traffic variables was also examined using correlation and regression analyses. Figure 5 shows the coefficients of correlation between all performance measures and traffic variables for the combined data at all study sites, as well as class I, II, and III data. The most important observations are summarized below.

For combined and class I data, combined flow shows notably high correlations with performance measures followed by traffic split which is associated with much lower correlation coefficients. Headway-related and composite performance measures generally exhibited high correlations with combined flow, with coefficients higher than 0.8 for FD, FF, ID and IF. Speed variance and percent heavy vehicles generally show very low correlations with performance measures. Percent heavy vehicles exhibits very low correlation coefficients with all performance measures.

For class II data, while combined flow shows again higher correlations with performance measures compared to other traffic variables, those correlations are notably lower than their counterparts on class I highways. Although traffic split exhibited lower correlation coefficients compared with combined flow, those coefficients are generally greater than their counterparts on class I highways. Further, though still considered low in value, percent heavy vehicles exhibit relatively higher correlation coefficients compared with their counterparts on class I highways. Speed variance and percent heavy vehicles exhibit relatively weak correlations with performance measures except for the correlation between ATS and percent heavy vehicles.

For class III data, combined flow shows highest correlations with performance measures compared to other traffic variables. Again, while traffic split exhibits lower correlation coefficients compared with combined flow, those coefficients are generally greater than their counterparts on class I highways. Headway-related and composite performance measures exhibit relatively high correlations with combined flow, with coefficients around 0.80 or greater for PF, FD, FF, ID and IF. For speed-related measures, ATS/FFS shows higher correlation with combined flow, traffic split and speed variance while ATS shows higher correlation with percent heavy vehicles.

FIGURE 5 Correlation results for combined, class I, class II, and class III data.

In order to explore the relationships between performance measures and traffic variables, multiple linear regression was also performed using the data for each class type. Tables 2, 3 and 4 summarize the results of regression analysis for each class using 95% confidence level. In these models, performance measures represented the response (dependent) variable and traffic variables were used as predictor (independent) variables. Values not found significant were removed from the results.

For class 1, all of the 8 regression models are considered statistically significant with R^2 between 0.07 and 0.81. Follower flow followed by follower density resulted in models with highest R^2 values (0.81 and 0.8, respectively). Regarding the results of class II study sites shown in Table 3, all models were found statistically significant at 95% confidence level. However, the models for headway-related and composite performance measures yielded notably lower R^2 values while those for speed-related performance measures yielded higher R^2 values compared with class I data. Again, Follower flow followed by follower density resulted in models with the highest R^2 values. Further, speed variance was not found significant in six out of eight regression models (at 95% confidence level).

Class III results shown in Table 4 suggest that all regression models are statistically significant at 95% confidence level. Models for headway-related and composite measures yielded R^2 values that are greater than those of class II study sites but lower than those for class I study sites. In regards to speed-related measures, the model for ATS/FFS yielded the highest R^2 compared to other classes. Further, speed variance was not found significant in six out of 8 class III models.

TABLE 2 Results from Multivariate Linear Regression Analysis for Class I Sites

Performance Measure	Regression Model		Coefficients and P-value from t-test				
	R squared	SE	Intercept	Combined Flow	Traffic Split	Percent HV	Speed Variance
Class 1							
ATS	0.12	4.7	64.05 0.00	-0.007 0.00	-2.69 0.00	-0.02 0.00	0.004 0.00
ATS/FFS	0.07	0.02	1.01 0.00	-0.00002 0.00	-0.01 0.00	-0.0004 0.00	-0.00001 0.00
% Follower	0.59	11.21	-7.3 0.00	0.05 0.00	29.68 0.00	0.07 0.00	-0.008 0.00
Follower Flow	0.81	36.08	-118.46 0.00	0.29 0.00	164.7 0.00	---	-0.03 0.00
Follower Density	0.80	0.63	-2.09 0.00	0.005 0.00	2.87 0.00	---	-0.0006 0.00
% Impeded	0.50	8.29	-4.78 0.00	0.03 0.00	17.69 0.00	0.06 0.00	---
Impeded Flow	0.76	24.98	-71.81 0.00	0.17 0.00	98.82 0.00	0.06 0.01	-0.01 0.00
Impeded Density	0.75	0.45	-1.28 0.00	0.003 0.00	1.73 0.00	0.001 0.01	-0.0002 0.00

TABLE 3 Results from Multivariate Linear Regression Analysis for Class II Sites

Performance Measure	Regression Model		Coefficients and P-value from t-test				
	R squared	SE	Intercept	Combined Flow	Traffic Split	Percent HV	Speed Variance
Class 2							
ATS	0.25	3.27	62.75 0.00	0.006 0.00	-1.63 0.00	-0.23 0.00	-0.007 0.01
ATS/FFS	0.04	0.02	1.009 0.00	-0.00002 0.00	-0.01 0.00	-0.0003 0.00	-0.00004 0.00
% Follower	0.27	7.65	-9.17 0.00	0.05 0.00	18.36 0.00	0.27 0.00	---
Follower Flow	0.54	8.17	-27.18 0.00	0.11 0.00	33.99 0.00	0.26 0.00	---
Follower Density	0.51	0.14	-0.44 0.00	0.002 0.00	0.56 0.00	0.005 0.00	---
% Impeded	0.25	5.62	-7.61 0.00	0.04 0.00	12.69 0.00	0.18 0.00	---
Impeded Flow	0.50	6.05	-19.24 0.00	0.08 0.00	22.89 0.00	0.17 0.00	---
Impeded Density	0.48	0.10	-0.31 0.00	0.001 0.00	0.38 0.00	0.003 0.00	---

TABLE 4 Results from Multivariate Linear Regression Analysis for Class III Sites

Performance Measure	Regression Model		Coefficients and P-value from t-test				
	R squared	SE	Intercept	Combined Flow	Traffic Split	Percent HV	Speed Variance
Class 3							
ATS	0.14	6.99	63.37 0.00	-0.01 0.00	-5.96 0.00	-0.29 0.00	---
ATS/FFS	0.16	0.01	1.01 0.00	-0.00003 0.00	-0.01 0.00	---	0.0002 0.00
% Follower	0.62	7.27	-11.71 0.00	0.05 0.00	30.83 0.00	0.08 0.00	-0.04 0.00
Follower Flow	0.75	20.22	-81.66 0.00	0.17 0.00	129.82 0.00	---	---
Follower Density	0.68	0.47	-1.72 0.00	0.003 0.00	2.58 0.00	0.007 0.00	---
% Impeded	0.52	5.58	-8.2 0.00	0.03 0.00	19.26 0.00	---	---
Impeded Flow	0.68	14.58	-52.03 0.00	0.11 0.00	81.52 0.00	---	---
Impeded Density	0.63	0.33	-1.09 0.00	0.002 0.00	1.63 0.00	0.004 0.00	---

Regression results at the sixteen study sites were used to rank performance measures in terms of their relationship with traffic variables investigated in this research. Figure 6 shows the rankings of performance measures by R^2 value for different classes of two-lane highways. As the results show, follower flow and follower density are the first and second ranked performance measures followed by impeded flow and impeded density. Speed-related measures ranked last for all highway classes.

FIGURE 6 Performance measures rank by class using R^2 .

Table 5 shows the number of times traffic variables were found significant for each performance measure using class regression runs. Combined flow and traffic split were consistently found significant in almost all regression runs for all highway classes particularly in models of headway-related and composite performance measures. Speed variance was found significant more often in ATS models for all highway classes. Percent heavy vehicles was found significant less often compared to all other traffic variables.

Table 5 Number of Times Variable Found Significant Using Class Regression Runs

Performance Measure	Sites											
	Class I (12 sites)				Class II (2 sites)				Class III (2 sites)			
	Combined Flow	Traffic Split	% Trucks	Speed Variance	Combined Flow	Traffic Split	% Trucks	Speed Variance	Combined Flow	Traffic Split	% Trucks	Speed Variance
ATS	12	7	7	10	2	1	1	2	1	0	0	2
ATS/FFS	10	4	3	10	2	2	1	2	2	1	0	2
% Follower	12	12	6	4	2	2	1	0	2	2	1	0
Follower Flow	12	12	3	5	2	2	1	0	2	2	1	0
Follower Density	12	12	3	5	2	2	1	0	2	2	1	0
% Impeded	12	12	7	8	2	2	1	1	2	2	1	1
Impeded Flow	12	12	3	7	2	2	1	1	2	2	1	0
Impeded Density	12	12	3	9	2	2	1	1	2	2	1	2

SUMMARY OF FINDINGS

This paper presented an empirical investigation of several performance measures for operational analysis on two-lane highways. Graphical examination, correlation and regression analyses were conducted to better understand the relationship between performance measures and traffic variables. Composite measures showed highest correlations followed by the headway-related measure (percent followers) and speed-related measures respectively. Among all composite measures, follower flow followed by follower density exhibited highest correlations with traffic variables. In regards to traffic variables, combined flow exhibited highest correlations with performance measures followed by traffic split which reflects the proportion of traffic in the analysis direction. Speed variance and percentage of heavy vehicles exhibited the lowest correlations with performance measures. No major differences were observed between different classes of highways, however, the model for ATS/FFS showed higher R^2 compared to other highway classes.

Findings from this study provide valuable information about the merits, or lack thereof, of many performance measures that were either used in practice or proposed in the literature. This information is expected to help in the selection of the most appropriate performance measure(s) for use in future methodologies of two-lane highway operational analysis.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support provided for this study by the National Cooperative Highway Research Program (NCHRP). Further, the authors would like to thank the respective staff at the state Departments of Transportation for providing the data used in this study.

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