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Operational Impact of Horizontal and Vertical Alignment of Two-Lane Highways

Ana Tsui Moreno[1*], Carlos Llorca[2] and Alfredo García[2]
[1]*Department of Civil, Geo and Environmental Engineering, Technical University of Munich, Germany*
[2]*Highway Engineering Research Group, Universitat Politècnica de València, Spain*
ana.moreno@*tum.de, carlloga@cam.upv.es, agarciag@tra.upv.es*

Abstract
The effect of highway bendiness on traffic performance is not addressed on the current HCM analysis procedure for two-lane highways. Given the relationship between operating speed and horizontal alignment, highway bendiness could potentially affect speeds and platooning; and therefore the ideal performance measure should be sensitive to highway geometry variations. The influence of horizontal and vertical alignment on their traffic operation was studied on 19 uniform segments from Spanish two-lane highways using TWOPAS. Alignment was classified following the German procedure: curvature change rate (*CCR*) and class of gradient. Among the performance measures, follower density was correlated to both traffic and roadway conditions in a more meaningful way.

Keywords: Two-lane highways, Traffic operation, Microsimulation, Geometric Design, Horizontal alignment, Vertical alignment, *ATS*, *PTSF*, Follower density

1 Introduction

Spanish standards (Ministerio de Fomento 1999) rely on the U.S. Highway Capacity Manual (Transportation Research Board 2010) to analyze the level of service (LOS). For two-lane highways, LOS is based on one or more of three performance measures, depending on highway classification: average travel speed (*ATS*); percent time spent following (*PTSF*); and, percent of free-flow speed (*PFFS*). The three measures depend on some geometric and demand data, such as percent of no-passing zone, base design speed, directional traffic volume or directional split. Significant variations on the horizontal alignment are not included, neither on the analysis procedure nor the uniform segment identification. Given the relationship between operating speed and design elements, the average travel speed of a segment and platooning would be likely affected by a higher presence of curves (higher bendiness). [*]

In Germany, traffic performance is evaluated in terms of density, defined as the ratio between directional traffic volume and average travel speed of passenger cars. The performance measure is affected by both horizontal and vertical alignment (Forschungsgesellschaft für Strassen und

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Verkehrswesen 2015). Horizontal alignment is characterized through the curvature change rate (*CCR*); defined as the absolute angular change in horizontal direction per unit of distance. Boundaries for uniform segments consider significant variations of cumulative *CCR*. Vertical alignment considers the minimum speed that a heavy vehicle could obtain on the section and it depends on the length and grade of the most restrictive ramp along the segment. The heavy vehicle used in the analysis has a weight/power ratio of 0.138 kg/W (228 lb/HP). For each class of horizontal alignment, vertical alignment and percentage of trucks, speed-flow diagrams were developed using simulation results from the traffic microsimulation program Landstraßensimulation (LASI) (Weiser et al. 2011). Ideal segments were composed of a fictitious sequence of curves and tangents. The radii of the fictitious curves were constant and equal to the minimum radius defined on the German Geometric Design guideline (Forschungsgesellschaft für Strassen und Verkehrswesen 2013). Therefore, it might not be representative of actual two-lane highways alignment, as a sequence of curves with different radii and different tangent lengths. Directional analysis was used with balanced flows (directional split 50/50). Contrary to the US HCM, directional split and passing restrictions were not considered. Passing restrictions were removed from the analysis procedure because the influence of passes on speeds had been significantly overestimated (Weiser et al. 2011); and passing restrictions are usually a result of the horizontal alignment, which is already considered on the German HCM.

Moreno et al. (2015) analyzed the relationship between horizontal alignment and traffic performance for the Spanish conditions. The horizontal alignment of 8 Spanish uniform segments was introduced in the TWOPAS microsimulation program, which was previously calibrated and validated with Spanish field data. *ATS* was highly affected by *CCR* and the HCM analysis procedure overestimated *ATS* up to 20 km/h in sinuous highways (*CCR* higher than 75 gon/km). *PTSF* did not depend significantly on *CCR*. The research did not include the influence of vertical alignment or directional splits. In another research, passing restrictions did not influence much *ATS* in straight segments (Moreno et al., 2016). However, directional split had a great effect on both *ATS* and *PTSF*.

On the other hand, the most appropriate performance measure for two-lane highways is still open for discussion. Luttinen et al. (2003) proposed some conditions that ideal performance measures should present. Ideally, they should reflect the perception of road users on the quality of traffic flow; be easy to measure and estimate; and correlate to traffic and roadway conditions in a meaningful way, among others. Given the difficulties to measure *PTSF* in the field, some authors developed alternative performance measures, such as follower density (van As 2006); percent impeded (Al-Kaisy and Durbin 2008); freedom of flow (Polus and Cohen 2009); or number of followers as proportion to capacity (Penmetsa et al., 2015). Speed limit is usually included in the analysis procedure to determine the previous performance measures, but is not considered as a performance measure itself because it remains constant with all traffic flows. Field studies indicated that follower density was the most promising performance measure, as it presented the highest correlation to traffic variables (Al-Kaisy and Karjala 2008; Oregon Department of Transportation 2010; Hashim and Abdel-Wahed 2011; Moreno et al. 2014).

Even though follower density is indicated as the most promising performance measure for two-lane highways, it has not been verified its correlation to roadway conditions. Moreover, given the relationship between operating speed and horizontal alignment, highway bendiness could potentially affect speeds and platooning.

Therefore, there is a need to evaluate in actual (in operation) highways the influence of horizontal and vertical alignment on traffic operations. The study should not be limited to the HCM performance measures (*ATS, PTSF*), but also include alternative performance measures. Moreover, traffic demand should consider unbalanced flows and percentages of trucks. The results could provide guidance on which performance measure is correlated to traffic and roadway conditions in a more meaningful way.

2 Objectives

The objective of the research was to evaluate the relationship between traffic performance, traffic demand and highway alignment using the geometry of actual (in operation) two-lane highways in Spain. HCM performance measures, as well as alternative performance measures, were considered. The results can provide guidance on which performance measure is more appropriate for two-lane highways, considering its correlation with traffic and roadway conditions.

The study included two main parts: (1) characterization of horizontal and vertical alignment from a sample of two-lane highways in Spain; and (2) operational analysis of uniform segments using the TWOPAS microsimulation program.

The research feed from two previous studies. The first study analyzed the influence of horizontal alignment on *ATS* and *PTSF* using a sample of 8 uniform segments (Moreno et al. 2015). The second study calibrated and validated the TWOPAS microsimulation program for Spanish conditions (Moreno 2015; Moreno et al. 2016). A summary of both studies will be provided on the corresponding section.

3 Uniform segments characterization

A sample of 9 two-lane highways in Spain with 100 km/h posted speed limit was selected from the previous study that included 25 two-lane highways (Moreno et al. 2015). Highways were located in rural environments, without additional passing or climbing lanes, and randomly distributed throughout Spain. Horizontal alignment and vertical alignment were characterized. 19 uniform segments were identified from the sample of 9 two-lane highways.

3.1 Horizontal alignment

The first step was to divide the two-lane highways in uniform segments based on their bendiness. Each uniform segment was classified in one of the four classes of horizontal alignment according to the German HCM (Forschungsgesellschaft für Strassen und Verkehrswesen 2015). Table 1 summarizes the classification criteria.

Table 1. Class of horizontal alignment depending on *CCR* *(Forschungsgesellschaft für Strassen und Verkehrswesen, 2015)*

Class of horizontal alignment	1	2	3	4
CCR (gon/km)	0 – 50	50 - 100	100 – 150	> 150

Uniform road segments were identified as segments with similar cumulative *CCR* slope or gradient. To calculate cumulative *CCR*, the elements of the highway horizontal alignment (tangent, curve, spiral) should be determined. A specially developed software program was used (Camacho-Torregrosa et al. 2014). It used as inputs centerline roadway coordinates (x,y) from aerial images of Google Earth and provided as outputs the elements of the highway horizontal alignment. Then, curvature change rate (*CCR*) of each element was calculated using Equation 1.

$$CCR_i = \frac{\Delta_i}{L_i} \tag{1}$$

Where:

- CCR_i: curvature change rate (gon/km).
- Δ_i: deflection angle (gon; 400 gon = 360 degrees).

- L_i: length of the element (km).

The analysis of the 9 two-lane highways led to 19 uniform segments (38 directional uniform segments). The horizontal alignment characteristics are summarized on Table 4.

3.2 Vertical alignment

Similarly, vertical alignment was classified using the criteria of the German HCM (Forschungsgesellschaft für Strassen und Verkehrswesen 2015). The class of gradient depended on the minimum speed that a reference truck could obtain on the section because of upgrades. Table 2 summarizes the classification criterion.

Table 2. Class of gradient depending on the minimum speed of the reference truck *(Forschungsgesellschaft für Strassen und Verkehrswesen, 2015)*

Class of gradient	1	2	3	4	5
Minimum speed of the reference truck (km/h)	> 70	60 - 70	45 - 60	30 - 45	< 30

This criterion could be directly applied to our conditions. Nevertheless, truck performance differed in Spain and Germany: the most representative truck observed in Spain has a weight/power ratio of 0.116 kg/W (191 lb/HP) (Llorca et al. 2014), compared to the 0.138 kg/W (228 lb/HP) of the German HCM (Forschungsgesellschaft für Strassen und Verkehrswesen 2015; Brilon and Weiser 2006). Therefore, new speed profiles for Spanish trucks were generated using the TWOPAS program, which was previously calibrated to the Spanish conditions, as explained on Section 4.1.

To estimate the speed reduction of trucks along the upgrades, the directional traffic flow was set at 10 veh/h and 100 % of trucks, while the opposing traffic flow (downgrade) was equal to zero. Upgrade length varied between 200 and 5,000 m; while the grade varied between 1 and 6 % (steps 0.5 %). For each upgrade, 15 random seeds were used. The speed of the trucks at the end of the upgrade was computed, averaged and compared to the speed thresholds from the German HCM. Table 3 summarizes the results. Not surprisingly, the classes for the Spanish conditions were more restrictive than the German HCM, as the weight/power ratio of the representative truck was lower in Spain than in Germany.

Table 3. Class of gradient for the Spanish conditions depending on the upgrade length and grade

Upgrade length (m)	Grade (%)				
	< 2	3	4	5	6
< 300	1	1	1	1	1
< 450	1	1	1	1	2
< 600	1	1	1	2	2
< 750	1	1	1	2	3
< 1000	1	1	2	2	3
< 2000	1	1	2	2	3
> 2000	1	1	2	2	4

Vertical alignment (grade and length of upgrades and downgrades) of the uniform segments was obtained from GPS data of Wikiloc (wikiloc 2015). The website provides free GPS trails and waypoints that members upload and share. Uniform segments with only downgrades were automatically classified as class of gradient 1. Uniform segments with upgrades were classified applying the criteria of Table 3 to the most restrictive upgrade. The vertical alignment characteristics are summarized on Table 4.

4 Operational analysis on TWOPAS

TWOPAS microsimulation program was selected for the simulation, and it was previously calibrated and validated with Spanish field data. The geometry of 19 uniform segments of Spanish two-lane highways was implemented in TWOPAS, in contrast with previous studies that used fictitious alignments.

It should be noted that TWOPAS considers a normal distribution of desired speeds in a horizontal curve. The maximum and minimum speed are based on the lateral acceleration. An individual vehicle has the same percentile on the curve desired speed distribution than on the desired speed distribution.

4.1 Calibration and validation of TWOPAS

The goal of the calibration is to find the combination of parameters that minimize the differences (*ATS, PTSF*, passing rate) between the simulation and field data. The genetic algorithm used in Brazil for calibrating TWOPAS (Bessa and Setti 2011) was utilized. Field data were collected in four passing zones in Spain and included *ATS*, percent followers and passing rates (Moreno et al. 2013; Moreno et al. 2014).

Calibration parameters of TWOPAS included: passing reconsider probability, car following factor and stochastic driver type factors. This fitness function was defined as the average difference between the simulation result and field data. It depended on 20 parameters (10 per direction): passing rate, percent followers at the end of the segment; and speeds (average, standard deviation, percentiles). A sensitivity analysis produced the best combination of weights for the fitness function and for the genetic parameters (diversity, mutation and predation).

For the calibration, 30 non-overlapped counting periods (i.e., 0-15, 15-30 min, etc.) were used, and the 60 remaining periods were left for validation (i.e., 5-20, 10-25, 20-35 min, etc.). The genetic algorithm was executed in 80 generations of 40 individuals, 5 random seeds and 30 traffic scenarios. The total number of simulations was 480,000. Each simulation was 15 minute long, with 15 minute warm-up. The minimum error was reduced from 7.9 % (default values) to 3.8 % (calibrated parameters).

The 25 best combinations of calibration parameters were validated with more field data. The average error was 4.3 %, very close to the calibration error of 3.8 %. Further details can be found in Moreno (2015) and Moreno et al. (2016).

4.2 Case study scenarios

Case study scenarios included 19 uniform segments. Horizontal alignment, posted speed limit, passing zones and available sight distances were introduced in TWOPAS. Contrary to the previous study (Moreno et al. 2015), vertical alignment was also implemented and more uniform segments were added. The scenarios covered different *CCR* (from 2 to 351 gon/km), upgrades (grades from 0 to 6 %, ramp length up to 4,000 m), percentage of no-passing zones (from 0 % to 100 %), and average passing zone length (from 230 to 1,955 m). Table 4 summarizes their characteristics.

The uniform segments were evaluated for directional traffic volumes between 100 to 1,500 veh/h, with steps of 100 veh/h, and directional split of traffic varied between 20/80 and 80/20. Three percentages of trucks were considered: 0, 10 and 20 %. For each uniform segment and traffic demand, 15 replicate runs were made. The replicates varied the random seed and calibration parameters.

The TWOPAS microsimulation program provided a total of 125,766 directional scenarios in 38 directional uniform segments.

Average travel speed (*ATS*), average travel speed of passenger cars (*ATSpc*), percent time spent following (*PTSF*) and percent followers (*PF*) were obtained from the individual output file of TWOPAS (*.OUT). Density (*K*) was calculated as the ratio between directional traffic volume and *ATSpc.*

Follower density (*FD*) was calculated multiplying *PF* by density (directional traffic volume divided by *ATS*).

Table 4. Case study scenarios

Highway		Horizontal alignment			Vertical alignment					
					Bound 1			Bound 2		
ID	Name	L_U (m)	*CCR* (gon/km)	Class	L_V (m)	G (%)	Class	L_V (m)	G (%)	Class
01_1	N-211	6,790	6	*CCR1*	485	2.3	*G1*	730	2.1	*G1*
01_2	N-211	4,075	74	*CCR2*	1,082	2.5	*G1*	370	2.2	*G1*
04_1	CV-35	1,560	60	*CCR2*	925	3.5	*G2*	NA	NA	*G1*
04_2	CV-35	10,605	8	*CCR1*	1,240	3.5	*G2*	585	2.6	*G1*
06_1	C-5001	3,630	2	*CCR1*	410	3.0	*G1*	95	2.3	*G1*
06_2	C-5001	3,170	39	*CCR1*	500	3.6	*G1*	200	2.3	*G1*
11_1	CV-800	6,830	351	*CCR4*	6,830	4.5	*G3*	NA	NA	*G1*
11_2	CV-800	5,940	131	*CCR3*	5,985	4.5	*G3*	NA	NA	*G1*
11_3	CV-800	3,830	254	*CCR4*	NA	NA	*G1*	3,830	4.5	*G3*
13_1	N-611	4,570	178	*CCR4*	4,570	3.2	*G2*	470	4.1	*G1*
13_2	N-611	2,950	73	*CCR2*	940	2.1	*G1*	935	6.0	*G1*
16_1	A-306	4,285	60	*CCR2*	750	1.2	*G1*	960	2.4	*G1*
18_1	N-240	7,895	45	*CCR1*	2,800	4.9	*G3*	395	4.0	*G1*
18_2	N-240	2,635	4	*CCR1*	435	2.5	*G1*	NA	NA	*G1*
19_1	A-132	5,530	31	*CCR1*	450	2.7	*G1*	1,340	1.0	*G1*
19_2	A-132	3,980	7	*CCR1*	3,980	1.9	*G1*	NA	NA	*G1*
20_1	NA-150	9,420	61	*CCR2*	935	2.6	*G1*	2,215	2.2	*G1*
20_2	NA-150	3,945	21	*CCR1*	NA	NA	*G1*	3,945	0.4	*G1*
20_3	NA-150	2,060	91	*CCR2*	1,170	4.5	*G3*	595	3.9	*G1*

L_U: length of the uniform segment
CCR: curvature change rate
L_V: length of the most restrictive upgrade on the uniform segment
G: grade of the most restrictive upgrade on the uniform segment

5 Results

The five traffic performance measures were plotted depending on the *CCR* class and class of gradient: *ATS* (Figure 1), *PTSF* (Figure 2), *PF* (Figure 3), *K* (Figure 4) and *FD* (Figure 5). Given the large number of combinations for horizontal and vertical alignments, and the different sample of each combination, class of gradient 2, 3 and 4 were grouped into class of gradient 2; and *CCR 3* and 4 was grouped into *CCR* 3.

As expected, highway alignment influenced highly *ATS* (Figure 1). *ATS* decreased as bendiness increased, for both types of gradient. Free flow speed decreased from an average of 90 km/h with *G1_CCR1* to 60 km/h with *G1_CCR3*. For more sinuous highways, capacity was reached at significant low traffic volumes (1,100 veh/h). The colors of Figure 1 depended on the most significant variable on *ATS*: the percentage of trucks. Not surprisingly, the higher the percentage of trucks, the lower the average travel speed. Moreover, some stripes of results can be visually identifiable, as a result from various percentages of trucks. the class combinations with higher sample (*G1_CCR1; G1_CCR2, G2_CCR3*) presented higher dispersion on the results, around 10 km/h, which could indicate that the boundaries for *CCR* might not be appropriate and further study is required.

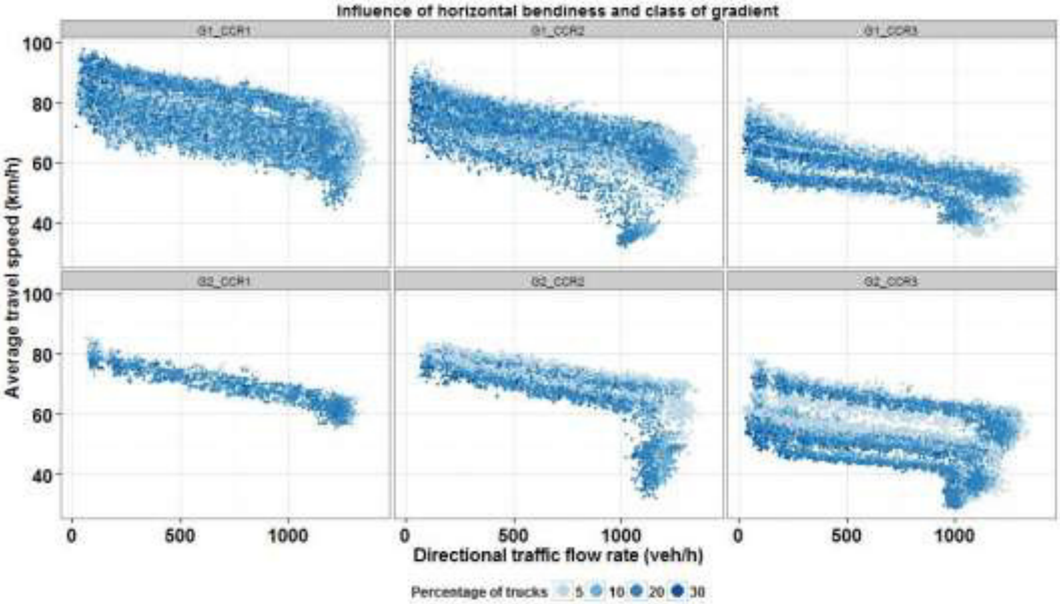

Figure 1. Average travel speed (*ATS*) depending on the directional traffic volume, percentage of trucks, horizontal bendiness and class of gradient

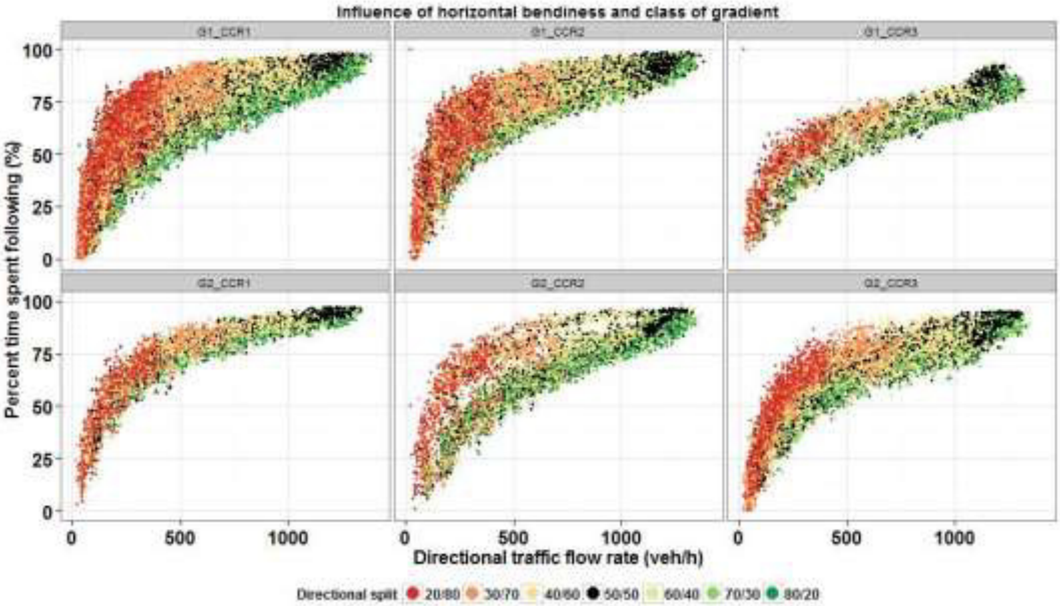

Figure 2. Percent time spent following (*PTSF*) depending on the directional traffic volume, directional split, horizontal bendiness and class of gradient

PSTF (Figure 2) presented lower dispersion on the results than *ATS*. In fact, directional splits were more significant of *PTSF* than the percentage of trucks. For the same geometry, unbalanced directional splits reduced *PTSF* in a meaningful way (up to 20 %). The influence of directional split is higher for the less restrictive scenarios (*G1_CCR1*, *G1_CCR2*). On the other hand, *PTSF* decreased as bendiness increased, for class of gradient 1. This indicates and improvement on platooning conditions on more sinuous segments, which may seem counterintuitive: a higher presence of curves would be related to more passing restrictions and therefore higher platooning due to the inability to pass. However, the higher presence of curves also reduces speed dispersion among vehicles on several sections of the highway compared to a straight segment, thus reducing the probability of encountering other vehicles and therefore platooning. In this case, speed would be controlled by geometry rather than freely being selected by drivers. Further analysis should be carried out to evaluate speed dispersion and confirm this hypothesis.

PF has much higher dispersion than *PTSF* (Figure 3). This variable is not totally related to *PTSF*, as they differ in both shape and value. The maximum value of *PF* was lower than 80 %, compared to 100 % on *PTSF*; plus differences on their average value. Therefore, *PF* should be used as surrogate of *PTSF* with caution. Similar to *PTSF*, *PF* decreased for more restrictive scenarios. Surprisingly, the percentage of trucks had a similar effect: for the same geometry, the higher percentage of trucks, the lower *PF*. This counterintuitive result could also be caused because a slightly increasing the percentage of trucks may reduce overall speed dispersion and consequently platooning decreases at the end of the segment.

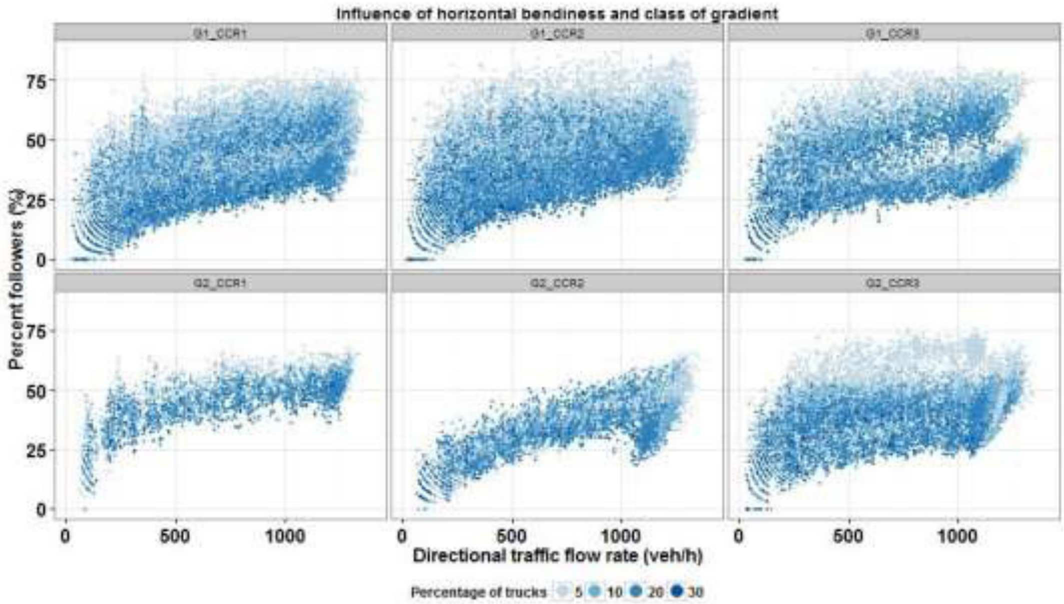

Figure 3. Percent followers (*PF*) depending on the directional traffic volume, directional split, horizontal bendiness and class of gradient

Density presented the lowest dispersion among the performance measures (Figure 4). The relationship between density and directional flow rate was almost linear. A slight increase of density with highway bendiness could be observed. The breakdown on the facility was produced at a similar density, around 22 veh/km. For unbalanced directional splits, the value could be increased to 25 km/h.

Finally, follower density (*FD*) combines percent followers and density (Figure 5). Similar to *PF*, for the same geometry, increasing the percentage of trucks improved *FD*. This effect was similar for all geometries. The effect of bendiness was to increase *FD:* even though platooning improved as bendiness increased, *ATS* was significantly reduced at classes *CCR* 2 and CCR 3. Compared to density, *FD* was more sensitive at high traffic flows: a slight increase on traffic flow could lead to a significant increase on *FD*. This would better represent the highway performance in conditions closer to capacity since marginal changes of traffic volume could worsen traffic operations considerably.

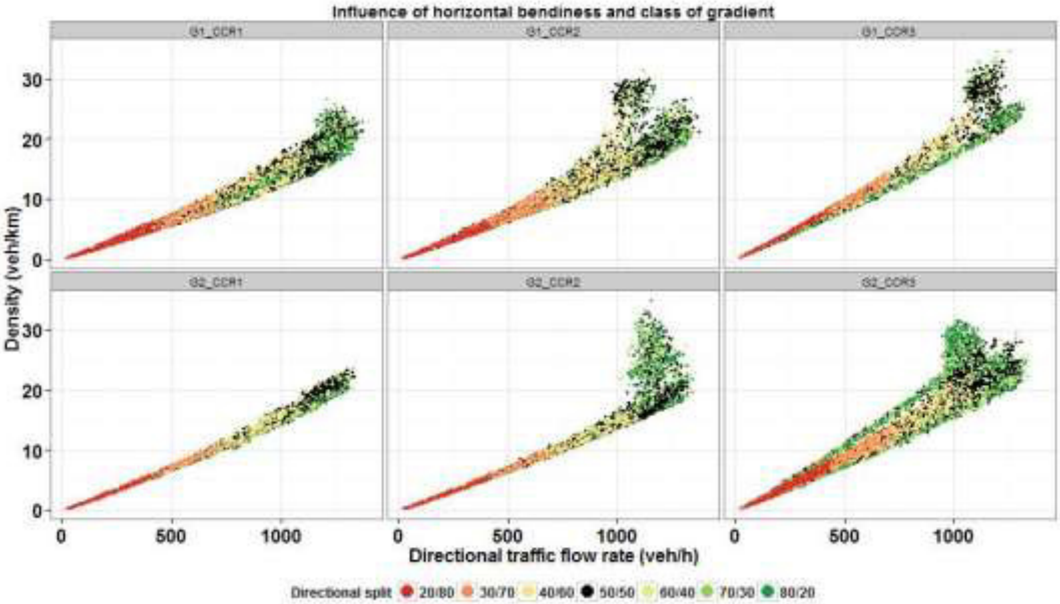

Figure 4. Density (*K*) depending on the directional traffic volume, directional split, horizontal bendiness and class of gradient

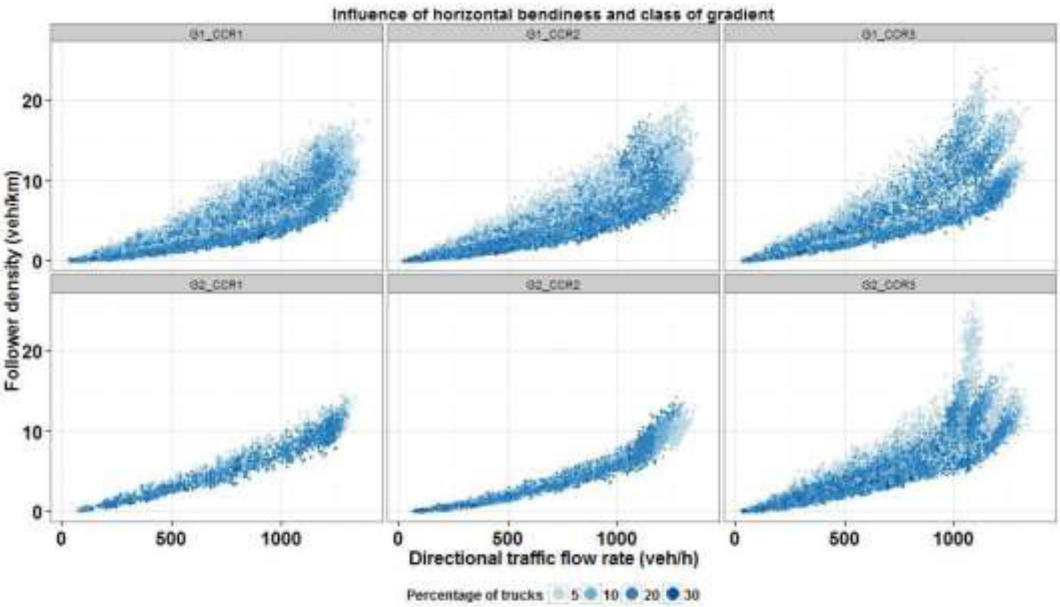

Figure 5. Follower density (*FD*) depending on the directional traffic volume, directional split, horizontal bendiness and class of gradient

6 Discussion

Performance measures for two-lane highways should ideally be correlated to traffic and roadway conditions in a meaningful way, reflect the perception of road users on the quality of traffic flow and be easy to measure and estimate (Luttinen et al., 2003).

ATS presented the highest influence of highway alignment and percentage of trucks. Deviations on horizontal alignment or longitudinal profile may produce bad estimates if they are not considered on the analysis procedure. Moreover, the performance measure is less sensitive to traffic flow, which causes the low coefficient of determination on the field studies (Al-Kaisy and Karjala 2008; Oregon Department of Transportation 2010; Moreno et al. 2014). Therefore, more prediction variables, such as percentage of trucks, bendiness or class of gradient, must be included to adequately estimate *ATS*.

Dispersion of *PF* was very large, for all traffic and geometry scenarios. Moreover, it was not completely correlated to *PTSF:* the highest value was 75 %, much lower than the highest results on *PTSF* (100 %). The results agree with previous analysis on straight segments using microsimulation (Moreno et al. 2016). *PTSF* presented lower dispersion than *PF*, but it cannot be measured in the field. Proper platooning performance measures should be defined, following the conclusions of Luttinen et al. (2003) and van As (2006).

Among the analyzed performance measures, density presented the strongest correlation to traffic demand, although it could not capture platooning. Moreover, its behavior was linear with traffic demand and failed to reflect the significant changes on traffic performance that a marginal change on directional traffic volume could produce in near-capacity conditions. Facility breakdown was produced for the same density value (around 22 veh/km), and could be valuable to predict the need of capacity improvements (Brilon and Weiser 1997).

Follower density slightly included the effect of highway geometry and directional split, although the dispersion was higher than density. Compared to percent followers, the estimation could be more reliable due to its lower dispersion. Moreover, the relationship with directional traffic flow was not linear and could better capture the decrease on operating quality as demand flow increases; which was qualitatively described on HCM (Transportation Research Board 2010). Previous field studies proposed linear models to predict follower density based on traffic demand and passing restrictions (Al-Kaisy and Karjala 2008; Oregon Department of Transportation 2010; Moreno et al. 2014). Nevertheless, medium-low traffic flows were used to model *FD*, and the rapid increase of *FD* on high traffic flows could not be captured.

7 Conclusions and recommendations

The present research provides guidance on the selection of the most appropriate measure(s) for two-lane highways, considering not only the correlation to traffic variables but also the influence of highway horizontal and vertical geometry.

The conclusions of the study are:

- Directional split produced differences in practically all the performance measures, with the most sensitive being the percent time spent following. This indicated the need not only to introduce the directional traffic volume on the analysis procedure, but also simulate different directional splits to evaluate traffic performance.
- *ATS* presented the highest influence of highway alignment. Deviations on horizontal alignment or longitudinal profile may produce bad estimates if they are not considered on the analysis procedure. Therefore, more prediction variables, such as percentage of trucks, bendiness or class of gradient, must be included to adequately estimate ATS, instead of passing restrictions.

- Class combinations with higher sample (*G1_CCR1; G1_CCR2*, *G2_CCR3*) presented a high dispersion on the results of *ATS* and *PTSF*, which could indicate that the boundaries for *CCR* might not be appropriate.
- For high traffic volumes, density indicated the breakdown of the facility better than the other performance measures. Depending on the aim of the analysis, it could be preferred over platooning-related measures, such as follower density or percent followers.
- Percent followers was not totally correlated to *PTSF*. It should be used with caution as a surrogate of *PTSF*.
- Follower density had a strong correlation with directional traffic volume and was sensitive to geometry variations. Compared to density, *FD* was more sensitive at high traffic flows: a slight increase on traffic flow could lead to a significant increase on *FD*.

From the conclusions, it is recommended:

- The use of *ATS* as a performance measure will require including the percentage of trucks, and horizontal and vertical highway alignment in the analysis procedure.
- Follower density is the most promising performance measure as it maintains the strong relationship with traffic flow and also incorporates some dependence on geometry. Moreover, it would better represent the highway performance in conditions closer to capacity since marginal changes of traffic volume could worsen traffic operations considerably. Given the counterintuitive effect of the percentage of trucks on follower density, this variable should be further studied.
- Horizontal bendiness and vertical class of gradient boundaries should be further studied.

The results and conclusions are valid within the simulation range and the observed scenarios. Therefore, posted speed limit should be 100 km/h and the percentage of heavy vehicles should remain below 35 %. Moreover, the data was collected with good weather conditions and daytime conditions, so influence of rain or nighttime conditions should be studied separately. Different highway configurations, such as 2+1 highways or passing lanes, should also be studied separately. Further research will be needed to model the performance measure(s), which should account for heterocedasticity.

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