PROCEDURES TO FACILITATE PASSING ON CONVENTIONAL HIGHWAYS BY MEANS OF SIMULATION

Subject: Simulation and geometric design

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ABSTRACT

Objectives:

- To calibrate the TWOPAS model (Interactive Highway Safety Design Model-IHSDM) for Colombia

- To apply the TWOPAS in order to propose a procedure for justifying the inclusion of climbing lanes, estimating their operational benefits, and establishing design criteria

For the TWOPAS calibration, an experimental section on a two-lane road for assessing vehicular operation (particularly uphill passing maneuver) was considered.

The vehicular movement was tape-recorded, which required close observation in order to manually convert the information to the required data for traffic simulation by using the TWOPAS microscopic model. Its calibration was based on a model results sensitivity analysis as a parameters, input data, and simulation logic change effect.

For climbing lanes assessment, simulated vehicular operation criteria using the TWOPAS calibrated (as percentage of time spent following and average spatial speed) were used.

Calibration (comparison between simulated and observed results) resulted in 15% approximation on a circulation direction and 18% on the other. A procedure to facilitate passing on conventional highways through the combination of additional lanes was proposed.

Main Conclusions:

- Calibration is amenable of improvement through further studies; however, the employed method may be applied under many conditions

- A procedure to ease passing by implementing ancillary lanes using the TWOPAS is recommended

- Employed methods and obtained results may be replicated in other countries

1. INTRODUCTION

The quality of the operation and safety on two-lane highways deteriorate as the opportunities of passing are reduced, either by an increase in volume or by a decrease in visibility. One of the solutions to this problem is to make a partial widening of the transversal section to facilitate passing: this document presents a procedure to facilitate passing by using simple and more cost-effective improvements, like a series of ancillary lanes by using simulation.

Objetives:

- To calibrate the TWOPAS model to the Colombian environment.
- To apply the TWOPAS model (IHSDM) in the creation of procedures to justify the inclusion of a series of climbing lanes, to asses its operational benefits, and to establish design criteria for their location.

2. BIBLIOGRAPHIC REVISION

In regards to passing lanes, Khan et al (1) consider them to be adequate solutions for low and medium flow highways for which a four-lane highway is not justified.

On the other hand, they considered several operational indicators to measure the change of the Level of Service when a passing lane is added, which are the percent of traffic platoon and the average speed.

Messer (2) observed the possibility of relating the average time delay to the degree of platooning as measured on the field, considering those vehicles with intervals less than 5 s.

Khan et al (1) develop guidelines to define the length of the passing lane and its effective distance.

Harwood and St. John (3) found that the reduction in the platooning percentage along the highway after a passing lane can be extended from 8 to 12.8 km. (5 to 8 miles), depending on the length of the passing lane, traffic flow, composition and availability of opportunities of passing downstream. They related these effects, and their results provide per se a method of estimating the operational effectiveness of passing lanes.

The measure of operational effectiveness of passing lanes recommended by Morrall and Thomson (4) are the percentage of time spent on following and the opportunity of passing.

May (5) used the Percentage Delay Time, Percentage of 2-second headways, Percentage of Solitary vehicles platoon, and Percentage of Solitary Vehicles Platoon. It was preferred the number of passes per length of the passing lane.

Taylor and Jain (6) ratify that speed is necessary to establish the effects on the travel time that are generated by the passing lanes on an economic effectiveness analysis.

Morral and Werner (7) and Werner and Morrall (8) have suggested the rate of passing as a measurement of the balance between the supply of opportunities and the demand for passings.

In regards to the dimensions of the passing lanes, AASHTO (9) recommends that the necessary length depends on the influence of the bottleneck that seeks to be resolved by adding of a passing lane with the purpose of reducing delays with a minimum of 0.5 km. (0.3 miles) and an optimum of 1 to 2 km.. (0.6 to 1.2 miles). The operational benefits are the reduction on the platoon formation between 5 to 15 km. (3.1 to 9.3 miles) downstream in the lane, depending on the volume and the opportunities of passing.

Morrall and Thomson (4) offer recommendations for the design of the passing lanes, indicating a method that considers the selection of the site, its justification, the determining of the physical characteristics that will meet the assessed needs, construction, parking and signs.

May (5) determined a new measurement of effectiveness as the number of passings in the section of the passing lane by the length of the lane that allows to compare several options of lengths. He also observed the frequency of passing maneuvers related to the flow and to the types of vehicles.

Hardwood (10) considers that the development of a method of operational evaluation requires the use of simulation models, since it is not only less costly than the taking of field data, but the model also allows comparisons of operations in several sections of the highway under identical traffic conditions with or without a passing lane.

In its Highway Capacity Manual (HCM) the TRB (11) specifically show the methods to determine the capacity and the level of service of only one passing and climbing lane, but in order to evaluate the interaction among several climbing or passing lanes, which is complex, it is not possible to carry it out with the procedures contained in the HCM.

The effect of supplying an additional passing lane in the same direction of traffic within the effective length of the first passing lane is quite complex to be evaluated, the current work was oriented toward the analysis of that aspect through the use of a calibrated simulation model.

Khan et al. (1) proposed a methodology to analyze the cost effectiveness and economic feasibility of passing lanes and sensitivity test; in this case they could be study the effects on the changes in volume and other factors.

The cost effectiveness depends on that the measurements of effectiveness (reduction of delays and enhancement of safety) can be contrasted to the cost. Although the longer passing lanes have a bigger impact than the shorter ones on the reduction of platoons and the improvement in the speed, as far as financial efficiency, the best length is between 1 and 2 km. (0.2 and 1.2 miles).

Taylor and Jain (4) conducted the economic evaluation of the passing lanes. The benefits are the reductions in delays and accidents. The savings in costs to the highway user associated with these benefits were compared to the costs of construction and maintenance of the passing lanes. The reduction in delays results in savings of operational costs to the highway user. The reduction in delay was used to calculate the savings in cost of time. The total benefits correspond to the sum total of the benefits by delays and by accidents.

For a highway with smooth grades, the benefits for delay for a passing lane can be insignificant. However, the value of the time saved will increase significantly with the type of trip and with the unitary value of the travel time. Then, if a series of passing lanes are built in an exclusive route, the accumulated time savings could reach a high value, which will increase the benefits by a factor of 17.

AASHTO (9) suggests to build passing lanes systematically along the highway at regular intervals in places where the Passing Sight Distance (PSD) is limited, to enhance the Level of Service (LOS).

3. METHODOLOGY

3.1. Calibration of the TWOPAS

3.1.1. TWOPAS

The TWOPAS was chosen because of its background of use in Colombia by the Pontificia Universidad Javeriana (12) and the studies done with it by Valencia (13).

The TWOPAS computer program was originally developed by the Midwest Research Institute (MRI) between 1971 and 1974. As part of a research by the Pan American Highway Institute, an extensive Sensibility Analysis was completed to identify key input parameters and verify how the TWOPAS simulation model performs in a wide range of conditions. In order to identify important parameter values and assumptions embedded in the program, a detailed revision of its logic was conducted and the logic of some subroutines was carried out by Archilla (14).

The enhanced model, the TWOPAS98, was used to develop the analytical procedures in the chapter of two-lane highways from the 2000 Capacity Manual. The key enhancements include: The capability to simulate reduced-speed zones; automatic calculation of the Available Sight Distances and generating of no-passing zones; an increased array of dimensions to allow the simulation of highways up to 50 km. (31 mi) in length; updated vehicle performance characteristics; converted embedded data and constants to variables with default values that can be modified by advanced users, as concluded by Leiman, Archilla and May (15).

The TWOPAS model simulates traffic operations on two-lane highways by reviewing the position, speed, and acceleration of each individual vehicle along the highway at one-second intervals and advancing those vehicles along the highway in a realistic manner. The model incorporates realistic passing and pass-abort decisions by drivers in two-lane highway passing zones. The model can also simulate traffic operations in passing and climbing lanes.

The program incorporates the major features: Highway Geometry, Traffic control, Vehicle Characteristics, Driver Characteristics and Preferences, and Entering Traffic.

The heart of the Traffic Analysis Module (TAM) is the simulation model of the rural traffic TWOPAS. The TAM is one of five sub-models that compose the Interactive Highway Safety Design Model (IHSDM). It delivers accumulated results in reports about platooning, as well as total travel time, speed, delays and percentage time spent following.

3.1.2. Experimental Section

The section of highway between stations km3+387.630 (Crucero de Totoró Intersection) and km12+174.000 (Las Margaritas Development) is located on the highway that connects Popayán with Cali (Colombia). It has 37 vertical curves, 17 simple horizontal curves and 12 spiralized curves. The highway unfolds in a rolling and mountainous terrain, with geometrical specifications and good pavement conditions.

With the purpose of calibrating the TWOPAS, Valencia y Garcia (16) observed in detail the passing maneuver in the experimental section located between stations km10+650 to km10+880. With an Average ascendant grade of 5.32%, registered laterally (stations km10+650 to km10+770) and longitudinally (stations k10+650 to km10+880) to the highway, a video of the circulation of the vehicles through several transversal sections to determine the instants of the passing of each vehicle's front and rear bumpers by each transversal section, each 20 meters apart, and thus prepare diagrams of time vs. space that would allow to establish the individual trajectory of each vehicle through time, to ascertain the passing maneuvers in detail, and to estimate the spatial and temporal spot speed, the headways between vehicles, following gaps, accepted and rejected gaps in passing maneuvers, flow, vehicular composition, platoon formation, percentage time spent following, accelerations, delays in following, weight/power ratio, and speeds, etc.; in all, enough information to calculate the values of the indicators delivered by TWOPAS in their outputs of the experimental section, and to be able to compare them to those simulated in order to establish the degree of approximation among them and to determine the degree of the obtained calibration.

3.1.3. Calibration of the TWOPAS.

Archilla (14) believes that given the fact that TWOPAS requires too much data entry and contains too many parameters in the models that makes it up, it makes its calibration difficult to the wide range of conditions of rural highways, of vehicles, and of traffic found in other countries. Therefore, the main goal of his research was to make easier to the users the calibration and application of TWOPAS to evaluate the improvements in rural highways. For this, he established an extensive sensibility analysis to verify the behavior of TWOPAS under a wide range of conditions, and to identify key assumptions and restrictions of the model.

The development of the calibration involved modifying some parameters and entry data in a way that represented the operational conditions of the experimental section through a series of simulations oriented by the results of the sensibility analysis carried out by Archilla (14), and supplemented with other simulations seeking that the degree of adjustment between indicators measured in the experimental section and those simulated by TWOPAS were the best possible.

For instance, it required increasing the average spatial speed and reducing the delays in the experimental section, so that the simulated values would come close to those measured on the highway; then, changes were attempted in the data entry and parameters of the model, as follows:

- Decreasing the coefficient of variation of the desired speed.
- In ascendant grades, the spatial average speed is further reduced by the presence of vehicles with poor performance, although their drivers' desired speed is low, and because of the presence of drivers with low desired speed, even though their vehicles are capable of performance good enough to ascend the grades. As such, consideration is given to increasing the desired speed for the trucks in both directions.
- When there are trucks operating on ascendant grades, according to Archilla (14), it seems that the traffic delay component is much greater than that of geometric delay. In other words, that there is a greater impact as a result of vehicular interaction than because of the grade. Given that the behavior of the delay is generally contrary to speed, then consideration was given to adjusting the decrease of the trucks' weight/power ration (enhancing their operational capabilities) and decreasing the minimum Passing Sight Distance (PSD) so that the trucks will not delay the rest of the vehicles; yet this did not help much.
- In regards to the performance parameters of the vehicles, Achillas's recommendation (14) was welcomed in the sense of taking advantage that TWOPAS allows to specify five categories of passenger cars to represent their diversity of the operational capacity and, as such, their operation on the experimental section. This is useful not only for low traffic flows as in this case, but also for high flows. The passenger car's operational capacity was reduced in terms of maximum acceleration and pseudo-maximum speed; however, it is necessary to conduct further research to better understand these operational characteristics of passenger cars.
- In equivalent manner, the operational capacity of the vehicles classified as recreational (RV's) was increased in terms of maximum acceleration and pseudo-maximum speed.
- Additional operational gains can be obtained by reducing the No-passing Zones, which is achieved by reasonably decreasing the minimum Passing Sight Distance (PSD), which uses the Traffic Analysis Module (TAM) to automatically demarcate them. This change, as the others, have effects on other operational variables that must be watched to prevent them from getting away from the values measured on the field, as is the case in the number of passes.

3.1.5. Comparison between Measurements taken on the Highway and the Simulation with TWOPAS

Once the adjustments to the parameters were made, the results of the simulation were compared to the operational indicators measured on the experimental section, and the results obtained are displayed in Table 1.

TABLE 1. Degree of TWOPAS Calibration.

PERCENTAGE OF EXCESS OF THE VALUE OF THE OPERATIONAL INDICATOR SIMULATED BY TWOPAS WITH RESPECT TO THE ONE MEASURE IN THE EXPERIMENTAL SECTION			
Stations of the experimental section (10650.000 to 10770.000 increasing; 10770.000 to 10650.000 decreasing)			
Traffic Output Data	Direction of Travel		
	Increasing Station	Decreasing Station	Combined
Flow Rate from Simulation (v/hr)	6%	1%	3%
Percent Time Spent Following (%)	143%	25%	94%
Average Travel Speed (km/h)	-13%	5%	-2%
Trip Time (min/veh)	33%	0%	0%
Traffic Delay (min/veh)	ND	ND	ND
Geometric Delay (min/veh)	0%	-100%	ND
Total Delay (minutes/vehicle)	200%	-200%	ND
Number of Passes	-7%	-100%	0%
Vehicle km Traveled	5%	0%	0%
Total Travel Time (veh-hrs)	25%	0%	0%
AVERAGE PERCENTAGE	27%	-10%	14%
AVERAGE PERCENTAGE OF THE ABSOLUTE VALUE	15%	18%	1%

The Percentage of Time Following (PTF) was not counted within the Approximation Average Percentage, since the value simulated by TWOPAS produced very different values to those observed on the experimental section because the simulated value takes into consideration the accumulated vehicular operation before the experimental section, which is not reflected on the field observations that are characteristic of the length of the studied highway. This is why the percentage of difference between the value simulated and measured in the direction of travel corresponding to the increasing stations (143%) is greater because the experimental section is very far from the beginning of the highway; and in the direction of circulation of decreasing stations (25%) the opposite happens because the experimental section is located close to the beginning of the highway.

On the other hand, the high percentages obtained for the total and geometric delay are mainly due to the fact that the values of theses indicators simulated and measured by TWOPAS are very small (in the value of hundredths) given the short length of the experimental section, and that the significant figures used in the estimation of value of the measured indicator produced such percentages (in the value of hundredths.)

3.2. Procedure to Facilitate Passing

The calibrated TWOPAS is a useful tool to evaluate the operation in two-lane highways and the impact of simple improvements such as the modifications to the transversal section with the purpose of facilitating the passing maneuver.

When the faster vehicles are delayed by slower ones, a passing demand is generated that can be unsatisfactory due to the geometric conditions that restrict the Passing Sight Distance, or to the medium or high volume present. A cost-effective option to resolve this need is by the widening or special use of the transversal section of the highway along a length that produces the best results between the operational benefits and the costs of implementing it. These options are far more cost-effective than a complete widening of the transversal section along the entire highway to two or more lanes in each direction.

3.2.3. Benefits and Costs of Adding Climbing Lanes along the Highway

Any of the options to help improve passing, in terms of widening the transversal section, or a special use of it, generates operational benefits and reduction in the accident rate under the geometric conditions and volume of traffic. In itself, the developing of this infrastructure involves costs of engineering studies, construction and maintenance that should be less than or equal to the benefits to justify its implementation.

In this article, the calibrated TWOPAS was used as a tool to establish a procedure that facilitates passing on a two-lane highway that is produced by adding a series of ancillary lanes based on the operational effects that are generated.

3.2.4. Procedures to Justify the Adding of Climbing Lanes

The following procedure is proposed to facilitate passing with climbing lanes and that can be extended to the other options such as passing lanes, turnouts and shoulder driving:

- If the highway to be evaluated is located in rolling or mountainous terrain, it is reasonable to take into consideration, as an option to improve passing, the addition of a series of climbing lanes. If the terrain is flat or rolling, it is appropriate to consider the addition of a series of passing lanes. And if the highway has a combination of terrains, it must be broken down into homogeneous segments; in other words, with only one type of terrain. Prior to the development of the procedure, all geometric and traffic information required by TWOPAS to implement it must be gathered.
- The operation of vehicles on the highway without ancillary lanes is evaluated with the TWOPAS, and the outputs that are necessary for this procedure are given out in terms of the speed of the vehicles and the Percentage of Time Following (PTF) along the entire highway in both directions. The Level of Service (LOS) in the U.S. is associated with the value of PTF, and in Colombia mainly with the speed, which allows to determine the zones in the highway where it is required to facilitate passing by its low LOS, be it for the PTF's low values as in the case of the U.S., o low speed in the case of Colombia, according to the type of highway and the engineer's judgment. The speed and its correspondence with the LOS, as in the case of Colombia, it is considered in the Two-lane Highway Capacity and Levels of Services Manual in Colombia, a regulation of the Colombian Ministry of Transportation (17.)
- The more precise location of the first climbing lane is obtained by taking into consideration several recommendations of geometric, operational, safety and constructive type, as in the following:

- The start of the climbing lane must be where it generates the most operational benefits; in other words, where the PTF is great or the average speed is low corresponding to poor LOS, since at the beginning of an ascendant grade the high speed of trucks does not result in important benefits in terms of operation and safety; and as orientation is recommended to place it at the end of the Critical Length Grade (CLG).
- The lane addition and lane-drop transition of the climbing lane must be located in places where the visibility is greater than the minimum PSD, and for that purpose the No-passing Zones automatically determined by the TAM are used as reference.
- The end of the climbing lane must be located, in general terms, at the end of the ascendant grade where it began. The length of the lane is specifically determined by taking advantage of the facilities and results of the simulation, testing the length that turns out to be more efficient in terms of the relationship between the number of passes done per each kilometer of additional lane.

• The operation of the vehicles on the highway with the first climbing lane operating in one direction is evaluated with the TWOPAS. This generates operational improvements of different magnitude according to the indicator considered and the particular conditions of route design, possibilities of passing, and volume and vehicular composition after the climbing lane. The operational benefits that are generated in the climbing lane, mainly the reduction in PTF and the increase in speed, extend a length beyond the end of it that varies according to the characteristics of said highway; and according to the total length of the highway being studied, and it can continue to the end of the highway. If these benefits do not extend all the way to the end of the highway, then it is possible to repeat the procedure to consider the relevance of building one or several ancillary lanes until the benefit generates satisfactory operational conditions. If the location of an ancillary lane is within the length of extension of the benefits of the last ancillary lane, then conditions are generated that do not produce enough benefits to justify their construction, and there will arise the need to consider another less costly improvement alternative for passings, such as turnouts or shoulder driving.

3.2.5. Application of the Procedure to Facilitate Passing

The case of a highway located in Colombia, whose characteristics were previously described, is being studied; and due to its rolling and mountainous terrain, the effect of a series of climbing lanes in one direction of circulation is being evaluated. The steps taken are described below:

• TWOPAS is applied to evaluate the operation of the highway without climbing lanes, obtaining the results in terms of PTF, speed, platoon size and number of passes that occur along the highway. As it can be observed in Figure 1, for two-lane highways, the PTF is increasing in the direction of circulation 1, indicating very poor LOS.

• The general location of the first climbing lane is determined by the following considerations:

- There is a key ramp that starts at station k7+425, and ends at K8+325. Between these two stations, among other operational indicators, the fact that the PTF varies from 60.4% to 64.5% is stressed.
- There are no-passing zones, indicated by the TWOPA outputs, among which can be arranged the length of lane addition transition of the climbing lane; moreover, a horizontal tangent starts that allows specifying the beginning of the climbing lane at the station k7+849.
- In order to arrange the lane-drop transition of the climbing lane, the fact that there are permitted passing zones among which they could be placed, is taken into consideration. Moreover, a horizontal tangent starts that allows specifying the beginning. The length of this transition is 67 meters, causing that the end of this transition be located at station k8+457.
- Based on the aforementioned, the dimensions of the climbing lane would result in 541 meters (0.3 miles), covering ascendant grades of 8.13%, 1.93% and -2.48%.

• With the previous characteristics of climbing lane 1, the traffic operation with the TWOPAS was simulated, and the outputs of PTF illustrated in Figure 1 were obtained. When comparing the values of the traffic indicators of the highway, both including and not including climbing lane 1, the following changes could be noticed:

- Speed of all the traffic: An increase starting at station k7+800 and a maximum of 14 km/h (8.7 mi/hr) at station k10+500, being gradually reduced until the end of the highway.

- PTF: In the first 100 meters a light increase, almost negligible, can be perceived; but the maximum reduction of 17.9% occurs at station k8+000, the difference being reduced to a value around 13%, staying on for several meters and then gradually reducing the difference until station k11+300, where it is virtually zero until the end of the highway.
- Platoon size: The reduction in the platoon size becomes evident at stations k8+000, with reductions of 0.6 vehicles, and it increases to a maximum of 2.5 vehicles beyond the end of the climbing lane. It finally decreases until the end of the highway, where there still occur reductions on the platoon size of 1.1 vehicles.
- Number of passes: With the start of the climbing lane, the increase of the difference in the number of passes that take place begins, growing along the route of the ancillary lane, reaching up to a maximum value of 27, which occurs almost in the middle of the climbing lane, and then this difference in the number of passes is reduced until it is nearly zero at the end of the climbing lane. It is very important to mention that in the highway of this case study, the experimental section is located at a station beyond that of climbing lane 1, and that in said section the field measurements permit to establish the number of real passes. When climbing lane 1 works, the number of passes is reduced, thus allowing to conclude that the demand for passings in stations that follow the ancillary lane is reduced, creating conditions that would not justify a probable climbing lane 2, since the benefits that could be generated would be lesser.

• With the results of applying the TWOPAS on the highway with climbing lane 1 in operation, an analysis is in progress to determine the most adequate location for climbing lane 2, similar to the steps taken before, taking into consideration that:

- There is an important ramp that starts at station k10+258.74 and ends at station k11+418.74. Among other operational indicators, it is emphasized that the PTF varies from 61.7% to 65.4%. If there was no climbing lane 1, among other operational indicators it is emphasized that the PTF varies from 77%, passing through a maximum of 77.4%, to 64.8%, the new conditions becoming less favorable to generate greater operational benefits.
- There is a permitted passing zone, indicated by the TWOPAS outputs, among which can be located the lane addition transition of the climbing lane, past station km10+258.74, which ends the tangent where there is a bridge, and a slope of 8.27% of inclination begins and, according to Valencia (18), the Critical Length Grade (CLG) for an inclination of 8.5% is of 173.8 meters (0.1 miles), which would be the distance from the beginning of the slope where the climbing lane should start; the beginning of the climbing lane would be at the station close to k10+432. At the closest station (k10+300), the PTF is 63.3%.
- The slope ends with enough Passing Sight Distance (PSD); then, if the lane-drop transition of climbing lane 2 is 87 meters (0.05 mi), the end of the climbing lane would be located at station k11+332, resulting in a length of 900 meters (0.56 mi) of the climbing lane that would travel through ascendant grades like this: 8.27%, 4.57%, 5.67%, 4.61%, 5.76% y 3.26%.

• With the previously mentioned characteristics of climbing lane 2, the traffic operation was simulated with the TWOPAS model, and the PTF results displayed in Figure 1 were obtained. When comparing the values of the traffic indicators of the highway, including climbing lanes 1 and 2, and only including lane 1, the following changes can be mentioned:

- Speed of all the traffic: It increased from station k10+400, reaching its maximum of 10 km/hr (6.2 mi/hr) at station k11+000, then being gradually reduced at the end of the road, not quite reaching zero.
- Trucks' speed: A decrease between 1 and 3 km/hr (0.6 and 1.8 mi/hr) from station k10+400, to station k10+500; then it stays the same until it increases between 2 and 5 km/hr (1.2 and 3.1 mi/hr) from station k11+500, to the end of the highway.
- PTF: In the first 100 meters (0.06 mi) a light increase of 2.5% can be perceived, but the maximum reduction of 29% occurs at station k10+650; then the difference is reduced to a value around 10.4%, when the climbing lane ends at station k11+400, after which the PTF difference increases again to a maximum of 15.1%, to then reduce such difference at the end of the highway, where it reaches 14.8%.
- Platoon size: The light increase between 0.3 and 0.6 vehicles takes place at stations k10+300 and k10+400; but then it is reduced to a maximum difference of 1.5 vehicles at station k10+900, then the size is reduced to attain a difference of 0.7 vehicles at

station k11+700, maintaining it to the end of the highway, where there are further decreases in the platoon size that result in a difference of 0.7 vehicles.

- Number of passes: With the start of the climbing lane, the variable increase of the difference in the number of passes that take place appears, maintaining this high difference along the route of the ancillary lane, reaching up to a maximum value of 25 other passes that occur in the middle of the climbing lane, and then this difference in the number of passes is reduced until reaching zero at the end of the climbing lane.

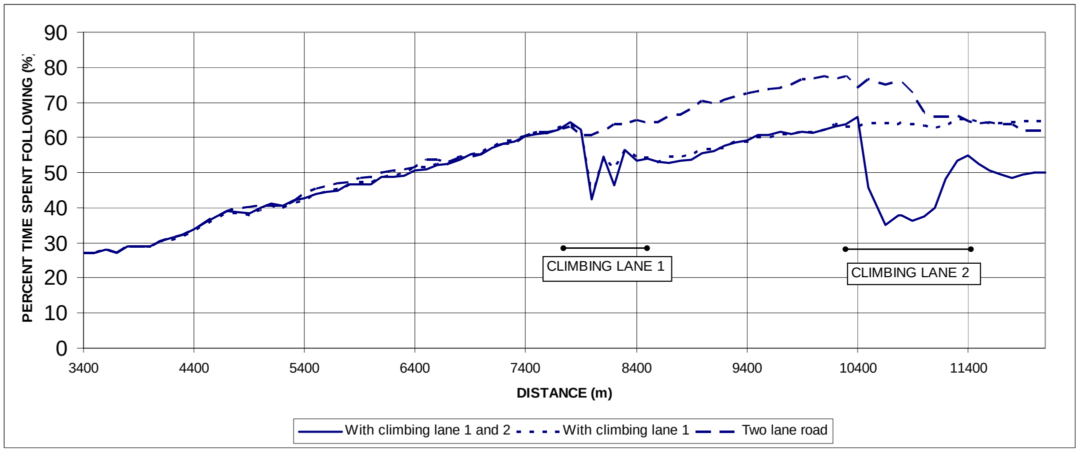

FIGURE 1: Percentage of Time Spent Following on a two-lane highway with climbing lanes 1 and 2 in one direction

4. CONCLUSIONS

- The TWOPAS calibration methodology used is applicable for the use of the model under different conditions of the traffic and the highway.
- The TWOPAS calibration reached a 15% degree of approximation of the operational indicators such as volume, travel time, delays, number of passes, vehicles to km. traveled, and total travel time simulated, with respect to those observed in the direction of increasing stations, of 18% in the decreasing stations, and of 1% in the combination of both, calculated as the average percentage of the absolute values of the differences between the indicators without including in this calculation the PTF, given its dependent behavior on the length of travel to the experimental section considered for the calibration where it was measured, but it is not comparable.
- It is possible to enhance the degree of the TWOPAS calibration with additional studies that will allow to better assessing the operational capacity of automobiles and recreational vehicles, parameters of the following model and behavior of the drivers.
- The application of the TWOPAS to evaluate from an operational capacity the effect that the incorporation of a series of ancillary lanes produces on the traffic is of great help, due to the realistic representation of the traffic in the particular conditions of a highway that is not otherwise possible with the procedures as presented in the capacity manuals and levels of service available in international literature that only allows to evaluate, from an operational capacity, a climbing or passing lane, under assumptions that do not cover a diversity of true conditions that arise on a highway.
- Although the procedure presented in this article to facilitate passing in two-lane highways has been broadly described, it allows for the operational evaluation of a series of ancillary lanes as climbing lanes, passing lanes and turnouts.
- The operational benefits generated by an ancillary lane extend to a length that goes beyond its location, and most probably will not favor the building of an ancillary lane as a result of the reduced benefits it would generate, and that in the event of the lack of the first ancillary lane it could be justified.

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