DECELERATION LANE LENGTH EVALUATION BASED ON A NEW CONFLICT INDICATOR

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ABSTRACT

Traditionally, road safety studies are carried out through statistical analysis of accidents and their consequences, including life loss, injuries, and property damages. However, the sample size in many locations is not large enough to validate the statistic analysis; or the geometrical improvements of the road reduce the validity of historical crash data. Therefore, this type of analysis often cannot be applied to the entire road network.

Traffic Conflict Techniques are an indirect measure of road safety that use near-accident indicators. The indicators are based on spatial and temporal measures between road users. These techniques allow us to perform a quantitative assessment of the hazard. Safety analysis based on Traffic Conflict Techniques identify and evaluate operational deficiencies and improvements; even when a statistical correlation between proposed conflict indicators and number of crashes is complex to define but necessary.

Until now, various indicators have been developed to analyze the conflict associated with crossing maneuvers. In contrast, maneuvers without a clearly defined conflict zone have been poorly studied. Therefore, a new conflict indicator, called Potential Time to Lateral or Rear-End Collision (PTLRC), has been developed. PTLRC is applicable to follow up and lane-changing maneuvers, that occur in different road sections, especially in weaving lanes and diverging lanes.

Derived indicators of PLTRC were developed to analyze: (1) a specific conflict between two vehicles; (2) a specific maneuver; and (3) multiple maneuvers at the same location.

A comparative analysis between the crash data and PTLRC in 10 deceleration lanes is presented. PTLRC highlights different risk levels based on the deceleration lane length. New deceleration lane lengths are recommended based on this analysis.

INTRODUCTION

Road safety is related to a complex set of factors, which include road users and vehicles. Any change in the behavior of vehicles or humans requires long-term solutions. However, improvements in traffic-related issues, such as design changes , can be accomplished relatively quickly.

Traditionally, road safety studies are carried out through statistical analysis of accidents and their consequences, including life loss, injuries, and property damages. However, the sample size in many locations is not large enough to validate the statistic analysis; or the historical crash data loses its validity due to geometrical improvements of the road. Therefore, this type of analysis cannot be applied to the entire road network. Traffic Conflicts Technique (TCT) is used to assess road safety using "proximity to the accident" measures, in both time and space.

The main advantage of using TCT is that situations with a certain degree of danger occur much more frequently than accidents; so TCT allows us to study road safety before accidents happen [1].

Validity of TCT has been criticized while trying to establish a statistical correlation between accident data and TCT results. Chin and Quek [2] claimed that TCT can be used taking into account that TCT are used as a diagnostic tool and for assessment and not as a prediction method. Migletz [3] and Svensson [4] studies have indicated that TCT can produce accident occurrence estimates as good as those based on accident statistics; TCT studies also require less time for data collection.

Until now, various indicators have been developed to analyze conflicts associated with crossing maneuvers. In contrast, maneuvers that do not have a clearly defined conflict zone such as merging, weaving, exiting and following up, have less developed indicators applicable to them. In order to analyze such maneuvers we developed a new conflict indicator called Potential Time to Lateral or Rear-End Collision (PTLRC), and its derived indicators.

This paper presents traffic conflict analysis for deceleration lanes and proposes some indicators. Obtained results are compared with crash data of 10 deceleration lanes for validating the PTLRC conflict indicator.

FIELD STUDY

The field study was developed in two phases. The first was an experimental phase where the construction of a section of the freeway CV-35 was used. The second phase was a verification of the obtained results in 10 deceleration lanes with different lengths.

The case study selected for the first phase was from the CV-35. The closing of an entry converted the existing weaving lane into an exit lane. The design and operation of the deceleration lane length was experimentally studied. Other highway characteristics and traffic were constant during the first phase.

Four configurations for the diverging lane were established. The constraints were: the available length, the Spanish design guidelines [5] and existing road markings. In order to avoid interfering with drivers' behavior, the lane's length was modified using road marking tapes. After the experimental phase, the definitive road markings were painted.

The maximum length of the deceleration lane was conditioned by the existing road markings; a total length of 440 meters from the end of the continuous edge line to the beginning of the exit ramp was available.

The deceleration lane length and its characteristics followed the Spanish design guidelines [5]. The deceleration lane length (*L*) is defined as the distance between two sections. The first section of the road is where the taper is 1.5 m wide. The second section is located where the exit nose width is 1.0 m. *L* is defined as a function of: the road grade (*g*); the minimum between design speed and posted speed limit (S_{do}); and the posted speed limit for the exit ramp (S_{df}). It is calculated using equation 1.

$$L = \frac{S_{do}^2 - S_{df}^2}{254 \cdot g + 50} \qquad (1)$$

The values of the parameters in the case study are: grade -2% (-0.02); posted speed limit for the exit 40 km/h; and no speed limit posted on the freeway. Therefore, different operating speeds were used

(130 km/h, 120 km/h, 100 km/h and 80 km/h) to determine different configuration of lane lengths. Four deceleration lane lengths were selected. The first one was used to analyze lane lengths longer than the required while configuration 3 and 4 were used to analyze shorter lanes.

Before gathering the information, each configuration was installed. The field data were collected at least one week after the installation of the configuration to accustom drivers to the new lane length. Four video cameras recorded simultaneously the deceleration lane in order to cover the whole section. Data were collected between 8:30 a.m. and 11:30 a.m with favorable weather conditions and dry pavement. Different traffic situations were analyzed.

In the second phase, 10 additional deceleration lanes with different lengths were evaluated. These deceleration lanes were selected taking into consideration: a deceleration lane located on a tangent section of a freeway and the availability of a recording camera from the Traffic Control Center of Valencia.

The images were digitized at 25 frames per second, with a resolution of 768 x 576 pixels. Later, the videos were processed with a specific software developed using the conic perspective restitution technique [9]. This technique allows the reconstruction at scale of an object. It starts from the object's conic perspective and additional data are used. Homology relations between a 2D figure and its perspective are established. Then, the object can be restituted with two known distances and its shape. These software applications give the position of the vehicles at each frame. Speed and acceleration are calculated by relating the positions through the elapsed time using numerical derivatives. All exiting maneuvers during a period of 1 hour at each deceleration lane were digitalized.

In order to compare the operation and safety on the different deceleration lanes, Traffic Conflict Techniques were used. We needed a suitable indicator that takes into account the characteristics of exit maneuvers. The existing indicators that could be used on non-bounded conflict zones are: Approximate Time to Collision (α-TTC), Possibility Index for Collision with Urgent Deceleration (PICUD) [6] and Potential Time to Collision (PTTC) [7]. These indicators are applicable mainly in conflicts related to follow up maneuvers. Nevertheless, these indicators do not take into account lateral conflicts, which occur in merging, exiting and weaving maneuvers.

PROPOSED CONFLICT INDICATOR

To bear in mind follow up and lateral conflicts, the Potential Time to Lateral or Rear-End Collision (PTLRC) conflict indicator was developed. PTLRC is a conditional indicator that assesses the time between two situations. The first situation is associated to the maneuver of the leading vehicle. The second situation is the collision time if the follower vehicle does not make any evasive maneuver.

On the evaluation of the longitudinal conflict (follow up conflict), the indicator would be equivalent to the Potential Time to Collision (PTTC) proposed by Wakabayashi and Renge [7]. The applied deceleration should be that suggested for PTTC. However, a difference lies in the type of maneuvers that the leading vehicle can make. Table 1 shows the leading vehicle's types of maneuvers evaluated by the present research. To evaluate lane changing, the cosine function is considered. The function shrinks or expands if the vehicle accelerates or decelerates according to Rioux [8].

TABLE 1 Leading Vehicle Shares for PTLRC

Evaluated Conflict	Action	Acronym	Deceleration (km/h/s)	Mean Transv. Speed (m/s)
Follow emergency	Braking	PTTC	-20	0
Lateral	Lanes changes	PTTLC	0	1
Slows down and lanes changes	Both	PTTCCf	-10	1
Decelerates and lanes changes	Both	PTTCCd	-3.33	1

The PTLRC value changes while the vehicle moves. Therefore, the indicator should be evaluated over time to find the situation where the minimum value is obtained. Then, the conflict is characterized.

The data needed to calculate the PTLRC indicator are: longitudinal and transverse initial speed of the two vehicles involved in the conflict; and their initial positions.

The potential time to the collision is calculated for each possible leader action. Consequently, an iterative process in which initial conditions are known is carried out. So, the time between the beginning action of the leading vehicle and the moment that a collision would occur is calculated in different scenarios. The PTLRC value corresponds to the minimum value within the considered scenarios.

To measure the exposure to dangerous levels of conflict, lapse during PTLRC value below a threshold value is used. The result time is called Time under PTLTC threshold (T_PTLRC_T). Besides the time of exposure to hazardous PTLRC values, it is important to know the seriousness of exposure. The integral under a threshold value of PTLRC is used. Therefore, Integral under PTLTC threshold (I_PTLRC_T) is defined. I_PTLRC_T represents the seriousness of the conflict. Finally, the Ratio PTLRC (R_PTLRC_T) is calculated as the difference between the threshold and the ratio I_PTLRC_T / T_PTLRC_T. The value represents the average hazard exposure during the conflict.

To compare two locations or two different traffic situations, it is necessary to have aggregated conflict indicators. Thus, the following derived indicators from PTLRC were developed:

- TT_PTLRC_T: Total time under PTLRC threshold per time unit.
- $TI\_ PTLRC_T$: Total integral under PTLRC threshold per time unit.
- MT_PTLRC_T: Average time under a PTLRC threshold per maneuver.
- MI_PTLRC_T: Average integral under PTLRC threshold per maneuver.

The first two indicators represent the frequency of exposure and severity of conflict over a period of time. The others represent the average value per maneuver. Figure 1 shows graphically the representation of these indicators.

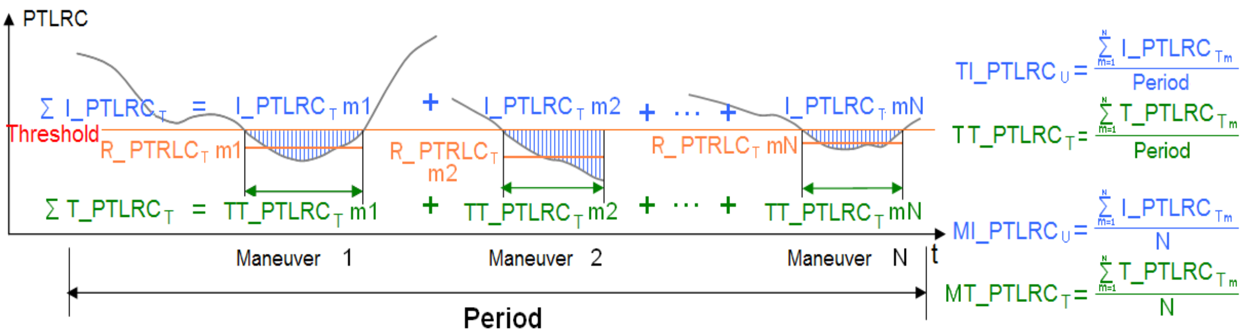

FIGURE 1 PTLRC Indicators Group.

The application of PTLRC indicators group is described. The case studies are: conflict between two vehicles; specific maneuver; and multiple maneuvers.

Specific Conflict Evaluation using PTLRC

In order to calculate the PTLRC indicator for a specific conflict, it is necessary to obtain at every frame: the longitudinal and transverse placement of the two vehicles; and the speed of the involved vehicles.

At each vehicle's position, PTTC, PTTLC, $PTTCC_f$ and $PTTCC_d$, values are calculated taking into account both lane changing directions. This calculation is performed twice by exchanging the leader role between the two vehicles. Finally, the minimum conflict value is selected for every frame. Figure 2 shows graphically how the conflict indicator varies.

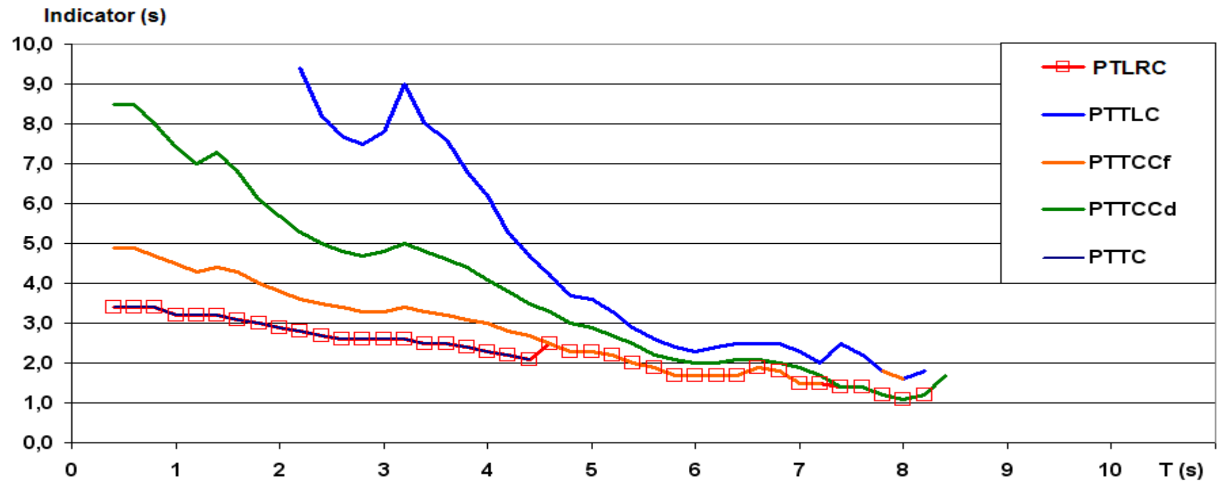

FIGURE 2 PTLRC in a Specific Conflict.

Specific Maneuver Evaluation Using PTLRC

PTLRC for a specific maneuver is used to evaluate the conflict of one vehicle maneuvering through traffic flow. Consequently, the conflict between that particular vehicle and every other vehicles around it is calculated. The methodology calculates PTLRC on each specific conflict and the lowest value within all conflicts is selected each time. Fig. 3 shows graphically the described calculation. It is possible to observe the $I\_PTLRC_{2.0}$, $T\_PTLRC_{2.0}$ and $R\_PTLRC_{2.0}$ values.

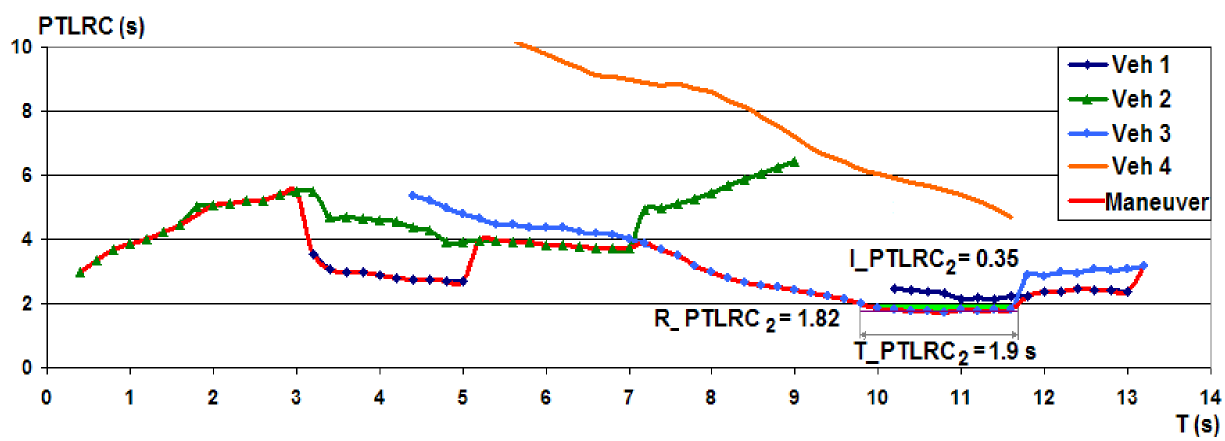

FIGURE 3 PTLRC Calculation for a Specific Maneuver.

As seen in Fig. 3, the PTLRC selected value changes from one vehicle to another along the path.

Multiple Maneuvers Evaluation with PTLRC

To analyze a specific location, I_PTLRC_T and T_PTLRC_T indicators are calculated for each maneuver during a continuous sample. The sum of I_PTLRC_T is calculated. Then, to obtain MI_PTLRC_T, the previous result is divided by the number of maneuvers. TI_PTLRC_T is obtained as the sum of I_PTLRC_T divided by the total time. MT_PTLRC_T and TT_PTLRC_T values are calculated following the same methodology using the sum of T_PTLRC_T.

It is important to highlight how these values depend on the selected threshold. Recommended thresholds are within the range [1.3, 1.7] s. The most dangerous maneuvers that occur on the road are included in the former interval. The interactions between vehicles that can be considered normal are excluded in the interval.

Figure 4 shows the variation of these indicators according to the threshold.

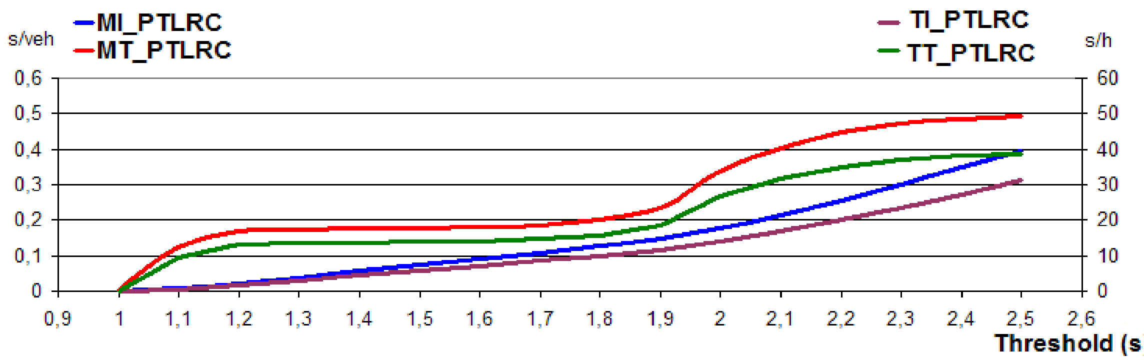

FIGURE 4 Variation of Indicators in function of the threshold.

APPLICATION

The PTLRC indicators group was applied in a total of 1143 exiting maneuvers in order to analyze the design and operation of deceleration lanes based on their lengths. First, a pilot study was performed by varying the deceleration lane length. Next, 10 additional deceleration lanes with different characteristics were studied.

A comparison between accident data of the 10 deceleration lanes and the results of the PTLRC indicators with different threshold was carried out by using multiple regression analysis and the Wilcoxon signed-rank test. Then, the threshold that best describes the conflicts at the deceleration lanes was selected.

Table 2 shows the fatal or injury accident rate per 100 M vehicle km for the studied deceleration lanes. It is Important to highlight that the accidents that were taken are located between 400 m before the taper and the 320 meters after the nose, as proposed by Cirillo [10].

TABLE 2 Deceleration lanes characteristics and accidents data

Lane ID	mean fatal or Injury accidents (2004-2007)	Acc/100 M veh	Acc/100 M veh km	Length (m)	L_0 (m)	Exiting vehicles (%)	No. of lanes	Heavy vehicles (%)	ADT (veh/day)
V21-143-1	0,5	4,1	4,1	215	216	16,20%	2	5%	36190
V21-985	0,25	2,91	2,91	209	228	15,30%	2	7%	26531
V21-51	0,5	5,96	5,96	187	256	16,00%	2	11%	26531
V30-49	1,25	11,14	11,14	88	215	16,00%	2	17%	37057
V31-68	1,25	9,43	9,43	137	256	13,10%	3	13%	44010
V31-85	1	7,89	7,89	100	217	7,10%	3	17%	44010
V31-98	0,25	1,85	1,85	229	189	12,70%	3	18%	38775
A3-351	1,5	17,96	17,96	80	54	34,50%	3	11%	33560
A7-484	1,75	12,56	12,56	217	256	18,60%	3	37%	40455
CV-35	0,5	3,52	3,52	385	285	8,20%	3	12%	47135

As shown in Fig. 5, the coefficient R^2 is almost constant for thresholds above 1.5 s. To better delimit the threshold range, the Wilcoxon test was used to select the threshold that best fits the ordering of the

PTRLC indicators and accident data lists. It was found that the threshold that best fits MI_PTLRC_T and MT_PTLRC_T indicators with the considered accident data is 1.5 s.

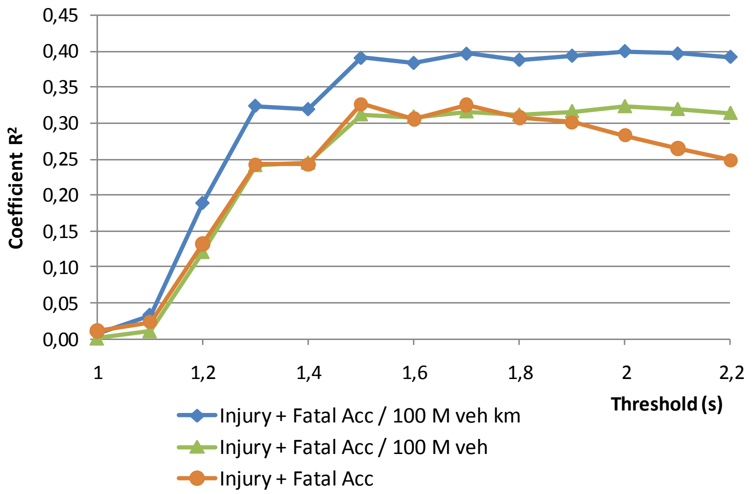

FIGURE 5 Coefficient R^2 between MI_PTLRC and accident data

A multiple regression analysis was done to determine from which variables the $MI\_PTLRC_{1.5}$ depends. It was found that the variables that best explain the variability of the $MI\_PTLRC_{1.5}$ indicator are: ratio between actual length (*L)* and the design length (L_0) ($RL = L/L_0$); the percentage of heavy vehicles, (*HV*); and the number of lanes on the main road (*NL*).

MI_PTLRC Analysis

Table 3 shows the multiple regression analysis for the first model. There is a statistically significant relationship between the $MI\_PTLRC_{1.5}$ indicator and the ratio L/L_0 (*RL*), the percentage of heavy vehicles (*HV*) and the number of lanes on the main road, for a confidence level of 95%. However, the confidence level of the number of lanes on the main road (*NL*) is only 90%, so the model should be simplified.

TABLE 3 Multiple Regression Analysis for $MI\_PTLRC_{1.5}$

Multiple Regression Analysis					Variance Analysis					
Parameter	Estimate	standard error	t-statistic	P-value	Source	Squares Sum	LD	mean square	F-Ratio	P-Value
CONSTANT	0.255266	0.10113	2.52413	0.0325	Model	0.0308197	4	0.0077049	6.38	0.0102
RL	-0.0047527	0.00166055	-2.8622	0.0187	Residue	0.0108747	9	0.0012083		
RL^2	0.270889	0.0924847	2.92902	0.0168	Total (Corr.)	0.0416944	13			
NL	0.0469608	0.0245964	1.90926	0.0886						
HV (%)	-0.0037390	0.00141263	-2.6468	0.0266						

R^2 = 73.918 %; R2 (adjusted) = 62.326 %; Standard Error of Est. = 0.0347606; Average absolute error = 0.0253006

Using the *RL* ration only as explanatory variable and a polynomial regression, equation 2 is obtained. It is possible to explain 52.37% of this variation with a confidence level of 95% as shown in table 4.

$MI\_PTLRC_{1.5} = 0.363595 - 0.00586906 * RL + 0.0000343622 * RL^2$ (2)

TABLE 4 Polynomial Regression Analysis for MI_PTLRC1.5

Multiple Regression Analysis					Variance Analysis					
Parameter	Estimate	standard error	t-statistic	P-value	Source	Squares Sum	LD	mean square	F-Ratio	P-Value
CONSTANT	0.363595	0.0779656	4.66353	0.0007	Model	0.0218351	2	0.0109175	6.05	0.0169
RL	-0.00586906	0.00188057	-3.1209	0.0097	Residue	0.0198594	11	0.0018054		
RL^2	0.0000343622	0.000010264	3.34784	0.0065	Total (Corr.)	0.0416944	13			

R^2 = 52.3693 %; R2 (adjusted) = 43.709 %; Standard Error of Est.=0.04249; Average absolute error = 0.0299416

It was also studied the deceleration lane length as an explanatory variable. It was found a statistically significant relationship between the $MI\_PTLRC_{1.5}$ indicator and *L* within a confidence level of 90% using a polynomial regression. It explains only 39.22% of the variability of the indicator, so *RL* is a better explanatory variable.

MT_PTLRC Analysis

The analysis of correlation between the $MT\_PTLRC_{1.5}$ indicator and the possible explanatory variables was done. Models containing all combinations of variables were adjusted to determinate which of them best predict the phenomenon according to adjusted R-squared value.

It was found that the same variables that explain the variability of $MI\_PTLRC_{1.5}$ also explain the variability of the $MT\_PTLRC_{1.5}$ indicator. These parameters are: *RL*; *HV*; and *NL*.

After simplifying the model, using *RL* as the only explanatory variable and a polynomial regression, equation 3 was obtained. It is possible to explain 62.73% of this variation with a confidence level of 99% as shown in table 5.

$MT\_PTLRC_{1.5} = 0.752604 - 0.0119924 * RL + 0.0000750379 * RL^2$ (3)

TABLE 5 Polynomial Regression Analysis for MT_PTLRC1.5

Multiple Regression Analysis					Variance Analysis					
Parameter	Estimate	standard error	t-statistic	P-value	Source	Squares Sum	LD	mean square	F-Ratio	P-Value
CONSTANT	0.752604	0.155223	4.84852	0.0005	Model	0.132509	2	0.0662546	9.26	0.0044
RL	-0.0119924	0.00374407	-3.2030	0.0084	Residue	0.078718	11	0.00715618		
RL^2	0.000075038	0.0000204348	3.67206	0.0037	Total (Corr.)	0.211227	13			

R^2 = 62.733 %; R2 (adjusted) = 55.9572 %; Standard Error of Est.=0.0845942; Average absolute error = 0.061648

The relationship between the $MT\_PTLRC_{1.5}$ indicators and *L* as the only explanatory variable was not statistically significant with a confidence level of 90%.

Accident Analysis

The same analysis with accident data were carried out. It was found that the variables that best explain the variability of the accident ratio are: *L* and *RL*.

TABLE 6 Multiple Regression Analysis for Accident Ratio (Accidents per 100 M vehicles)

Multiple Regression Analysis					Variance Analysis					
Parameter	Estimate	standard error	t-statistic	P-value	Source	Squares Sum	LD	mean square	F-Ratio	P-Value
CONSTANT	27.7495	7.32598	3.78782	0.0091	Model	285.995	3	95.3317	4.66	0.0521
L	-0.198063	0.0677325	-2.9242	0.0265	Residue	122.704	6	20.4506		
L^2	0.000344951	0.000148998	2.31513	0.0598	Total (Corr.)	408.699	9			
RL	9.79547	4.18072	2.34301	0.0576						

R^2 = 69.977 %; R2 (adjusted) = 54.9665 %; Standard Error of Est. = 4.52224; Average absolute error = 2.49729

Fig. 6 shows the variation of the accidents ratio as a function of the deceleration lane length (L) and the design length (L_0). The first hypothesis was that the minimum accident rates are obtained when both lengths are equal. However, it was found that this hypothesis is only valid if the length is 220 m. If L_0 is shorter than 220 m a longer L is needed. On the contrary if L_0 is longer than 220 m a shorter length is preferably.

A new design model should be proposed that takes into account this behavior in order to minimize accident rates in deceleration lanes.

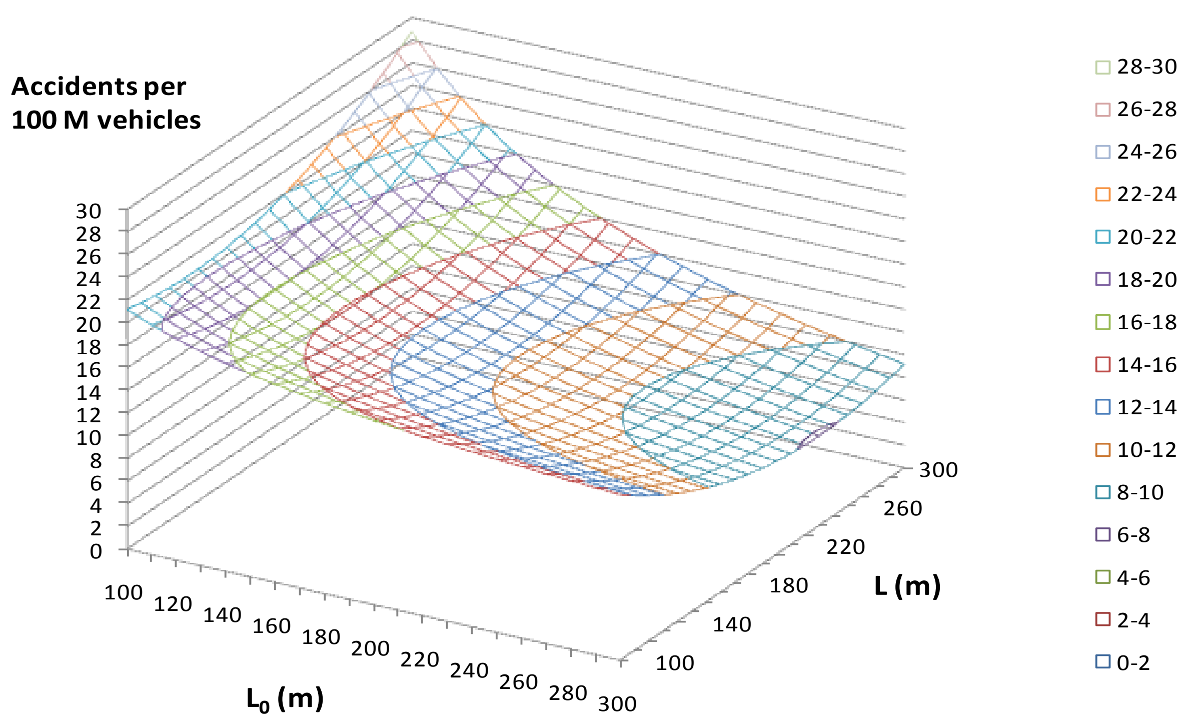

FIGURE 6 Accidents per 100 M vehicles in function of the deceleration lane length and the design length.

CONCLUSIONS

The new PTLRC indicator allows assessment not only of follow up conflicts but also of lateral conflicts between vehicles. Thus, Traffic Conflict Techniques could be implemented in situations where the conflict zone is not clearly defined. This is the case of deceleration, acceleration and weaving lanes, and, in general, driving on road sections with more than one lane in each direction.

The use of PTLRC indicators allows us to compare hazard levels in different situations and locations.

The recommended threshold for PTLRC indicators is 1.5 s. This threshold contains most dangerous maneuvers that occur on the road and excludes the interactions between vehicles that can be considered normal.

It is possible to say that the conflict level in parallel deceleration lanes mainly depends on the ratio between actual length (L) and the design length (L_0) ($RL = L/L_0$). Accident rates depend not only on this ratio, but also on the actual lane length.

A new design model should be proposed that takes into account the accident rate behavior in order to be able to minimize accidents in deceleration lanes. From the road safety point of view, it is possible to say that the shorter and the longer lane lengths are less safe. The safest lengths are intermediate.

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