Operational And Safety Effects Of The Deceleration Lane Length

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Abstract

Researchers have reported high accident rates on exit ramps with the highest percentage of accidents taking place on the deceleration lane, since these rates change according to the deceleration lane length. Longer deceleration lanes are recommended but limit the length on benefit-cost analysis. Previous experimental observations carried out by various researchers, did not correspond to the kinematic models of uniform deceleration that is usually adopted. In the construction to improve a section of the freeway CV-35, near the city of Valencia, a weaving lane was changed to an exit lane because the access had been closed. In order to study operational and safety effects of a deceleration lane as a function of its length, four configurations for the diverging lane were established, using road marking tapes. Two additional configurations were evaluated: the initial configuration to study the drivers' behavior with the original weaving lane but being used as deceleration lane since the entrance was already closed, and the final configuration adding a barrier along the edge of the taper, to test the barrier's effect. Up to now, research has been carried out in field study of the phenomenon using various deceleration lanes, with different road and traffic characteristics according to their locations. In this research, for the first time, experiments were carried out in the same place, which allow us to study vehicle behavior as a function of the length, maintaining constant the other highway characteristics as well as controlling traffic characteristics. In each configuration of the deceleration lane video recordings with four cameras were taken for tracking the vehicle evolution on leaving the main road. Later, the videos were digitized and specific software was developed to convert the information from 2D to 3D. The successive positions of the vehicles on the roadway associated to times, gave us the trajectories, speeds, decelerations and accelerations. Then, the exit phenomenon was analyzed in function to the lane length: exit trajectory types; speeds; decelerations and their localization. A detailed study of the potentially dangerous maneuvers was also carried out, not only in the studied configurations, but also in other two deceleration lanes. A very interested conclusion has been obtained: the shorter and the longer lane length, the less safety. The optimal lengths are intermediate.

Operational And Safety Effects Of The Deceleration Lane Length

INTRODUCTION

Traffic safety is a priority for highways but unfortunately accidents do occur on a regular basis. Researchers have reported high accident rates on exit ramps. According to Lundy (1967) in an exit ramp the highest percentage of accidents take place on the deceleration lane, but these rates change according to the lane length, but the effect of increasing the length of the lanes is not as great, Cirillo (1970). Bared J et al. (1999) recommend longer deceleration lanes but limit the length on benefit-cost analysis.

However, this research found, that in long deceleration lanes, vehicles do not decelerate and often overtake vehicles on the main road, thus increasing accident risk. Road safety could be evaluated as a function of deceleration lane length, from short length to longer than norm recommended lengths.

Furthermore, speeds at the beginning of the deceleration lane are always lower than speeds on the main road, which means that exiting vehicles start deceleration on the main road, thus interfering with the main flow; this difference in vehicle speed should be evaluated as a function of the deceleration lane length. The current study started with the aim to evaluate the design and operation of the deceleration lanes as a function of their length.

Though previous experimental observations did not correspond to the models of uniform deceleration that is usually adopted (de la Iglesia and García, 2000), to determine the deceleration lanes length there are two main types of models: kinematic and dynamic, based on the behavior of passenger cars, because, even though heavy vehicles need longer distances to decelerate, longer deceleration lanes are not needed since average speeds for heavy vehicles are lower than those for cars.

AASHTO (2001) proposes a kinematic model with tapered exit, while the Italian norm uses the kinematic model but with parallel deceleration lanes. On the other hand, Spanish norm (Ministerio de Fomento, 1999), proposes parallel deceleration lanes and determines their length from a dynamic model.

FIELD STUDY

The field study has been developed in two phases, the first one, an experimental phase taking advantage of the construction to improve a section of the highway CV-35, near the city of Valencia. And the second one, a verifying phase, in various deceleration lanes, with long, average and short lengths.

In the freeway CV-35, the access of a weaving lane was closed turning it into an exit lane. It allows us to study the design and operation of a deceleration lane based on its length.

Up to now, research has been carried out in field study of the phenomenon using various deceleration lanes, with different road and traffic characteristics according to their locations. In this research, for the first time, experiments were carried out in the same place, which allow us to study vehicle behavior as a function of the lane length, maintaining constant the other highway characteristics as well as controlling traffic characteristics.

Experimental Constraints

It was necessary to avoid any disturbance that modifies the drivers behavior, reason why the lane’s length was modified using road marking tapes, and after the experimental phase, the definitive markings were painted.

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

The deceleration lane length and characteristics, used in this research (Figure 1), conform to the Spanish norm for road geometric design (Ministerio de Fomento, 1999).

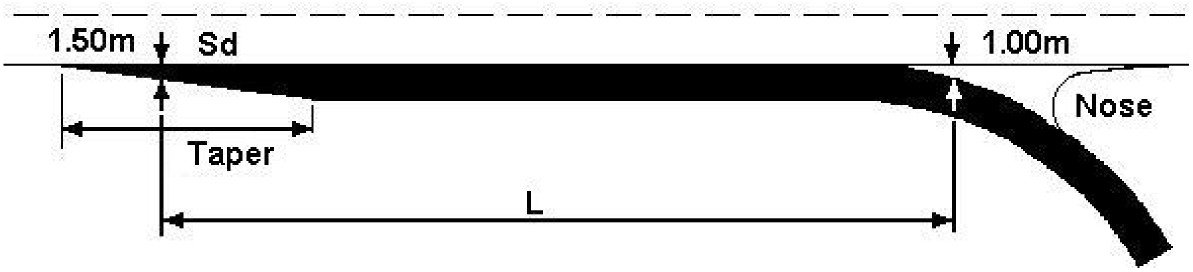

FIGURE 1 Parallel deceleration lane

The length of the transition taper for the parallel deceleration lanes is determined, as a function of the designed speed, or the current posted speed limit at the taper, whichever is lower, as shown in Table 1.

TABLE 1 Length (m) of the triangular taper

S_{do} = Min (S_d,S_p) (Km/h)	Taper's Length (m)
≤ 80	70
100	83
120	100

The deceleration lane length (*L*) is defined as the distance between the characteristic section where the taper is 1.5 m wide and the section where the nose width is 1.0 m, as a function of the road grade (*g*), the same speed used above for the taper length calculation (S_{do}) and the posted speed limit for the exit ramp (S_{df}), and is calculated using equation 1.

$$L = \frac{S_{do}^2 - S_{df}^2}{254 \cdot g + 50} \geq 100m \tag{1}$$

In the studied highway section, the grade is -2% (-0.02), the posted speed limit for the exit is 40 km/h and no speed limit is posted at the taper location.

According to the Spanish road marking norm, the edge line must be 20 cm wide, then the continuous line was painted according to the norm, and the 40 cm wide broken line was milled and finally the marking tape was placed (Figure 2).

FIGURE 2 Road marking tape

Originally, the continuous line length ahead of the exit ramp nose was 65 m, since it could affect the drivers' behavior when leaving in the shortest configuration, It was decided to shorten its length to 30 m, to avoid an additional variable.

Experimental Configurations

Six configurations for the diverging lane were established considering the previous constraints. Configuration 1 aims to study the drivers behavior with deceleration lanes longer than stated in the norm, therefore the maximum length available (395m) was chosen with a taper 100 m long, which is the equivalent to calculate using S_{do}=127 km/h.

For configurations 2, 3 and 4, different operating speeds were used (120 Km/h, 100 Km/h and 80 Km/h) to determine each taper length and each deceleration lane length.

The other two configurations were: the initial configuration, to study the drivers behavior with the original weaving lane but being used as a deceleration lane as the entrance was already closed, and the final configuration, equivalent to the configuration 1, due to a storage criterion for a possible traffic jam, but adding a barrier along the edge of the taper, to test the barrier's effect. Table 2 shows the deceleration lane configuration characteristics.

Additional Deceleration Lanes

Two additional deceleration lanes were selected, with average and short lengths, in order to verify the drivers behavior depending on the lane length, with the following requirements: the lane must be in a tangent section of a freeway, as the experimental lane, and it was necessary to have a camera of the "Centro de Gestión de Tráfico de Valencia" that could focus all the deceleration lane.

Two other deceleration lanes of 218 m and 187 m respectively were evaluated. The first one being little shorter than necessary (256 m according to the Spanish norm) while the second being short. Table 2 shows the additional deceleration lanes characteristics.

TABLE 2 Configuration characteristics

Configuration	S_{do} (Km/h)	Lane length (m)	Taper length (m)
Initial	---	440	No taper
1	127	395	100
2	120	285	100
3	100	187	83
4	80	107	70
Final	127	395	100
Additional 1	120	218	100
Additional 2	120	187	83

Gathering Information

Before gathering the information, during the experimental phase, each configuration was installed, and left at least one week in order to habituate drivers to the new lane length. To collect information, 4 video cameras were installed, each one focused on different points to include all the section. The evaluated time was between 8:30 a.m. and 11:30 a.m., where different traffic situations appear, for each one of the 6 deceleration lane configurations, making it possible to evaluate during peak period specially in the morning hours as well as free flow at later hours. All data were collected during favorable environment conditions with dry pavement. The video cameras were located in different positions depending on the deceleration lane length to track the complete vehicle path.

In the initial configuration and in configuration 1, camera 1 was located at the variable message signal panel located over the other carriageway, 125 m from the beginning of the taper, recording vehicles from the rear, and camera 4 was located in the same place but pointing at a cross-section in order to measure the vehicles' spot speed. The other cameras, were placed at the overpass before the exit, each on a different side of the overpass, recording the frontal (camera 2) and rear (camera 3) side of the vehicle, so that the superposition of the later restitution of the images allows seeing the complete vehicle path (Figure 3).

In configuration 2, the cameras' location is the same as configuration 1, but camera 2 focuses on a point located 125 m from the beginning of the taper, to measure the spot speeds at that point.

In configuration 3, location of camera 1 was moved to the nose to see the complete vehicle path including the section located underneath the overpass, and camera 2 was placed on the overpass pointing 125 m from the beginning of the taper, to measure the spot speed of the vehicles.

In configuration 4, the video cameras' location is similar to configuration 3, except that it was not necessary to use camera 4, because the spot speeds were measured from video camera 2.

Two other locations were evaluated using the CCTV of the “Centro de Gestión de Tráfico de Valencia“.

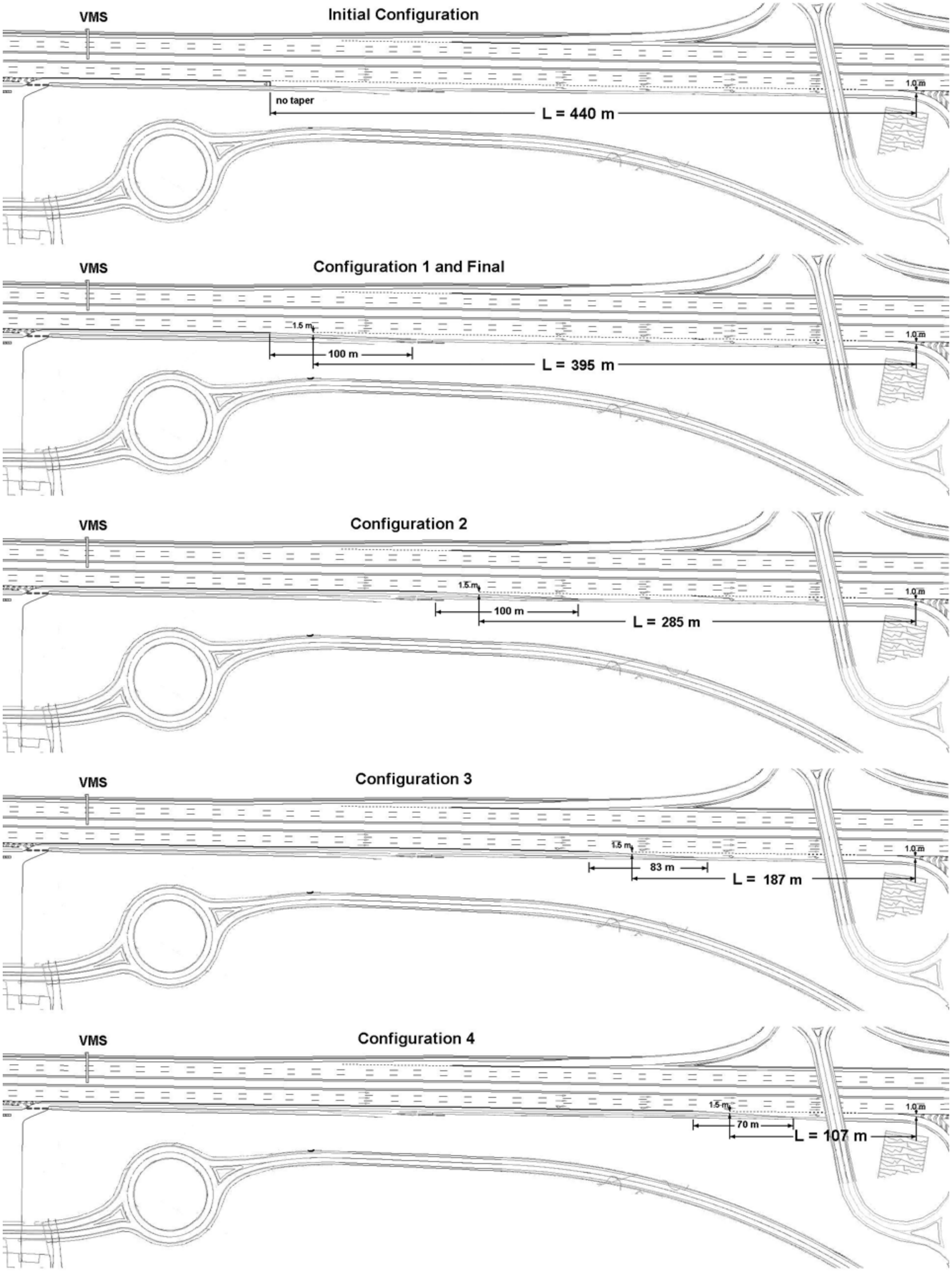

FIGURE 3 Location

DATA REDUCTION

Traffic was classed as heavy vehicles and passengers cars, and particular attention was given to vehicles for whose driver behavior was conditioned by the vehicles preceding them.

In each experimental configuration, 50 free maneuvers with the following conditions were selected: the leaving vehicle had to be a passenger car, its interval with relation to the preceding vehicle greater than 5 seconds and the diverging lane free at the exit moment.

The images were digitized at 25 frames per second, with a resolution of 768 x 576 pixels, and later processed with a specific software developed using the conic perspective restitution technique, with graphic media through transformation. This technique allows the reconstruction at scale of an object, starting from the object's conic perspective plus additional data, using homology relations between a 2D figure and its perspective, we can then restitute this with the knowledge of the figure form and some of its dimensions.

By using camera recorders, we obtained the conic perspectives and given that the road markings measurements were determined on site and thus known, providing the spatial location for the trajectories of the vehicles.

Time measurements have been taken from the video and with them the vehicles' speeds and decelerations were calculated.

A detailed study of the potentially dangerous maneuvers was also carried out, not only in the studied configurations, but also in the additional deceleration lanes.

EXPERIMENTAL RESULTS

Speeds

In the initial situation, measurement of the vehicles' speed were taken in each lane, at free flow. It was found that the operating speeds, S_{85}, in all lanes (130 Km/h, 123 Km/h and 154 Km/h) exceed the speed limit (120 Km/h). Additionally, a great dispersion on the right lane speeds is observed (lane 1), which increases the collision risk.

As Figure 4 shows, three speeds of each selected vehicle were evaluated: the first, on the right lane of the main roadway, before being affected by the exit maneuver; the second at the point where it completely leaves the main roadway; and the third, at the nose.

In the configurations 1, 2 and 3, a speed reduction in the interval [16, 18 ,21] Km/h of the 85th percentile was found between the first two points, but in configuration 4, this reduction was 42 Km/h, which shows us in the first place that the vehicles decelerate before taking the diverging lane, even if the deceleration lane is long, but if it is too short, the vehicles decelerate on the main roadway affecting its flow.

The speed measurement on the exit ramp was made to observe the vehicles' behavior as a function of the lane length, being found in all cases the S_{85} is greater than the speed limit (40 Km/h). Additionally, if the lane is too long or too short this speed is greater than if it was an intermediate length.

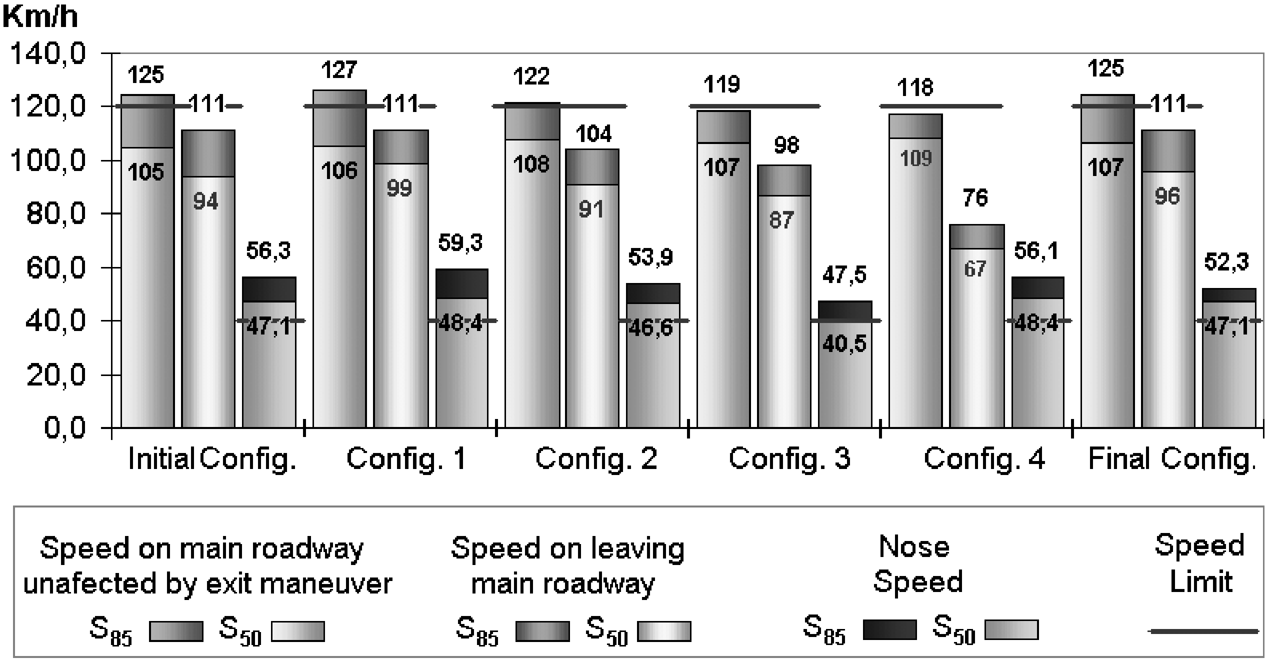

FIGURE 4 Speeds in each configuration

Trajectories

Based on the restitution trajectories of the selected vehicles, it is possible to say that on a parallel deceleration lane, drivers prefer a reverse curve trajectory instead of a direct maneuver, contrary to previous research.

Additionally, configurations 1 and 4 show, that the vehicles when arriving at the exit ramp modify their trajectory to maximize the radius at this point, confirming the behavior of the speed based on lane length.

Decelerations and Accelerations

When the lane is too long, there exists the possibility of accelerating and later decelerating to leave. The percentage of vehicles that accelerated in the deceleration lane was calculated, to determine the lane operation. Being the case in configurations initial, 1, 2 and final, approximately a third of the vehicles accelerate in the exit lane, whereas in configurations 3 and 4, not one vehicle did it.

The deceleration rate in gear, has an average value of -0.76 m/s^2, higher to that found by Polus et al. (1985), but closer to AASHTO (2001) recommended value, whereas on having applied the brakes one found an average value of -1.74 m/s^2, similar to that obtained by Colonna (1997) and by Canale (1998). Additionally, one found an average decelerating in gear duration of 6.9 s, close to that found by De la Iglesia and García (2000) of 6.4 s.

Road Safety

A qualitative evaluation by observation of the videos was carried out, to determine different behavior from all the vehicles that leave the roadway, many in a situation of conditional flow. Table 3 shows the number of evaluated maneuvers in each configuration and in the additional deceleration lanes.

TABLE 3 Number of observed maneuvers

Configuration	Observed Maneuvers
Initial	768
1	648
2	856
3	455
4	682
Final	546
Additional 1	267
Additional 2	232

In the evaluation, five main types of collision risk maneuvers were considered: overtaking maneuvers during the exit, exit originated from one of the fast lanes, return maneuvers to the main roadway, early and late exits.

Different types of overtaking maneuvers were classified into three types: outer overtaking, that corresponds to a vehicle that overtakes on the main roadway a vehicle on the deceleration lane, and then taking the deceleration lane to exit; inner overtaking, that is when the vehicle that is overtaking is on the deceleration lane and the vehicle being overtaken is on the main roadway; and inner merge overtaking, being similar to the previous one but in which the vehicle that is being overtaken also takes after the deceleration lane.

As Figure 5 shows, when the deceleration lane length diminishes, the number of overtaking also diminishes since the vehicles do not have the possibility of accelerating to overtake, reason why long deceleration lanes have higher collision risks because they allow this kind of maneuvering.

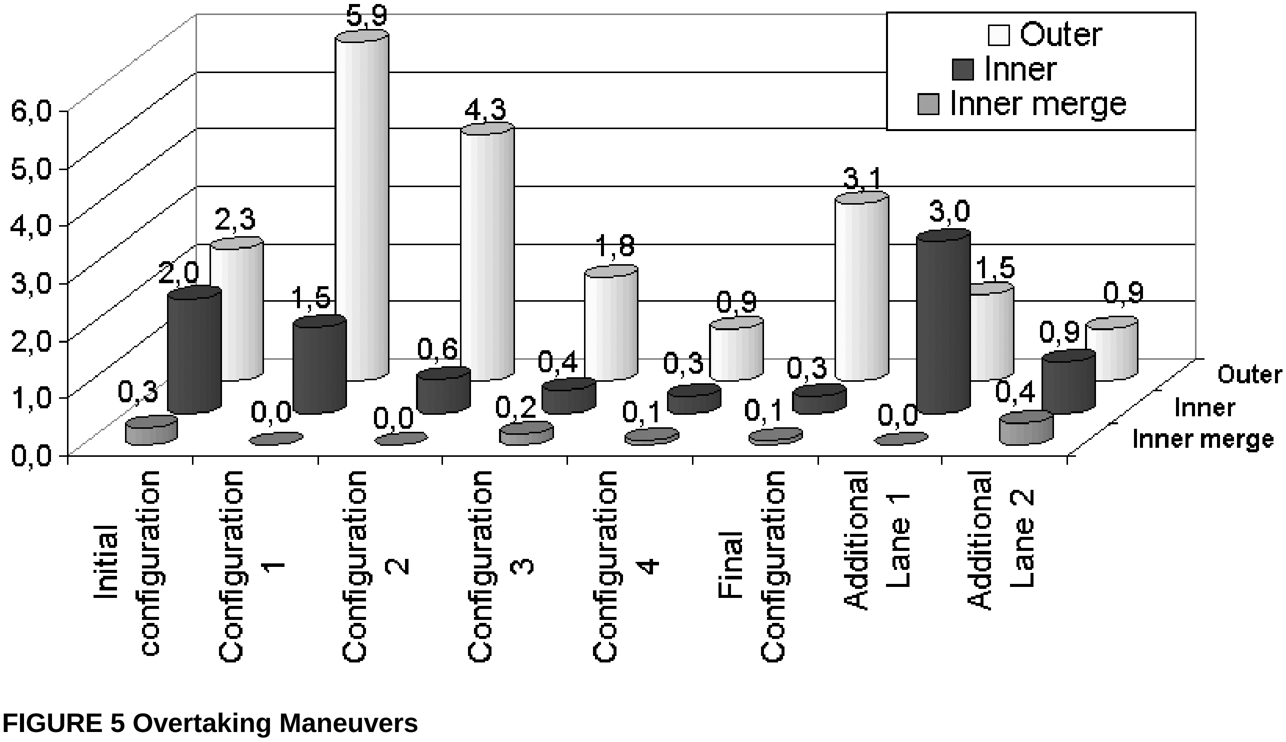

FIGURE 5 Overtaking Maneuvers

Exit maneuvers originating from the fast lanes diminishes as the length of deceleration lanes shorten, as well as the overtaking, except on the initial configuration due to the high percentage of late exists on this configuration, as Figure 6 shows.

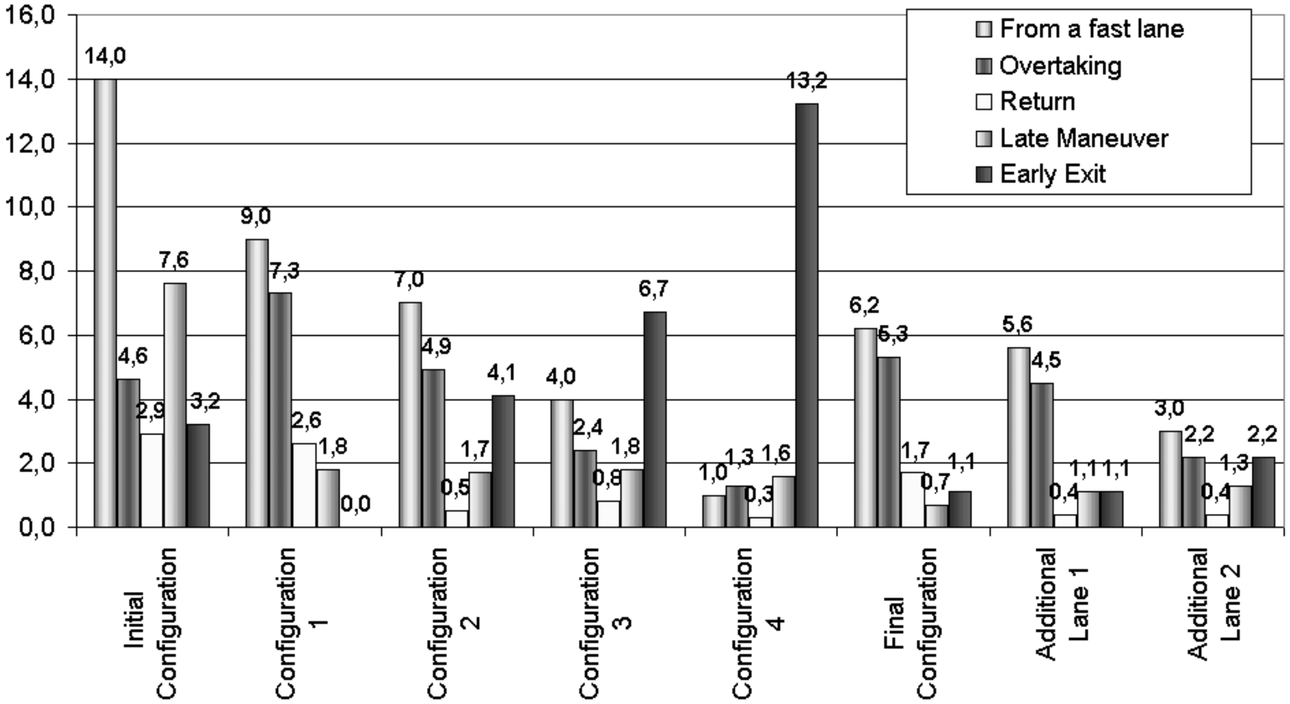

FIGURE 6 Risk maneuvers

The percentage of return maneuvers is greater when the length is greater and the delayed maneuvers diminish as well when the taper is marked.

As the initial configuration did not have the taper, the exit point is very dispersed throughout the lane, this situation changes with the taper. Figure 7 shows the percentage of maneuvers at the exit point for each configuration.

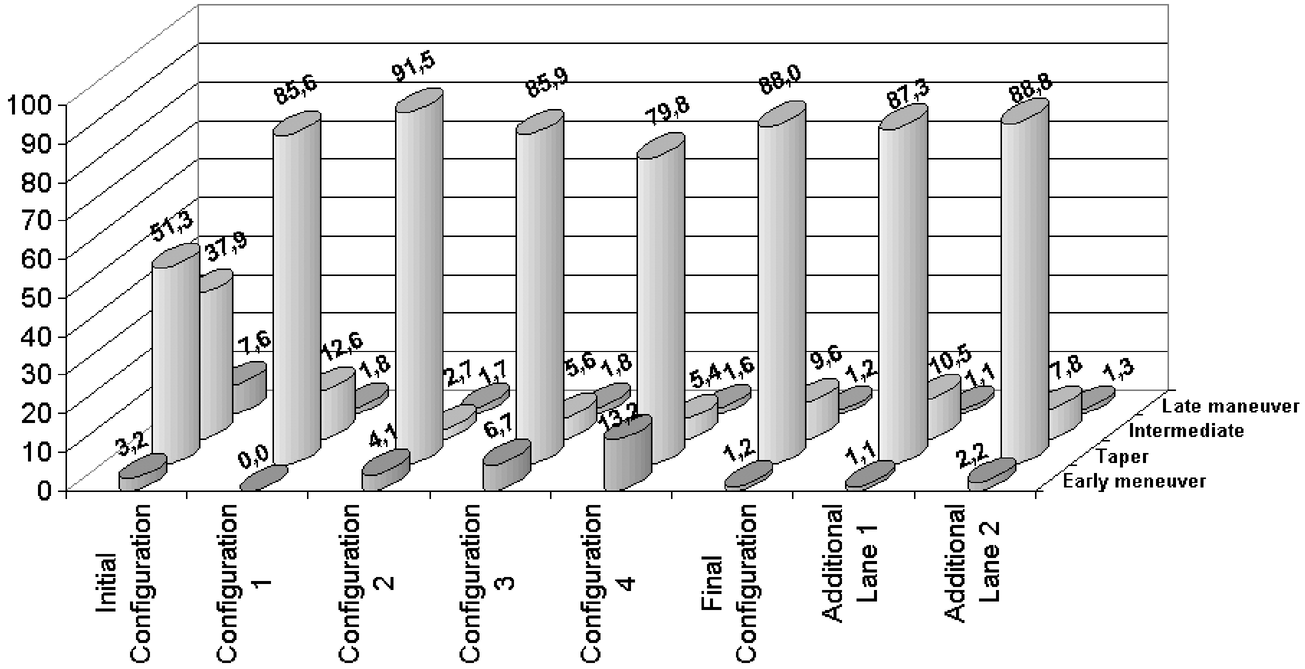

FIGURE 7 Exit zone

In configuration 1, a high percentage of vehicles leave the main road in the intermediate zone of the deceleration lane (12.6% of total or 11.8% of free maneuvers), which demonstrates that the lane length is greater than necessary. This percentage diminishes in the following configurations (2 to 4) and increases again in the final configuration to 9.6% of total or 9.9% of free maneuvers. The same behavior has been verified with the additional deceleration lanes (10.5% of the total in additional lane 1 and 7.8% in additional lane 2).

In the experimental configurations, the anticipated maneuvers increase as the lane length shortens, but with the additional lanes the percentage increase of this behavior does not take place, which shows us that this kind of maneuvering in the experimental configurations had been affected by the type of road marking and by drivers habits.

The percentage of late maneuvering is high in the initial configuration where there is no taper, which confuses a considerable number of drivers who are unable to view with sufficient time the exact exit position.

The observations in the additional deceleration lanes confirm that diminishing the lane length the collision risk maneuvers at the exit also diminish.

CONCLUSIONS

Drivers use the parallel deceleration lane correctly and they prefer a reverse curve trajectory instead of a direct one.

According to the configuration results of the qualitative analysis, the taper importance has been demonstrated to channel the exiting traffic, because it allows the driver to clearly view the exit point.

The early exit maneuvering behavior in the experimental configuration does not depend exclusively on the deceleration lane length, but the kind of road marking.

By diminishing the lane length the collision risk maneuvers at the exit diminishes but has a more relevant effect on the main roadway traffic. The shorter and the longer lane length, the less safety. The optimal lengths are intermediate. A balance between the effects on the main roadway speeds and the increase on operation and safety of the exits has to be agreed upon.

The speed at the beginning of the exit ramp is affected by the length of the deceleration lane, if the lane is too long or too short this speed is greater than if it was an intermediate length.

Drivers start decelerating before exiting the main road, even with long deceleration lanes, for which a speed reduction of 17 km/h on the main road was found.

Current design models are not valid because they do not properly represent the actual behavior of vehicles, since in a parallel deceleration lane, the exit maneuver is the union of two different maneuvers: the first one, a lane change maneuver, with a gear deceleration, followed by a braking deceleration. If the deceleration lane is too long, between the two maneuvers an acceleration maneuver could appear, and if it is too short, the lane change maneuver occurs within the braking deceleration. So, the length that balances the effects on the main road with the best functionality and safety of the deceleration lane, is the one that allows us to join the two maneuvers successively. For the first approximation, it is possible to use the Spanish dynamic model, calculating the length with a speed at the taper 17 km/h lower than the designed speed.

$$L = \frac{(S_{ds} - 17)^2 - S_{df}^2}{254 \cdot g + 50} \qquad (2)$$

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ACKNOWLEGEMENTS

This study was made possible thanks to the support of the “División de Carreteras de la Consellería de Infraestructuras y Transporte de la Generalidad Valenciana”, the “FCC Construcción, S.A.” company and the "Centro de Control de Tráfico de Valencia" of the "Dirección General de Tráfico"