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Toward smart active road studs for lane delineation

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Abstract

This article reports a driving simulator experiment, conducted within the framework of a European project aiming to develop intelligent road lighting applications. The experiment compared simulated night-time driving performance on a country road, with the Active Lane Delineation (studs) application that is being developed, to an unlit road. The analysis showed small variation in speed, with slower speeds inside the curves than before them, and with the studded condition inducing slightly faster speeds than the unlit condition, but only in straight road sections. The analysis of the lane positioning showed that the participants drove at or near the centre of their lane, in both the studded and the unlit road conditions, with the unlit condition inducing greater lateral variability than the studded condition, in both right and left curves, demonstrating better lateral vehicle control with the studs, as compared to without them. At a subjective level, the participants perceived the studded road as safer, more comfortable and allowing better control than the unlit road. Future directions are discussed.

Keywords: Intelligent transport systems; travel behaviour; active marking; lane keeping.

Résumé

Cet article présente une expérimentation sur simulateur de conduite réalisée dans le cadre d'un projet européen (INROADS). L'objectif du projet est de développer des applications routières innovantes utilisant des plots lumineux. L'expérimentation a permis de comparer la conduite de nuit, sur route inter-urbaine bi-directionnelle, avec et sans plots lumineux en virage. L'analyse des résultats montre que la vitesse est légèrement (mais significativement) plus élevée dans les virages qu'en approche, et que les plots lumineux induisent des vitesses légèrement plus élevées en approche, mais pas dans le virage. L'analyse de la position latérale des véhicules montre que les participants roulent au centre de leur voie, mais que les plots améliorent la variabilité de la position latérale dans le virage, et donc le contrôle de la trajectoire. Subjectivement, les participants ont trouvé que les plots lumineux rendent la route plus sûre et plus confortable. Les implications de ces travaux sont discutés.

Mots clé: ITS; comportement de conduite; plots lumineux; contrôle de trajectoire.

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Introduction

Efficient delineation of road space is a crucial element of a safe driving environment. Painted edge- and centre-line markings enhance the road edges and outline bends, providing visual cues on which drivers rely to predict the curvature of the road. Indeed, painted markings contribute to a large reduction of road crashes (Miller, 1992, Moses, 1986, cf. Horberry, Anderson, & Regan, 2006). However, improvement in driving safety performance indicators can be best achieved when they are used in conjunction with other treatments, such as raised pavement markers, post-mounted delineators and chevrons (Charlton, 2007a, 2007b, Zador, Stein, Wright & Hall, 1987), which further the ability of drivers to correctly assess the road ahead, thereby to appropriately adjust their position and speeds to the road demands.

Retro-reflective road studs, commonly referred to as 'cat's eyes', have been used to delineate traffic during night time and under conditions of poor visibility lanes, since decades, but it is only in recent years that with the development in light emitting diode (LED) technology, self-illuminating road studs have been introduced and manufactured for commercial use. The illumination of these active studs reaches a greater distance and can be observed from a wider range of viewing angles.

Crash statistics or any other scientific records documenting the yet uncommon use of active studs to delineate roadways are rare, as are studies examining their impact in a controlled environment. An informative document made available on the internet by ITS radar provides a few examples for active road delineation, such as on the N200 in Holland and in the A143 in England, where subsequent dramatic drop in accident frequency and/or accident severity has been reported. In the laboratory, in a simulator study examining driver behaviour in response to active studs (Reed, 2006), drivers from varying age groups drove the simulator through sections with active studs, with reflective studs, or without studs. It was found that the active studs were superior at improving drivers' lateral control of their vehicle, presumably by enhancing delineation of the offside road edge, and by improving lane guidance in right turns without causing drivers, particularly older ones, to proceed at higher speeds.

INtelligent Renewable Optical ADvisory System (INROADS) is a European research and development collaboration project dedicated to the development of new intelligent road lighting applications integrating LED lighting capable of providing some or all of their power needs through renewable sources. The present study - conducted within the French Institute of Sciences and Technology for Transport, Development and Networks (IFSTTAR) involvement in INROADS - aimed to shed some light on the safety of one of several possible designs for an Active Lane Delineation (ALD) application (i.e., intelligent active studs) that is being developed by INROADS.

The application consists of stud sections, which turn on when a vehicle has been detected by sensors and are extinguished after the vehicle passes them. The colours in the tested design were the same and the stud spacing in the same range as, used in the UK (Department for Transport, 2003) and other countries. In accordance with the recommendations for use of active marking published by Province of North Holland in the Netherlands (2005), studded road sections consisted of an introductory straight road section preceding the curve, the curve and a subsequent straight road section (hereafter, curve preparation, curve and curve exit). The curve preparation section illuminated 300 metres before the vehicle reached it. Studs were fixed with shorter spacing inside the curves and just before them, while longer spacing was used at a greater distance before the curves entrances and at their exit. The reduction in the distance between studs at the approach to the curves was thought to lead drivers to perceive their approaching speeds as faster than what these really were, thereby motivating them to slow down (e.g., Argent, 1980; Denton, 1980; Drakopoulos & Vergou, 2003). By doing so, we aimed at reducing the likelihood that the drivers will increase their speed in the presence of the ALD due a reduction in the perceived levels of risk, as compared to an unlit road (e.g., Wilde, 1988).

All of the participants in this study completed a night time drive on the same winding inter-urban route under conditions of the active studs on an unlit road, and of an unlit road with only surface road markings. The experiment also consisted of a third condition, without the studs, but with conventional road luminaries, but these data are not reported in this article. The participants were compared on a number of criteria, both subjective (rating scales) and objective (performance measures of speed and of lateral positioning). Our foremost important prediction was that smaller variability of the vehicle's lateral position would be found in the unlit



condition as compared to the studded condition. This would provide evidence for superior lateral control of the virtual car in the latter than in the former condition, and would indicate that the application helps to inform the drivers about how they need to control the vehicle in order to negotiate the curves, most likely by enhancing delineation of the lane and road edges.

1. Method

1.1. Participants

Twelve drivers (mean age = 37.92 years, SD = 10.25; mean license seniority = 16 years, SD = 11.73), including eight males and four females volunteered to participate in this study. They were recruited through advertisements that were posted via a mailing list of the French Institute of Sciences and Technology for Transport, Development and Networks (IFSTTAR). All of them had normal or corrected-to-normal vision. The study was approved by the IFSTTAR's Ethics Committee.

1.2. Design

The basic design consisted of a (2 x 3) within-subjects design. The first factor, *illumination*, compared the studs condition to the unlit road condition (fully counterbalanced for order). The second variable was *road section* including a), the *straight portions*, commencing 52 metres after each curve (where the *exit sub-section* in the studs condition terminates) and terminating 286 metres before the following curve (where the *curve entrance section* in the studs condition begins), b), the *curve preparation* condition, commencing 286 metres before each curve and terminating at the beginning of the curve, and c), the *curved sections* condition, commencing at the beginning of the curve and terminating 52 metres after the curve exit.

The dependent variables included the mean (M) lateral positioning of the car and the standard deviations (SDs) of these means to reflect the lateral variability of the vehicle (analyzed as two separate variables), and the mean speed. Each of these variables was analyzed with (x 2) ANOVAs (studs, unlit) performed on the data of the straight road sections and (2 x 2) ANOVAs (*illumination x road section*) with two levels of *road section* (curve preparation, curved) performed separately on the data of right curves and of left curves, with each of the two illumination conditions consisting of eight left and eight right curves.

1.3. Apparatus and stimuli

The driving simulator consisted of a seat, a steering wheel, a gear stick and accelerator, clutch and brake pedals. With an average individual seated 160 cm from the central display, the scene presented a visual display approximating 114° x 21° across three 47 inch full high definition screens, with a screen resolution of 1920x1080. The central screen was a high dynamic range (HDR) with improved computer graphics performance (Vienne & Dang, 2014). The side views were displayed onto two further low dynamic range (LDR) screens positioned to the sides of the central screen. Figure 1 shows the simulator and the set-up.



Figure 1. Simulator set-up.



The track consisted of four repetitions of the same portion of a standard French single undivided carriageway, with discontinuous edge and central markings, in a rural environment. The repeated road portion consisted of a 150 metres long left curve with a 200 metres radius of curvature followed by a 400 metres long left curve with a 300 metres radius of curvature, which were followed by two identical right curves. All curves were separated by 1000 metres long straight sections. A medium volume of traffic consisted of oncoming vehicles in the contraflow lane. The virtual car's headlights illuminated a distance of approximately 60 metres, typical distance for low beam. The only difference between the two conditions was the inclusion of the studs in the studs condition.

In the studs condition, red, white and amber lights marked the right (nearside) edge of the road, the central line and the left (offside) edge of the road, respectively. Studs' aperture angles ranged between -15° to $+15^\circ$ at the horizontal and between 0° to $+20^\circ$ at the vertical, with luminance levels measured via a Minolta LS-110 luminance photometer, at 177.3, 299.93 and 693.13 cd/m² for the red, amber and white studs, respectively. For the 286 metres long *curve preparation sections* preceding all curves, 13 metres gaps separated the studs in the half (143 metres) more distant from the curve, whereas 6.5 metres gaps separated the studs in the half just before the curve. For the 150 metres long curves, a 202 metres long stud section followed the *curve preparation section*. It consisted of 6.5 metres spaced studs fixed across the 150 metres long curve, in addition to 13 metres spaced studs fixed across the 52 metres *exit subsection* that followed the curve. For the 400 metres long curves, the first *curve subsection* after the *preparation* section consisted of 6.5 metres spaced studs across 286 metres. A third, 166 metres long, section covered the remaining 114 metres of the curve (6.5 metres gaps between studs), and the additional 52 metres *curve exit subsection* (13 metres gaps). At a distance of 300 metres from the *curve preparation section*, both that section and the one to follow dimmed on simultaneously. In the 400 metres long curves, the 3rd section switched on as soon as the vehicle crossed the *preparation section*. Figure 2 displays the stud sections for the two types of curves. Figure 3 displays screenshots from the two experimental conditions.

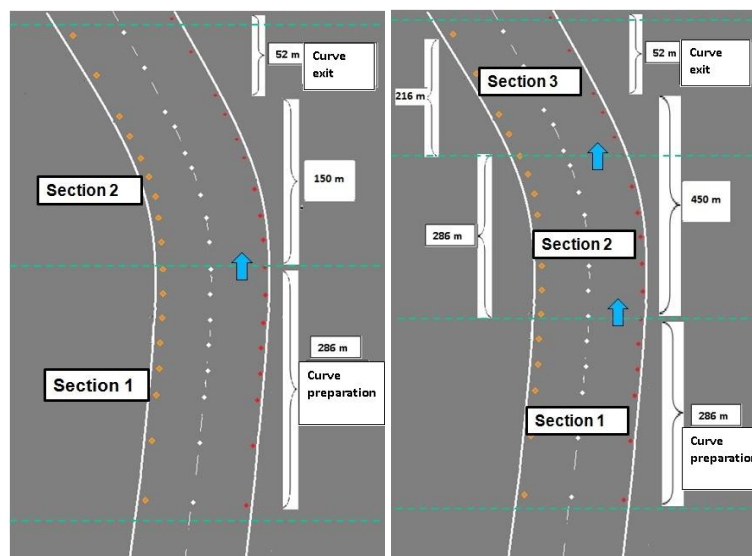


Figure 2. Stud sections for the 150 metres (left) and 400 metres (right) long curves. In both curves, sections 1 and 2 switch on simultaneously when the virtual car reaches a distance of 300 metres from section 1. In the 400 metres long curves, section 3 switches on as soon as the vehicle reaches section 2. Immediately after the vehicle (represented by the blue arrow) finalizes each of the sections, they extinguish.





Figure 3. Screenshots of the two conditions: unlit road (left) and studs (right).

2.4 Procedure

After filling in some details about their background and driving history, the participants read the instructions provided to them. These instructions revealed that the participants were about to participate in an experiment about driving, which would include driving on a simulator that operated similarly to a normal car including gears, steering, braking and acceleration, and completing a questionnaire. The instructions also revealed that following a short practice drive, they would drive on a route under varying night time conditions, while encouraging the participants to drive as they normally would. After these instructions, the participants completed a short practice drive on the same route in daylight conditions, followed by the assessment drives for each of the driving conditions. Immediately afterwards they completed the post-simulator questionnaire.

2. Results

3.1 Speed

The analysis of *speed* in the straight road sections yielded a significant *illumination* effect. The difference between the unlit ($M = 91.76$ Km/h) and studs ($M = 94.76$ Km/h) conditions was significant ($F(1, 191) = 9.15, p < .005$). The ANOVAs performed on the speed data in the curves preparation and curve road sections yielded significant effects of road section in both left curves ($F(1, 95) = 51.30, p < .001$) and right curves ($F(1, 95) = 31.128, p < .001$), indicating faster speeds before the curve than inside the curve. In both analyses (left and right), neither the effect of *illumination* nor the interaction approached significance levels [$p > .10$]. Figure 4 displays the means speeds for the eight sub-conditions created by the road section (curve preparation, curve) x illumination x curve side design.

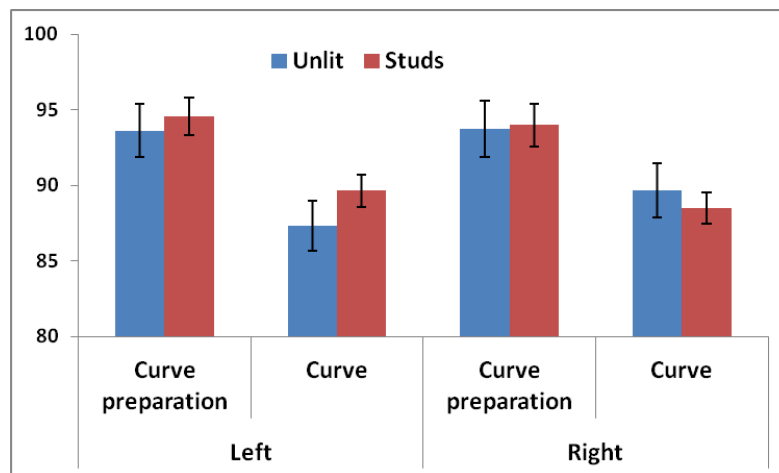


Figure 4. Means speeds for the eight sub-conditions created by the road section (curve preparation, curve) x illumination x curve side design. Error bars represent standard error of mean.

3.2 Lane positioning

3.2.1 Straight

The analysis of neither the *mean lane positioning*, nor of the *standard deviations* revealed any significant effects, with the participants in both conditions driving the virtual car with its centreline positioned approximately 15 cm to the right of the lane centre, with a 5 centimeters difference between the means for two conditions approaching standard levels of significance [$p = .10$] and with a similar 28 centimetres average of lateral position variability, in both conditions.

3.2.1 Curve preparation and curves



Figures 5 and 6 display the means lateral positioning (Fig. 5) and the means SDs of the mean lateral positioning (Fig. 6) for the eight sub-conditions created by the road section x illumination x curve side design.

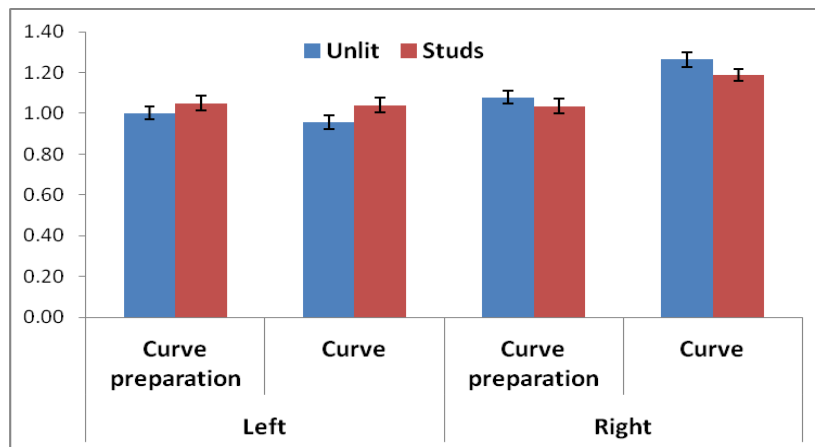


Figure 5. Means lateral position for the eight sub-conditions created by the road section x illumination x curve side design. At zero values the external left side of the virtual car is at the centre marking of the undivided carriageway. At 0.90 the centreline of the 1.70 metre wide car is at the centre of the 3.50 metre wide lane. At 1.80 the right side of the virtual car is at the marking of nearside road edge. Error bars represent standard error of mean.

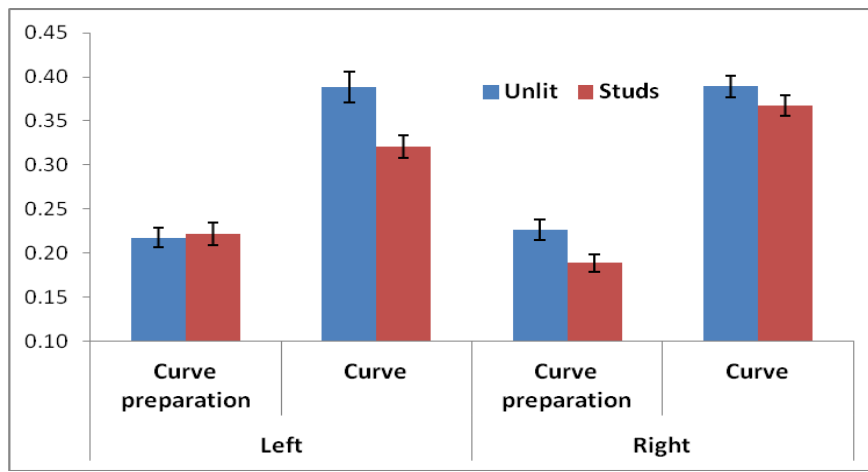


Figure 6. Means SDs of the mean lateral position for the eight sub-conditions created by the road section x illumination x curve side design. Error bars represent standard error of mean.

3.2.2 Right curves

The analysis of the mean lateral position of the right curves yielded a significant road section effect, $F(1, 95) = 30.95, p < .001$, with the participants driving the virtual car with its centreline positioned on average approximately 20 cm to the right of the lane centre, in the curve preparation section, and at a significantly greater distance from the lane centre, approximately another 20 centimetres (with the external right side of the car at a distance of 50 cm from the nearside edge of the road), inside the curve. The illumination effect was marginally significant, $F(1, 95) = 3.58, p = .06$, suggesting that the participants in the studs conditions drove the virtual car with its centreline positioned approximately 5 centimetres closer to the centre of the lane, as compared to the unlit condition. The interaction did not approach significance [$p > .10$].

The analysis of the mean SD of the lateral position revealed significant effects of road section ($F(1, 95) = 168.16, p < .001$), and of illumination $F(1, 95) = 6.91, p < .01$, but the interaction was not significant [$p > .10$].



The SDs were larger inside the curves, as compared to the section preceding the curves, and in the unlit condition as compared to the studs condition.

3.2.3 Left curves

The analysis of the mean lateral position for the left curves yielded a significant illumination effect, $F(1, 95) = 5.61, p < .05$, with the participants, driving the virtual car in the unlit condition with its centreline positioned approximately 15 centimeters to the right of the lane centre, and on average 5 centimetres further yet in the studs condition. Neither the effect of road section, nor the interaction approached level of significance [$p > .10$].

The analysis of the mean SD of the lateral position revealed significant effects of road section ($F(1, 95) = 91.20, p < .001$), illumination ($F(1, 95) = 6.92, p < .01$) and of the interaction ($F(1, 95) = 10.46, p < .005$). Larger SDs were found inside the curves, as compared to the preceding road section and in the unlit than in the studs condition. Tukey HSD tests for the interaction revealed differences for all comparisons except between the illumination conditions in the curve preparation section (all significant at .001). As can be seen in Figure 6 (left), the pattern of the interaction indicated larger SDs in the unlit than in the studs condition only inside the curve.

3.3 Subjective assessment

A French adaptation of questions presented by Reed (2006) was used as the basis for the subjective assessment of the ALD application. The participants rated the studded condition - on 7 point scales ranging from very unsafe to very safe, from very uncomfortable to very comfortable and from allowing poor vehicle control to excellent vehicle control - as safer ($M_s = 5.44$ vs. 3.44 ; $SD_s = 1.46$ vs. 1.62), more comfortable ($M_s = 5.50$ vs. 3.28 ; $SD_s = 1.58$ vs. 1.84) and allowing better control ($M_s = 5.44$ vs. 4.06 ; $SD_s = 1.10$ vs. 1.43), as compared to the unlit condition ($F_s(1, 17) = 18.55, 26.46, p_s < .001$ and $12.22, p < .005$, respectively).

3. Discussion

This study evaluated a design for an active lane delineation application that is being developed by members of the INROADS project. LED based road studs automatically turn on when a vehicle has been detected in order to outline the lane edges and highlight curves, and they are turned off otherwise.

3.1. Simulator data

The analysis of *speed* indicated that the participants varied their average speed about 5 Km/h between the road sections, with slowest speeds inside the curves and with the studded condition inducing speeds that were on average 3 Km/h faster than the unlit condition, but significant differences were revealed only in straight road sections. Although the studs were fixed only in the curve preparation and curve section, they became visible 300 meters before the curve preparation section, hence, when the drivers were still well inside the straight section; this might explain the small difference in speed. The absence of significant speed differences between the unlit and studded conditions in the curve preparation section and inside the curve may be or not be related to the reduction in the distance between studs at the approach to the curve and how this in turn might have affected the participants' perception of their approaching speeds; future research would need to directly target this question.

The *lane positioning* analysis of the straight road sections showed that in both the unlit and studded conditions, the participants drove near the centre of their lane, with a similar average of lateral position variability in both conditions. For the curve preparation and curved sections, the analysis of the *mean* lateral position showed some small differences between the road sections and between the illumination conditions, with the participants driving the virtual car at the approach to curves (i.e., in the curve preparation section) with its centreline positioned approximately 15 to 20 centimetres to the right of the lane centre, and, only inside right curves slightly further to the right, hence, closer to the road edge, but still, closer to the centre than to the road edge. The difference between the illumination conditions, even if marginally significant in the right curves and significant in the left curves was in both cases virtually non-existent (5 cm). In both right and left curves the interactions between *illumination* and *road section* were not significant, further suggesting that in both *illumination* conditions the participants followed the same trajectory.



The analysis of the SDs revealed significant effects of road section, and of illumination in both right and left curves, as well as a significant interaction for the data of the left curves. Larger SDs were found inside the curves and importantly, in the unlit condition than in the studded condition. In the left curves the pattern of the significant interaction indicated that in these left curves this difference between the illumination conditions was driven by the curved sections. Thus, the results of the SDs of the means lateral positioning clearly show greater lateral variability of the virtual car in the unlit condition than in the studded condition, in both left and right curves. They give objective support to the subjective impressions of the participants, who perceived the studded condition as more comfortable, safer and allowing better vehicle control. On the basis of these results, coupled with those of the mean lateral positioning, which help to rule out the unlikely possibility that the differences in SDs were due to a different trajectory, we can conclude that better lateral control of the virtual car has been demonstrated with the studs, as compared to without them.

3.2. Future directions

The current study constitutes an important step forward in direction of designing a smart active lane delineation application for country roads, but there is still much to be investigated before mass implementation on real roads could be recommended. In this study there was no traffic preceding the participants' virtual car and which might have triggered the application, but on a real road, such circumstances would result in what may be perceived to some drivers at greater distances as random chunks of lights switching on and off, or as a light 'wave' progressing in the opposite direction. Likewise, vehicles would illuminate studs that would then become visible in the mirrors (which did not exist in this experiment) of vehicles travelling in the opposite direction, possibly producing glare and potentially 'masking' traffic from behind that is about to overtake. Indeed, the large numbers of light points have the potential of masking vehicle headlights and lights that are returned by safety reflectors of any and of all, road users. On single undivided carriageways, these light points might induce failures to detect the headlights of an oncoming vehicle performing an overtaking maneuver and posing a risk of head-on collision.

Especially in conditions of poor visibility and when the painted markings are in poor conditions, stud delineation of only the nearside edge of the road, or only the central road marking on single carriageways may - at least in theory - result in some confused drivers accidentally proceeding to the wrong side of the studded delineation. However, delineation of both the near-edge and the centre line of the road, likewise, delineation of the offside edge, are not only more costly solutions but they also increase the risk of failures to detect oncoming vehicles posing a threat to a head-on collision. The difficulty to perceive the headlights of an oncoming vehicle on a studded road relative to an unlit road is illustrated in Figure 7.



Figure 7. Oncoming vehicle on an unlit road and on a studded (nearside, central and offside) road.

Not only, the results of this experiment and real driving performance may well be dependent on such gross characteristics of the design, but they also are most likely not independent of the exact parameters used for matters that are less, or even unnoticeable, by the road users, such as stud spacing and others. These ought to be compared with other alternatives that may produce advantages over the design examined in this study.



System failures may lead to unpredicted 'illumination patterns' capable of confusing drivers. At a practical level, control centers allowing to monitor, repair or at least to deactivate the application in case of malfunction are mandatory. Finally, the risk for power two wheelers of skidding over the studs is yet another concern to be taken into consideration.

In conclusion, this simulator study provides evidence demonstrating that the active lane delineation application designed, simulated and tested in the present study enhanced, as compared to an unlit road condition, the ability of drivers to control their virtual vehicle and to reduce its lateral displacement. Future research must compare other alternatives that may have advantages over the design tested in this study, in producing the safest driving performance, while eliminating or minimizing any potential adverse effects that might result from any of the causes discussed in this paper, or due to other causes that were not discussed.

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