A Driving Simulator Study to Evaluate the Effects of Different Types of Median Separation on Driving Performance on 2+1 Roads

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Abstract

In recent years, several countries have started to introduce 2+1 roads in their road networks. Although some studies have recognized the great benefits of using 2+1 roads, few studies have investigated the effects of different design features of 2+1 roads on driver behavior and driving performance, including the type of median separation between opposing traffic flows. The overall aim of this driving simulator study is to determine whether different types of median separation on 2+1 roads affect driving behavior, and to provide new insights for designing more effective and safer 2+1 roads. To achieve this goal, a driving simulator study was carried out and forty-six participants took part in the experiments. The scenario exactly reproduced an existing two-lane rural road in Poland where 2+1 sections are implemented; four different median separation types were tested: 1) double-line markings only; 2) reflective elements; 3) flexible guideposts; 4) cable barriers. The effects of the different types of median separation on driving performance were statistically analyzed using data from 184 simulation tests. The results of the study suggest that the type of median separation significantly affects driving performance on 2+1 roads. While the driving speeds on the passing lane did not differ significantly between the four configurations of the median separation, the lateral position of the passing vehicle on the additional lane was found to be significantly influenced by the type of separation, with a greater distance from the median recorded when the cable barriers were implemented. This study shows the potentiality of using driving simulation to test different solutions for 2+1 roads and selecting the most effective alternative in terms of safety and operation. In addition, the results of this study can also be used to improve the behavioral models that can be implemented in the traffic micro-simulation of 2+1 road conditions.

Keywords: 2+1 road; Road safety; Driving simulation; Driving performance; Traffic performance; Median separation.

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1. Introduction

As traffic volumes keep growing, traffic and safety performance have been decreasing especially on two-lane rural roads, resulting in increased travel time delay and number of crashes. The solution to expanding existing two-lane roads to four-lane facilities, in order to provide greater operational levels, is often an economically inconvenient solution, mostly due to environmental concerns and financial costs.
In these cases, the upgrade to a continuous single-carriageway with three-lane cross-section (2+1 road) has been shown to be a convenient alternative to increase traffic operation and provide safer opportunities for drivers' overtaking maneuvers. Indeed, 2+1 roads consist of two lanes in one travel direction and one lane in the opposite direction. The two-lane section provides drivers with a safe overtaking zone and it alternates with one-lane sections at set intervals.
The median separation on 2+1 roads is a fundamental design issue. According to the international experience, the median traffic separation on 2+1 roads could be with or without barrier and several solutions have been proposed and applied, with different guidelines and opinions among the countries on the effectiveness of the various median separation types. Moreover, the road design process for proposing the best solution for median barrier separation did not take into account the driving behavior and its relation with the different types of median separators solutions.
The current study has investigated the effects of different types of median separation on driving behavior, within the framework of a wider research project that focuses on the investigation of human factors and driving performance on 2+1 roads. The overall aim of the project consists in the introduction of innovative design guidelines based on traffic safety and driving behavior, as well as the improvement of behavioral models to be implemented in traffic microsimulation for future studies on 2+1 roads.

2. Methodology

2.1 Driving Simulator and Participants

The fixed-based medium-fidelity driving simulator of the Road Safety Laboratory of the Engineering Department at Roma TRE University (LASSTRE) was used for the experiments. The sample of participants consisted of forty-one drivers (16 women and 25 men) with an average age of 28.6 years (SD = 6.8 years) and ages between 22 to 41 years.

2.2 Simulated Scenario

A segment of a two-lane rural road in the Municipality of Piaski (Poland), including two 2+1 segments ("Piaski 1" 1600 m long and "Piaski 2" 800 m long) , was selected for the reconstruction in the driving simulator environment. Currently, the 2+1 road used flexible guideposts separators along the median to separate opposing traffic flows.
Each driver had to perform four different tests in the driving simulator; the only difference among the tests was in the way the 2+1 segments were configured in terms of the median separators between the two traffic directions. In fact, four different median separation types along the 2+1 segments were simulated in the experiments: double-line markings only ("Separation type 1", Fig. 1.a), double-line markings with reflective elements ("Separation type 2", Fig. 1.b), double-line markings with flexible guideposts ("Separation type 3" Fig. 1.c, that exactly reproduces the actual condition of the road), double-line markings with cable barriers ("Separation type 4" Fig. 1.d). Accordingly, four scenarios of the same road section were realized, one for each median separation type. The traffic volume was exactly implemented in the simulated environment according to on-site measurements, and was unchanged among the different tests and scenarios implemented.

2.3 Data Collection

Various driving performances were collected: driver's speed at the beginning of 2+1 lane (S_1), at the beginning of the lane change maneuver (S_2), and the average speed along 2+1 lane (S_{av}); driver's lateral position at the beginning of the lane change maneuver with respect to the beginning of 2+1 lane (P), the average lateral position along 2+1 lane (LP_{av1}) and along the right lane (LP_{av2}); driver's average (a_{av}) and maximum (a_{max}) acceleration along 2+1 lane. Moreover, an evaluation of traffic performance was also developed, evaluating the increase of the average travel speed and the reduction in travel time delay.

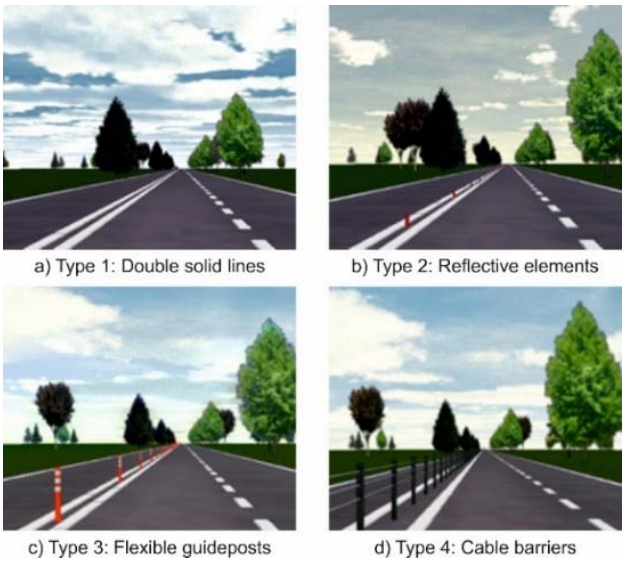

Figure 1: The median separation types

3. Analysis and Results

3.1 Effects on Driving Performance

For both "Piaski 1" and "Piaski 2", the analysis shows a statistically significant main effect of the separation types on LP_{av1} and LP_{av2}. Specifically, an increase in the overall encumbrance of the median separators always results in greater deviations to the right from the median of the vehicles' average trajectories. Figure 2 illustrates both the average lateral positions on 2+1 lane for all the four median separation types and the two lengths of the 2+1 segment. Conversely, the results of the analysis performed over the driving speeds revealed that there are no major effects on the drivers' speeds caused by the median separations under study. In fact, there is an absence of statistically significant differences for all the speed parameters (Figure 3).

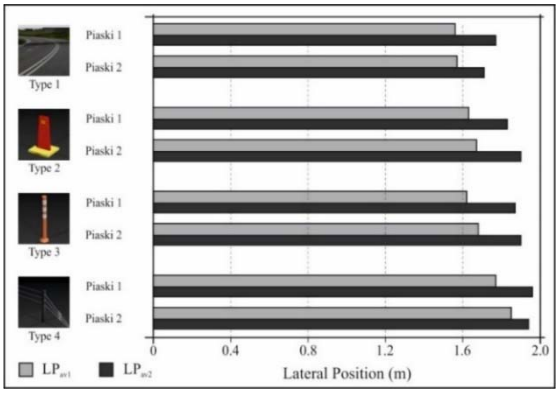

Figure 2: Average lateral position on 2+1 lane.

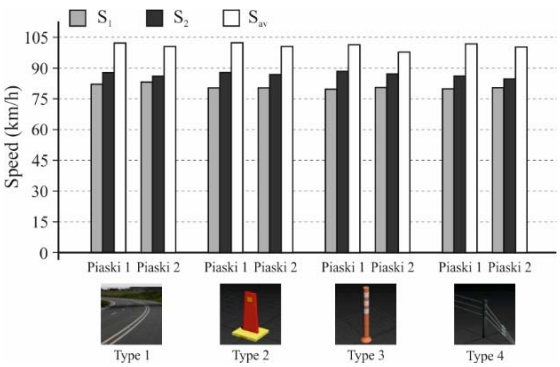

Figure 3: Speed values on 2+1 lanes.

3.2 Effects on Traffic Performance

The computed benefits related to the 2+1 configuration in comparison to a conventional two-lane roadway are remarkable, with average speed variation between 9.06 km/h and 10.92 km/h, and PTSF (Percent Time Spent Following), that is the average percentage of travel time that vehicles must travel behind slower vehicles because of their inability to pass) reduction between 8.18% and 9.18%. These results fully agree with findings from several other studies on 2+1 roads, and further validate the reliability of the results obtained through driving simulation while showing the operational benefits of 2+1 configuration.

4. Conclusions

The study reported in this paper analyzed the effect of median separation type on driving performance, and then evaluated the effectiveness of median separators on traffic performance to estimate the benefits of implementing the 2+1 configuration. The findings of this study indicate that the researched parameters have an effect on driving behavior on 2+1 roads, primarily on the drivers' lateral positions and trajectories. Based on the findings of this study, it can be concluded that using cable barriers as median separators on 2+1 roads is the best option when the primary goal of the facility is to drastically reduce fatal injury rates and crashes. However, larger lanes are recommended to compensate for the driver's higher deviation from the median while traveling in the passing or feeder lane. If this poses a difficulty when implementing a 2+1 configuration on an existing two-lane road, non-containing objects such as reflective components and flexible guideposts may be a better solution than using solely road markings.

Future research is necessary, not only to further validate these results, but also to expand the investigation on human factors on 2+1 roads to those aspects not explored in this study. Possible examples to conduct in a driving simulation environment are the modification of other geometric parameters of 2+1 roads, such as cross-section dimensions (lanes, median width, …) and the geometrical configuration of the changeovers, as well as the assessment of the effects of different traffic conditions, in terms of entity and composition.

The behavioral data obtained from this study also allows for in-depth micro-simulation analyses of many operational aspects, such as platooning, spacing between different segments with a 2+1 configuration, variation of the headway between the vehicles and level of service evaluations.