HOW TRAFFIC CONDITIONS AFFECT DRIVER BEHAVIOR IN PASSING MANEUVER

Francesco Bella
Associate Professor
Roma TRE University - Department of Sciences of Civil Engineering
via Vito Volterra n. 62 - 00146 Rome
Phone +39-06-57.33.34.16; fax +39-06-57.33.34.41
E-mail: bella@uniroma3.it

Paper submitted for
3rd International Conference on Road Safety and Simulation.
14-16 September, 2011 - Indianapolis, USA

ABSTRACT

The paper reports the outcomes of an experimental study carried out using an interactive fixed-base driving simulator. The research was aimed at analyzing the driver behavior in passing maneuver for different traffic conditions on two lane rural roads. A two-lane rural road of more than 8 km in length was designed and implemented in the driving simulator. The alignment was designed with tangents from 200 to 1000 m long, clothoids and curves with radii from 215 to 1000 m. Four different traffic conditions in terms of traffic volume and speeds of opposing vehicles and impeding vehicles were simulated. Thirty-two drivers drove in the simulator on the four scenarios. The data collected during the driving was analyzed in order to determine the following parameters of passing behavior: a) following gap between the passing vehicle and the impeding vehicle at the beginning of the passing; b) distance of passing; c) Time to Collision between the passing vehicle and the oncoming vehicle at the end of the maneuver. The influence of the traffic conditions on such parameters was evaluated. Potential applications of the obtained results include the modelling of driver behavior and the passing sight distance design criteria.

Keywords: driving simulation, driver behavior, road safety

INTRODUCTION

Considering the significant role played by human behavior in road accidents, improving road safety requires a careful analysis of those interactions between driver and factors which affect the driving task. Interference caused by traffic is among these factors. On a two-lane road, traffic interference is constituted by the slow down imposed by the slower lead-vehicle. Faced with this condition, a driver may adopt one of two different maneuvers: either tolerate the slowing down imposed by the slower lead-vehicle, and continue to follow behind it, or perform a passing maneuver.

While a previous study examined with the car-following maneuver (Bella and D'Agostini, 2010), this study seeks to analyze driver behavior during the passing maneuver under varying traffic conditions. Both these studies are part of a broader research program aimed at studying how traffic affects driver behavior.

There are no extensive studies concerning the passing maneuver and traffic related aspects in the literature. Only one single contribution highlighted the fact that the traffic volume affects the risk adopted by driver when performing a passing maneuver (Farah et al., 2009). It is interesting, regarding this fact, to note that the Passing Sight Distance (PSD) as well is determined on the basis of models which fail to consider the varying potential behavior induced by the different traffic conditions (AASHTO, 2004). Passing is a highly risky maneuver with significant impacts on safety and on system performance (Bar-Gera and Shinar, 2005). An in-depth study of this maneuver is consequently crucial. However field studies remain quite expensive, dangerous for drivers and observers and entail a myriad of problems such as how to observe vehicles throughout the entire passing maneuver, and how to control experiment conditions (Farah et al., 2009; Jenkins and Rillet, 2004).

One useful technique for studying the driver behavior in passing maneuver appears to be driving simulation. The notable quantity of the research carried out using driving simulators (see next section literature review) highlights the reliability of the driving simulation technique, which is deemed an effective tool for the study of a complex maneuver such as that involved in passing.

It should however be noted that driving simulators do have an important limit. In a driving simulator, the driver does not perceive any risk (or perhaps a very low one linked to the possible occurrence of a virtual crash with no damage occurring either to persons or to goods). The driver's awareness of being immersed in a simulated environment might give rise to a behavior which is different than that on a real road. However several simulator validation studies (some of these validation studies refer to the driving simulator used in the present study), carried out in different driving conditions (Bella, 2009) have afforded us sufficient guarantees regarding the reliability of the data recorded in the driving simulators.

The present study is aimed at analyzing, using driving simulation, the extent to which driver behavior during the passing maneuver is conditioned by different traffic-flow conditions on a two-lane rural road. More specifically the purpose is that of testing the following hypothesis: high traffic flows affect driver behavior in the passing maneuver, and induce the driver to adopt highly risky behavior. The CRISS (Inter-University Research Center for Road Safety) interactive fixed-base driving simulator, located at Roma TRE University, was used.

The research was organized into the following steps:

- the design of the experiment (design of a test alignment and later implementation in the driving simulator, definition and implementation of four traffic scenarios, driving test and data collection);
- the calculation of measurements for describing driver behavior at beginning of the maneuver (beginning of the acceleration step), while passing (travelling in left lane) and at the end of the maneuver (return to the right lane);
- the analysis of the relationship between the measures which describe driver behavior and the volume-to-capacity ratio.

The description of the most important experiences in literature addressing this issue has been preliminarily reported.

LITERATURE REVIEW

Several studies analyzing the passing maneuver are available in the literature. A number of these studies have been conducted in the field whilst others by means of driving simulators. Several parameters also are used to analyze driver behavior in passing maneuver.

Field Studies on Passing Maneuver

Polus et al. (2000) collected data by videotaping in six tangent two-lane highway sections. The study's aim was that of developing models which allowed the quantification of the major components of the passing process as well as the evaluation of several passing process time elements. While data was recorded for traffic volumes of 300 to 1,000 vehicles per hour, results were not provided for different traffic volumes. Harwood et al. (2008) carried out a field study on two-lane highways in Missouri and Pennsylvania using a combination of traffic classifiers and video recording. The traffic flow rates at the study sites for 15-min periods ranged from 36 to 476 veh/h, with most flow rates in the range from 100 to 250 veh/h. Based on data of 60 maneuvers, the mean left-lane travel distance for passing vehicles (282 m) and the mean left-lane travel time (10 s) were found. These values were equal to those of a study carried out in Texas (Carlson et al., 2006) which used video data from a moving vehicle (passed vehicle) inside the traffic flow. More recently Llorca and Garcia (2011) conducted out a field study on two different rural roads in the surrounding of Valencia. The passing maneuvers were recorded by six video cameras on horizontal passing zone with traffic volume between 250 and 300 veh/hour. Only in few maneuvers, was there an opposing vehicle approaching the passing and impeding vehicles.

Driving Simulator Studies on Passing Maneuver

Advanced-interactive driving simulators are considered useful and reliable tools for assessing the driver behavior which is induced by the road environment. They afford a high degree of realism, low costs in conducting experiments, easy data collection, the highest degree of safety for test drivers and allow experiments to be conducted in controlled conditions (weather, traffic, and drivers) (Bella, 2009). The driving simulators are able to render the visual perception process that a driver uses to perceive the relative motion that is established in vehicle interactions (Gray and Regan, 2005). Several studies have demonstrated that driving simulators (both the most advanced simulators consisting of a real vehicle mounted on a motion platform with a roadway scenario which is recreated on a totally immersive virtual environment on wrap-around screens as well as the systems constituted by real vehicles mounted on a fixed platform with a projection of the roadway scenario on several screens which ensure a field of view more than 120°) provide the driver with enough visual information to allow him to correctly perceive speed and distances (for exhaustive references see Bella, 2009). These features, especially the possibility of ensuring controlled experiment conditions and avoiding risky conditions, have led to an increasing use of driving simulators for examining the passing maneuver. A great deal of research into analyzing the passing maneuver using driving simulators is in the literature (Gray and Regan, 2005; Bar-Gera and Shinar, 2005; Farah et al., 2008; Farah et al., 2009; Jenkins and Rilett, 2005; El-Bassiouni and Sayed, 2010; Toledo et al., 2011).

Among the studies using driving simulators, the researches evaluating several parameters of the passing maneuver carried out by Jenkins and Rillet (2004) and El-Bassiouni and Sayed (2010) are particularly noteworthy. Nonetheless the results were obtained for single traffic condition or very narrow ranges of traffic volume. The only contribution which is available in literature providing results for different traffic volumes on driver behavior (only at the end of the passing maneuver) is Farah et al's study (2009) which was carried out using a low cost driving simulator.

Measurements Which Describe Driver Behavior in the Passing Maneuver

The parameters which are the most frequently utilized in the literature to describe the passing maneuvers are as follows.
The Following Gap (FG) is commonly used for the beginning of the maneuver. This is the distance between the passing and the passed vehicle at beginning of the maneuver. Rajalin et al. (1997) noted that in their preparation for passing, drivers often reduce their headways to a point where they are no longer maintaining a safe distance from the car ahead thus generating an increased risk of rear-end accidents as well. Several values are set out in the literature based on the data recorded both on the field (Hegeman, 2004; Llorca and Garcia, 2011) Polus et al., 2000) as well as in driving simulators (Jenkins and Rillet, 2004).

The Distance of Passing (DP) is the distance travelled on left lane by passing vehicle in order to complete the passing. Several values obtained from field studies (Llorca and Garcia, 2011; Harwood et al., 2008; Carlos et al, 2006; Polus et al., 2000) and simulator studies (Jenkins and Rilett, 2004; El-Bassiouni and Sayed, 2010) are reported in the literature.

The Time to Collision (TTC) (also called the Remaining Gap (RG)) is used for the end of the maneuver. It is the remaining gap (in terms of seconds) between passing and oncoming vehicle at the end of the passing maneuver. The Time-To-Collision notion was introduced in 1972 by the Hayward (1972). It is given from the following equation.

$$\mathrm{TTC} = \frac{\mathrm{x}_{\mathrm{op}}(t) - x_{pas}(t) - l}{s_{op}(t) - s_{pas}(t)} \qquad (1)$$

where:
s denotes speed, *x* the position of opposing and passing vehicle at the instant *t* when the maneuver finishes. *l* is the vehicle length.
The higher a TTC-value, the safer a maneuver is.
Also the remaining distance (RD) is used. It is the distance between the passing and opposing vehicle at the end of the maneuver.

Some studies in literature measured these parameters both on field (Polus et al., 2000; Llorca and Garcia, 2011) and in driving simulators (Jenkis et al.,2005; Farah et al., 2009; El-Bassiouni and Sayed, 2010).

Few studies have employed TTC for measuring the risk adopted by the driver during the passing maneuver. Farah et al. (2009) based on data recorded in a driving simulator, developed a model which predicts the risk in terms of the TTC associated with the passing behavior. It was found that the traffic related variables (speed of impeding vehicle, speed of opposing vehicle, traffic volume, etc.) had the most important effect on the measure of risk chosen. El Khoury and Hobeika (2007) using microscopic simulation defined a risk index, based on the value of the

clearance time between the passing and the opposing vehicles at the end of the passing maneuver. Passing with a final clearance time less than 2 s was deemed risky.
The Following Gap (FG), Distance of Passing (DP) and Time to Collision (TTC) values which are available in the literature are reported in the section Results and Discussion.

EXPERIMENTAL DESIGN

The driving simulator of the Inter-University Research Centre for Road Safety (CRISS) in the University of Roma TRE was used in order to collect data on drivers' passing behavior. First, a road alignment was reproduced in the driving simulator. A sample of drivers subsequently drove along the road in the simulator. Finally, the data were recorded to calculate the parameters and to evaluate driver behavior in passing maneuver.

Apparatus

The CRISS simulation system is an interactive fixed-base driving simulator (fig. 1). It includes a complete vehicle dynamics model based on the computer simulation Vehicle Dynamics Analysis Nonlinear. The model has been adapted to run in real time and it has been validated extensively (Allen et al., 1998). Several validation studies (Bella, 2005; Bella, 2008) ascertained the reliability of CRISS driving simulator in different driving conditions.

Figure 1 CRISS driving simulator

The hardware is composed of four networked computers and three hardware interfaces. One computer processes the motion equations, and the others generate the images. The hardware interfaces include a steering wheel, pedals and a gearshift lever and they are mounted on a real vehicle in order to reproduce a realistic driving environment. CRISS Driving Simulator allows to simulate several kinds of passenger cars with different mechanical performances. The driving scene is projected onto three screens, one in front of the vehicle and two on each side. The usual field of view is 135°. The scenario is updated dynamically in accordance with the traveling conditions of the vehicle, which depend on the actions of the driver on the pedals and the steering wheel. The resolution of the visual scene is 1024 × 768 pixels and the update rate is 30 to 60 Hz depending on scene complexity. The system is also equipped with a sound system reproducing the sounds of the engine. This set-up provides a realistic view of the road and surrounding environment.

It is possible to implement different traffic scenarios in terms of kinds of vehicles, numbers of vehicles for lane, speeds and path of each vehicle. A set of parameters can be recorded to describe traveling conditions (vehicle barycentre, relative position in relation to the road axis, local speed and acceleration, steering wheel rotation angle, pitching angle, rolling angle, etc.). The system also allows us to record the position and speed along the road of all the vehicles. All data can be recorded in intervals of time (a fraction of a second) or space (a meter).

Test Alignment and Traffic Scenarios

An alignment of a two-lane rural road was designed and implemented in the driving simulator. The alignment was 8.5 km long and had a cross-section 10.5 m wide (lane and shoulder widths were 3.75 m and 1.5 m respectively). In order to eliminate any possible influences of the profile on the driver's behavior, the road alignment was designed without longitudinal grades. The alignment consisted of tangents with length ranging between 200 m and 1000 m and horizontal curves made up of approach clothoid, circular curve and departure clothoid. The radii of the circular curve ranged between 215 m and 1000 m (fig. 2). The passing were permitted only in the tangents with length equal to or more than 400 m. No passing zones were marked. The speed limit was 90 km/h.

The traffic was introduced in both directions. Four scenarios were simulated with a growing total traffic volume (350 veh/h for scenario 1; 600 veh/h for scenario 2; 800 veh/h for scenario 3; 900 veh/h for scenario 4) in order to simulate four different volume-to-capacity ratios correspond to the Level-of-Service A (scenario 1), B (scenarios 2 and 3) and C (scenario 4).

The speed of each vehicle (excepting the subject vehicle) in the four scenarios was programmed in advance, in accordance with the traffic condition which is assumed in each scenario.
In particular, in the direction opposite that of the driver the speeds were equal to 85 km/h (in scenario 1), 80 km/h (in scenario 2), 75 km/h (in scenario 3) and 70 km/h (in scenario 4). In each scenario the gap between the opposing vehicles was constant; it was equal to the gap obtained as a function of traffic flow and speed of opposing vehicle.
For vehicles travelling in the same direction of the driver the speeds were 75 km/h (in scenario 1), 70 km/h (in scenario 2), 65 km/h (in scenario 3) and 60 km/h (in scenario 4). In order to ensure the same passing potential in the four scenarios, the number of vehicles on the driver's lane was held constant (5 vehicles) for all scenarios (however, as mentioned above, the speeds of impeding vehicles changed in the four scenario in accordance with the traffic conditions). The impeding vehicles (they were cars) were programmed in such a way that the driver intercepted them in the proximity of the curves, which were followed by long tangents (where the driver would be able to carry out the passing maneuver). Should an impeding vehicle not be passed, the gap between it and the slow vehicle ahead was programmed in such a way as to avoid platoon being formed. In this way the driver was always ensured the possibility passing one single vehicle.
The characteristics of traffic concerning the four scenarios are shown in table 1.

Table 1 Traffic Scenarios

Traffic Scenario	Traffic [veh/h]	Speed of oncoming vehicle [km/h]	Speed of impeding vehicle [km/h]
1 (low)	350	85	75
2 (medium)	600	80	70
3 (heavy)	800	75	65
4 (high)	900	70	60

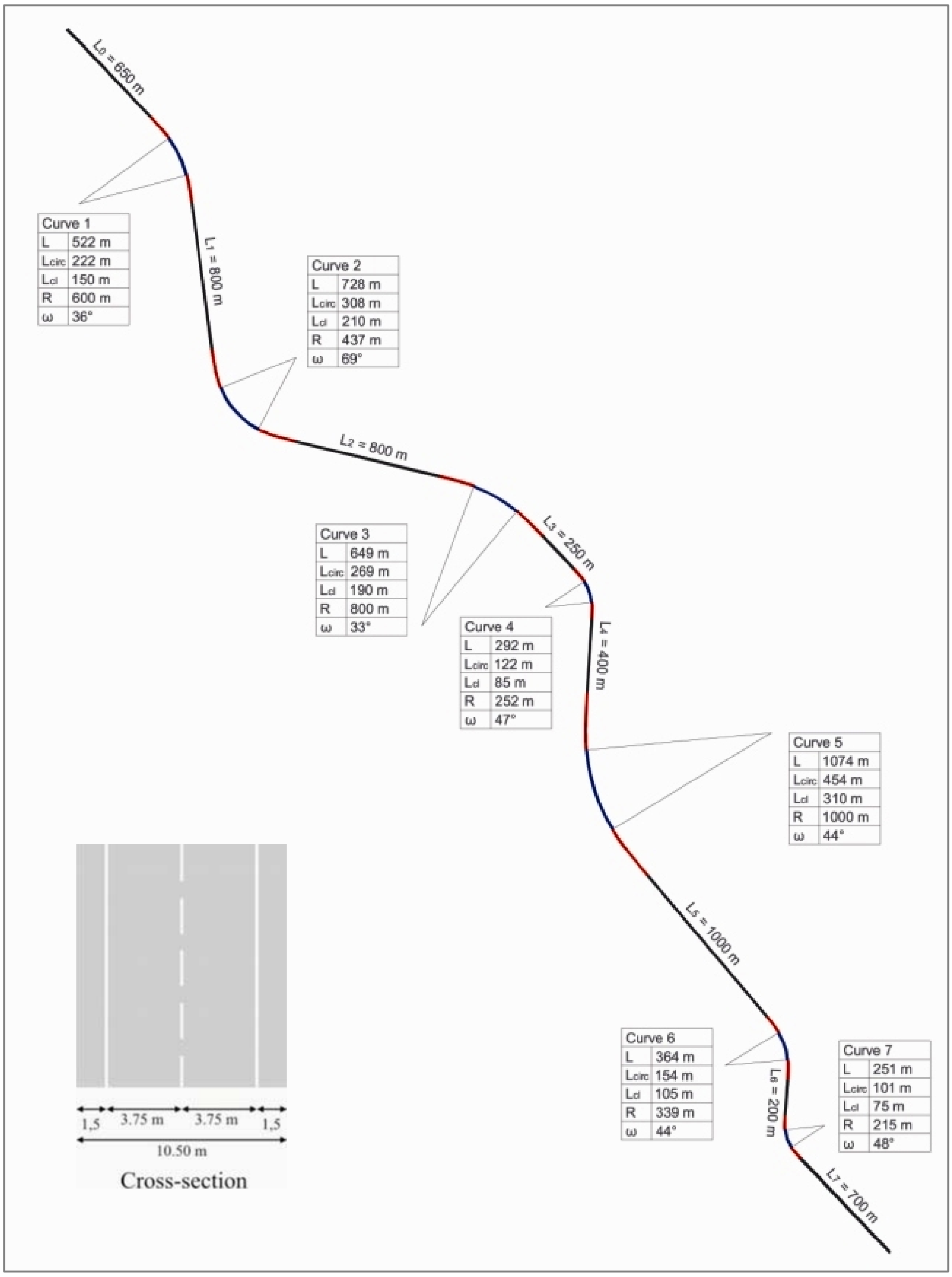

Figure 2 Geometric features of test alignment

Procedure and Participants

The study was carried out using dry pavement conditions in good state of maintenance, simulating the characteristics of a medium-class car, both as regards size and mechanical performance, with automatic gear-changes. The data recording system was set to acquire all the parameters at spatial intervals of 5m.
The driving procedure was broken down into the following steps: 1) communicating to the driver about the duration of the driving and the use of the steering wheel, pedals, and automatic gear; 2) training in the driving simulator on a specific alignment for approximately 10 min to allow the driver to become familiar with the simulator's control instruments; 3) the execution of two test scenarios in the established sequence; 4) the driver vacating the car for about 5 minutes in order to re-establish psychophysical conditions similar to those at the beginning of the test and filling in a form with personal data, years of driving experience, average annual distance driven; 5) the execution of the two remaining test scenarios in the established sequence; 6) filling in of an evaluation questionnaire about type (nausea, giddiness, daze, fatigue, other) and entity (null, light, medium, and high) of the discomfort perceived during the driving. The sequence of the four scenarios was counterbalanced in order to avoid influences due to the repetition of the same order in the experimental conditions. Drivers were instructed to drive as they would normally do in the real world. The simulation was performed by 32 drivers aged from 22 to 40, male (70%) and female (30%), with a driving experience of at least 3 years and an average annual driven distance on rural roads of at least 2,500 km. They were recruited as volunteers from staff and students of the Roma Tre University. From the analysis of the questionnaire filled in by the drivers at the end of the test, it emerged that no participant experienced any high or medium level of discomfort. Therefore no participant was excluded from the sample.

Data Processing

The data records during the tests in the driving simulator were processed in order to determine:

1. the number of displacements before the passing maneuver; these were determined on the basis of the vehicle's path. A displacement was considered to have occurred whenever the centerline was touched by the front left wheel of the vehicle;
2. the passes carried out; which were classified into:
   - flying pass: a pass in which the passing vehicle is not forced to slow down before making the pass;
   - accelerative pass: a pass in which the faster vehicle slows to the speed of the impeding vehicle before initiating the passing maneuver;
3. for accelerative passes, which account for the worst case passing maneuver scenario (El Khoury and Hobeika, 2007), the following parameters were quantified:

- Following Gap (FG);
- Distance of Passing (DP);
- Time to Collision (TTC) and Remaining Distance (RD).

The determination of such parameters compelled the preliminarily determination of the initial *(ti)* and final *(tf)* instances of the pass maneuver. These were consequently determined:

- instant of initial maneuver: the instant at which the driver, after a phase of deceleration, begins to accelerate in order to bring its in the left-lane and overtakes the slow vehicle;
- instant of end of maneuver: instant at which the passing vehicle wholly turns back into the right lane, in front of the impeding vehicle.

FG was determined in the instant of the initial maneuver, TTC was determined in the instant of the end of maneuver. DP was obtained by subtracting the position vector of the passing vehicle at the instant *ti* from its position vector at the instant *tf* (fig. 3).

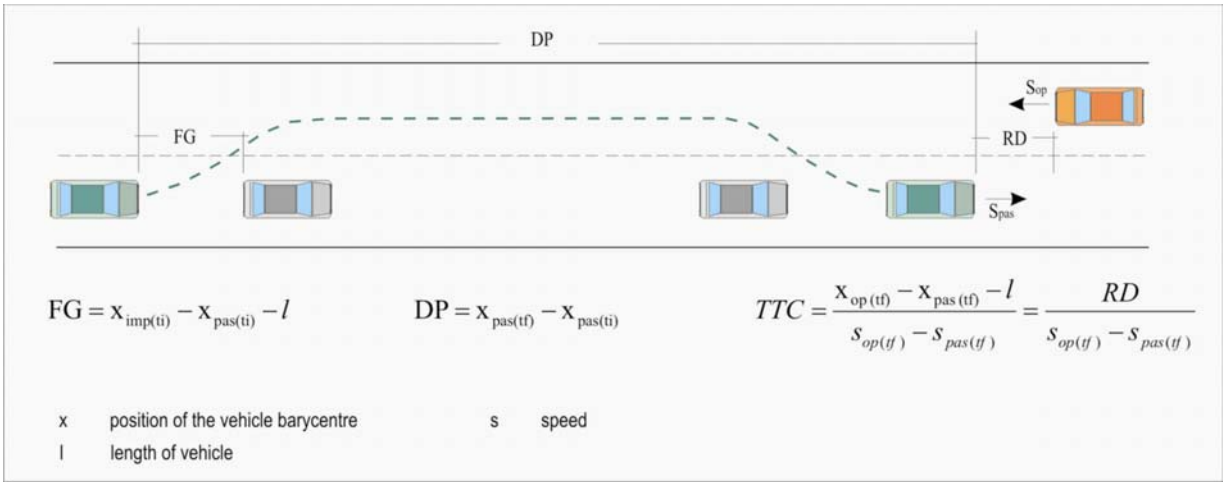

Figure 3 Stages and parameters of the passing maneuver

RESULTS AND DISCUSSION

Displacements and Passes

The data in table 2 show that the number of passes (totals, fly and accelerating) decreases as traffic increases while the number of displacements increases with traffic. This was expected and easily explainable considering that at the growth of traffic:

- demanding driving conditions (speed of vehicles and gap between the oncoming vehicles) increase which are deemed unsafe by drivers who, consequently, refused to pass;
- car-following condition continues over time. In this condition the driver effectuates displacements toward the left in order to verify the presence of conditions that he deems safe for carrying out the passing maneuver. The number of these displacements increases with the duration of the car-following condition and thus with the amount of traffic.

It should be noted that the number of displacements can be deemed an indicator of the discomfort experienced and generated by the traffic conditions which prevent the passing maneuver from being carried out.

It is interesting to note that the high percentage of fly passes in scenario 1 (equal to 25% of the total) is significantly reduced for the other scenarios (9.5%, 10% e 8.7%, respectively for scenarios 2, 3 and 4). This data shows how the amount of traffic significantly affects the kind of maneuver adopted by the driver. In the scenario characterized by low scenario traffic, a not particularly demanding passing maneuver is frequently allowed (1 fly pass ever 4 passes) which is rarely recorded in other scenarios characterized by higher traffic levels (less than 1 flay pass for every 10 passes).

Finally it is interesting to note that high levels of traffic are not necessarily required but that a medium traffic flow condition is sufficient to make a fly maneuver an infrequent occurrence. Consequently the models in literature which depict the passing maneuver as an accelerating maneuver appear to be appropriate (the accelerative pass is the more frequent and moreover the more critical).

Table 2 Displacements and Passes Recorded

scenario	displacements	flying passes	accelerative passes	Total passes
1	83	36	108	144
2	129	11	104	115
3	202	7	63	70
4	261	6	63	69

Parameters for Accelerative Passes

The data collected during the simulated drives were processed in order to obtain the quantification of FG, DP and TTC. Figure 4 shows the mean values for the four traffic scenarios. The errors bars represent the 95% confidence limits for the means.

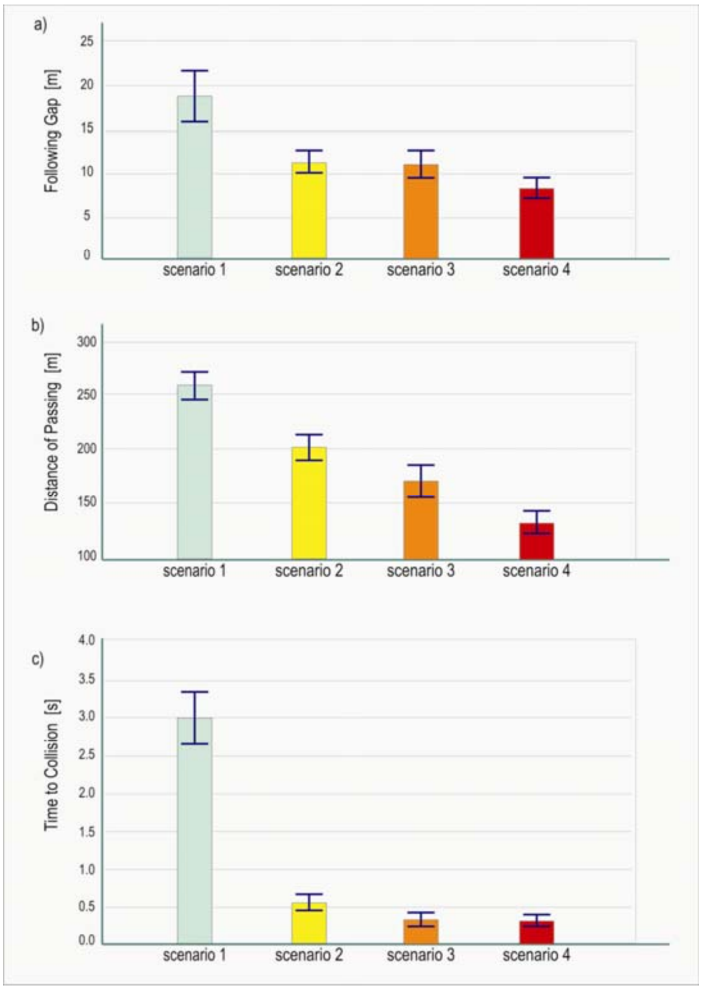

Figure 4 a) Following Gap; b) Distance of Passing; c) Time to Collision, for the four traffic scenarios

Following Gap

Figure 4a) shows that FG decreases as traffic increases. The mean value of FG for traffic scenario 1 is equal to approximately 19 m, while it is reduced to 11.2 and 11 m for scenarios 2 and 3 respectively. For the high traffic scenario (scenario 4) a mean FG equal to 8.2 m is recorded, which is about half of the value of FG for the scenario with low traffic.
These results were compared with the field observations and data obtained in other studies carried out using driving simulators.
Hegman (2004) found that, for fly and accelerative passes on two-lane real road, the mean value of the distance between the passing vehicle and the vehicle in front at the start of the passing maneuver was 17.8 m. Llorca and Garcia (2011) in a field study carried out on two different two-lane rural roads in the surrounding of Valencia (Spain), found a mean value of gap between passing and impeding vehicles at begin of maneuver equal to 13 m. Accelerative and fly maneuvers were recorded on passing zones with traffic volume between 250 and 300 veh/hour. Polus et al. (2000) in a field study found that distance between the passing vehicle and the impeding vehicle at the beginning of the passing process was 6.8 m for accelerative and fly maneuver to pass a car and for traffic volume of 300 to 1,000 vehicles per hour.
Jenkins and Rillet (2004), using a fixed-base simulator, found that the “start gaps” for accelerative maneuver to pass a car was 20.8 m. The opposing traffic was equal to 250 vehicles per hour with speed equal approximately to the speed limits. This condition is comparable to the conditions of traffic scenario 1 (low traffic) whilst the value obtained by Jenkins and Rillet is similar to that obtained in this study (19 m).

The other data above reported, which have been found in field studies, do not however allow a direct comparison with the data in the present study as it refers to different traffic conditions and maneuver types (both fly as well as accelerative) than that used in the present study. However the values obtained in this driving simulator study appear to be congruent with the values recorded on field and reported in the literature.

ANOVA was performed in order to determine the statistical significance of the effects of traffic on the FG values held by the drivers. The outcome of the ANOVA test ($F_{3,\,310} = 17.6$; p-value = 0.00) established that traffic significantly influences the behavior of drivers at the beginning of the passing maneuvers: the drivers adopt a lesser gap as the amount of traffic increases. Contrast tests showed that the null hypothesis is accepted only for the comparison scenario 2 – scenario 3 (t= 0.268; p-value= 0.789)
This can be explained by considering that the increase in traffic increases the discomfort accumulated by the drivers given that it reduced the possibility to carry out the pass and prolongs the car-following condition. In this condition the drivers is induced to tag behind the slow moving vehicle ahead of him at a distance which decreases as the discomfort increases. These results therefore highlight the fact that the risk related to the beginning of the passing maneuver, shown by the FG parameter, increases as the amount of traffic increases, i.e. as the accumulated discomfort before carrying out the passing increases.

Distance of Passing

The mean values of the parameter DP obtained for the different traffic scenarios changed between 260 m (in scenario 1), 205 m in scenario 2, 175 m in scenario 3 and 138 m in scenario 4 (fig 4b). Therefore the DP in the scenario with high traffic (scenario 4) was about twice the value recorded in scenario with low traffic. These values were compared with those in literature, in order to ascertain the reliability of the results obtained in the experiment.

Llorca and Garcia (2011) in their field study found a mean value of distance travelled on left lane by passing vehicle equal to 193 m (for fly and accelerative maneuver and traffic volume between 250 and 300 veh/hour). Harwood et al. (2008) found a mean left-lane travel distance for passing vehicles equal to 282 m (for flow rates in the range from 100 to 250 veh/h). A similar value (equal to 313 m) was found by Carlos et al (2006). Polus et al (2000) analyzed fly and accelerative maneuvers (for traffic volume of 300 to 1,000 vehicles per hour) to pass a car and found a mean value of 240 m for the distance travelled by the passing in the opposing lane.

Useful references are available also form studies carried out using driving simulator. Jenkins and Rilett (2004) in their driving simulator study found a distance travelled in the left line equal to 437 m for accelerative maneuver to pass a car with speed 8 and 16 km/h less than the speed limits. This value is higher than DP recorded in the traffic scenario 1 (260 m). The difference in these values is probably due to the speed limits (72km/h in industrial area and 88 km/h in the rural area) posted on the road used in experiment. In our simulator study on the contrary, no speed limits were posted. El-Bassiouni and Sayed (2010) also carried out a study using a driving simulator. The speed of opposing vehicle was 100 km/h. A range of 80 - 90 km/h was set for the impeding vehicle. The authors found a mean value of 266 m for the distance travelled by passing vehicle while it is in the left lane. No data was provided regarding the traffic volume on the simulated two-lane rural road.

For the DP as well, similarly to the FG, the data in literature do not allow a direct comparison with the values obtained in the present study. Bearing in mind the difference of the experiments, however it is reasonable to affirm that the results obtained would seem to be in agreement with those available in literature.

The values obtained seem to highlight the fact that the Distance of Passing is affected by traffic conditions. This conclusion is confirmed by ANOVA test which established ($F_{3,\ 324} = 65.0$; p-value = 0.00) that the traffic significantly influences driver behavior in the passing maneuver: the driver is induced to occupy the lengths of the left lane which decrease as traffic increases. Contrast tests showed that the null hypothesis is rejected for all comparisons.

This result was expected and can easily be explained considering that the greater volume of traffic creates an awareness that a passing maneuver becomes more difficult. This awareness also induces a behavior (in addition to a reduced number of passes carried out), in the cases in which the driver does not renounce passing, such that the length of the left lane occupied during the maneuver decreases with the increase of the traffic.

Time to Collision

The mean values of the parameter of TTC are shown in figure 4 c). For the scenario 1 the mean value of TTC was 3 s. For the other scenario the mean values were less than 1 s; 0.6 s for scenario 2, 0,37 s for scenario 3 and 0.35 s for scenario 4. The data highlight a very different driver behavior in scenario 1 compared to those in other scenarios. Similar results were obtained in terms of remaining distance: on scenario 1 the mean value was 161 m, on scenario 2 was 29 m, on scenario 3 was 18 m, on scenario 4 was 16 m.

Few studies are available in literature to compare the values of TTC obtained. Polus et al. (2000) in a previous field study found a mean value of remaining gap equal to 5.43 s to pass a car with accelerative maneuver. Farah et al. (2009) using a low cost driving simulator (steering and pedals not installed on a real vehicle, only one screen in front of the driver with an usual field of view of only 60°) found a mean value of 2.36 s. The fly and accelerative maneuvers were recorded in different opposing lane traffic volume, geometric design (good and poor), speeds of impeding and opposing vehicle. The traffic conditions and speeds of the vehicles are comparable to those used in our study. However the mean value obtained (2.36 s) is about 1 s higher than the mean value recorded for the four scenarios (equal to 1.30 s). The difference is probably due to the different configurations of the simulators.

Other studies in literature give the remaining distance (or clearance distance) between the passing and opposing vehicle at the end of maneuver. El-Bassiouni and Sayed (2010) in their driving simulator study obtained a mean value equal to 43 m. The speed of the opposing was 100 km/h and the speed of the impeding vehicle was changed between 80 and 90 km/h. Llorca and Garcia (2011) in their field study found a mean value of clearance distance equal to 163 m (for fly and accelerative maneuvers and traffic volume between 250 and 300 veh/hour). This value (although refers also to fly maneuvers) is comparable with the mean value obtained in scenario 1.

As can be seen from the data above reported, bearing in mind differences in equipment and traffic conditions used in the different experiments, the values in the current study are consistent with those obtained in previous studies carried out using driving simulators. The comparison with the field data shows a very similar value with the clearance distance obtained (in the similar traffic conditions) in the study by Llorca and Garcia, and a large difference with the higher value obtained by Polus et al. Such difference can be explained because the drivers in virtual reality take considerably more risks compared to real-world driving.

The ANOVA test confirmed that the mean value of TTC in the four traffic scenario are different ($F_{3, 320}$ = 138.43; p-value = 0.00). Contrast tests showed that the null hypothesis is accepted only for the comparison scenario 3-scenario 4 (t= 0.242; p-value=0.810). Similar results were obtained for remaining distance ($F_{3, 320}$ = 145.68; p-value = 0.00; scenario 3-scenario 4: t= 0.612; p-value=0.542). Drivers consequently adopt behavior in terms of risk at the end of the maneuver which differs greatly according to the changes in the traffic scenario. In low traffic conditions the driver turns back into the right lane with a very high mean value of TTC, whilst in medium, heavy and high traffic conditions the mean value is less than 1 s.

Given that Glennon (1988), in deriving his model, assumed a minimum head-on clearance of 1 s, AASHTO (2004) considers a minimum value of 2 s (for average passing speed of 56 km/h the clearance length is 30 m) and El Khoury and Hobeika (2007) classify risky passing maneuvers with clearance gaps of less than 2 s, only the maneuvers in scenario 1 are on average not risky. The maneuvers in the other scenarios are, on the contrary, to be deemed risky. Furthermore the maneuvers carried out in scenarios 2, 3 and 4 emerged as being more risky the smaller the mean value of TTC was, i.e. the greater the traffic volume was.

CONCLUSIONS AND FURTHER RESEARCH

The study carried out using an interactive driving simulator and aimed at analyzing the driver behavior in passing maneuver for different traffic conditions on two lane rural roads highlighted the following main results.

The amount of traffic significantly affects the kind of maneuver adopted by the driver. Such a result was expected. However the study showed that high levels of traffic are not necessarily required but that a medium traffic flow condition is sufficient to make a fly maneuver an infrequent occurrence. Consequently the models in literature which depict the passing maneuver as an accelerating maneuver appear to be appropriate.

Traffic significantly influences the behavior of drivers in all three phases of the passing maneuver analyzed (beginning of the maneuver, occupation of the left lane, re-entry in the right lane). This is demonstrated by the decrease of the mean values of the indicators associated with the passing maneuver FG, DP and TTC.

At the start of the passing maneuver drivers adopt a mean following gap that decreases as the amount of traffic increases. Therefore the result highlights that the risk associated with the beginning phase of the passing maneuver, displayed by parameter FG, increases with the amount of the traffic or the growing discomfort accumulated before carrying out the passing maneuver.

The length of left lane used to pass decreases as traffic increases. This result was expected and can be explained considering that the great volume of traffic induces an awareness of a more difficult maneuver in the driver and consequently encourages him to carry out the maneuver by using a shorter distance of the lane dedicated to the incoming traffic.

At the end of the passing maneuver the driver adopts a behavior which is very different according to the variations in the traffic scenarios. Compared to the threshold values given in the literature for classifying a risky maneuver, only the maneuvers in scenario 1 are on average deemed not risky. The maneuvers in the other scenarios are considered risky, the more risky they become, the lower the mean value of TTC is, i.e. the greater the traffic volume is.

The results of the study highlight to what extent it is necessary to:

- reduce the interference caused by traffic for the purpose of avoiding unsafe behaviors of the driver in carrying out the passing maneuver;
- impose design requirements not on the basis of design standards which are not correlated to traffic (such as Passing Sight Distance) but by considering the performance of the road system in the prevailing traffic conditions.

Useful measures could be those that satisfy the passing demand such as:

- limiting the sections the road sections with insufficient passing sight distance, to be determined in relation to the prevailing traffic conditions;
- limit the longitudinal grade or add additional lanes for slow moving vehicles, if there are a great deal of heavy vehicles that might result in significant decreases of Level of Service.

Consider the differences in equipment and traffic conditions used in other experiments using driving simulators or in field studies, the values obtained in the current study appear to be consistent with those reported in previous studies. In some case the higher value recorded on field can be explained because the drivers in virtual reality take considerably more risks compared to real-world driving. Despite this limitation the results reported here are promising and clearly show the effects of traffic on driver behavior in passing maneuver.

Future research would involve:

- performing validation of the simulation results against data from the real-world in the same conditions of traffic;
- analyzing the behavior of the driver as a function of age, sex, behavioral characteristics (conservative, aggressive, etc.);
- involving a truck as impeding vehicle;
- defining threshold of risk for the purpose of characterizing the unsafe maneuver;
- developing risk predicting models which include traffic volumes.

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