OBSERVATIONS OF DAYTIME AND NIGHTTIME PASSING MANEUVERS ON A TWO-LANE RURAL ROAD IN SPAIN

Corresponding Author:

Carlos Llorca
Ph.D. Candidate
Highway Engineering Research Group
Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877374
Fax: (34) 96 3877379
E-mail: carlloga@cam.upv.es

Other Authors:

Ana Tsui Moreno
Ph.D. Candidate
Highway Engineering Research Group, Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877374
Fax: (34) 96 3877379
E-mail: anmoch@cam.upv.es

Alfredo García
Professor
Highway Engineering Research Group, Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877374
Fax: (34) 96 3877379
E-mail: agarciag@tra.upv.es

Ana María Pérez-Zuriaga
Ph.D.
Highway Engineering Research Group, Universitat Politècnica de València
Camino de Vera, s/n. 46022 – Valencia. Spain
Tel: (34) 96 3877374
Fax: (34) 96 3877379
E-mail: anpezu@tra.upv.es

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ABSTRACT

Passing is one of the most complex maneuvers on two-lane rural roads, thus it has important effects on road safety and traffic operation. It is affected by driving behavior, road geometry, traffic volume, traffic composition as well as other external factors. This research was developed to compare passing process under daytime and nighttime conditions.

An experimental methodology was designed to collect video data of passing maneuvers at a two-lane rural road segment located in the surroundings of Valencia (Spain). Two methods were used: firstly, external observations with six video cameras of four passing zones; secondly, an instrumented vehicle equipped with video cameras and laser rangefinders, which was driven slightly below the operating speed along a longer road segment of the same road in order to be passed by other vehicles.

A total of 291 maneuvers were observed; up to 20% of them during night. A macroscopic analysis shows that approximately 17% of passes are under nighttime conditions, although passing frequency and passing demand decrease during night. Besides, individual behavior of drivers which pass is different at nighttime compared with daytime. Maneuvers limited by the presence of an opposing vehicle are performed faster at night, even if accepted gaps are longer. In this case, a more difficult perception of distances to opposing vehicles and of their speeds explains the differences. On the other hand, maneuvers limited by sight distance (without a visible opposing vehicle) are slower during night. This matches a traditional hypothesis, which assumed that passing at night is safer since headlights from opposing vehicles anticipate their position before being seen.

INTRODUCTION

Passing maneuver on two-lane rural highways allows different vehicles to drive at their desired speeds. Levels of service of those highways are increased due to the existence of passing zones, where sufficient passing sight distance is provided.

This maneuver is one of the most complex and dangerous on two-lane highways. It involves several decision processes, strongly affected by human factor, road geometry and vehicle performance. To pass a slower vehicle it is necessary to occupy the opposing lane, which causes a potential conflict. Severity of accidents related to passing maneuver is higher (*1*), involving very often seriously injured or fatalities.

Due to its importance, passing maneuver has been widely studied, especially to estimate passing sight distance (PSD), which is used as a criteria for road geometric design and marking. Several theoretical models have been formulated (*2, 3*). They explained the maneuver by defining equations of movement of the three involved vehicles: the impeding one; the passing one; and the opposing one. However, these deterministic approaches needed to be compared and calibrated with field data, since most variables have shown a high variability, and models were unable to explain accurately the phenomenon.

Recently, various field studies have been presented. Polus et al. (*4*) and Llorca and Garcia (*5*) video recorded maneuvers from external points of view, measuring different parameters of passing maneuver. Besides, Carlson et al. (*6*) and Llorca et al. (*7*) used instrumented vehicles to collect data, increasing the level of detail. On the other hand, Farah et al. (*8*) and Jenkins and Rilett (*9*) used driving simulators to evaluate the influence of human factor on passing decisions. However, simulators have not been validated with real data yet, and it could show a riskier behavior and differences in long distances perception.

Those studies analyzed the influence of highway characteristics (*5, 6, 7, 8*) or driver's behavior (*8, 10*) on passing maneuver. Some of them also considered the effect of external factors, like weather conditions (*11*).

However, the effect of lighting conditions on passing maneuver has been rarely considered. Night driving involves a different perception of roadway and traffic, as well as a different behavior, as some authors have observed (*12, 13*). Those results suggest that passing during night could be quite different from daytime.

In fact, in 1969, Farber (*14*) designed an experiment in order to evaluate the difference between nocturnal and diurnal passing maneuvers. The experiment consisted in driving an impeding vehicle in front of a previously observed vehicle. The speed of the researcher's vehicle was set between 10 and 20 mph (16 and 32 km/h) less than the desired speed of the observed passenger car, in order to ensure a close following position along a no-passing zone. The aim was to analyze how drivers reacted to passing opportunities in a single passing zone downstream. Observers positioned off the road recorded times of start and end of passing opportunities and passing maneuvers by using event recorders.

More than 400 maneuvers were observed with this methodology, and they were compared with daytime passing maneuvers at the same passing zone. Observations were divided into opposing-car-limited passing situations and sight-distance-limited passing situations, depending on the presence of opposing vehicles during left lane occupation.

A comparison between day and night was made only for opposing-car-limited situations. During night, drivers show a more conservative behavior, accepting longer passing opportunities. Besides, a higher dispersion was found in night data. According to the author, complexity to estimate distances and speeds at night could explain these differences.

Apart from a logical difficulty of collecting data during night, a previous hypothesis could explain the lack of recent data of nighttime passing maneuvers. During night, headlights of opposing vehicles anticipate their position, so drivers would detect them before seeing them. According to this, nighttime passing would be safer than daytime passing.

Farber (*14*) proposed this hypothesis for sight-distance-limited situations, which is also mentioned in AASHTO Green Book (*15*). However, there is no other experimental test which verifies this hypothesis.

The present research has carried out a field study on passing maneuvers both in daytime and nighttime conditions. Highly accurate and detailed data has been provided in order to characterize passing process under different lighting conditions.

OBJECTIVES AND HYPOTHESES

The main objective of this research is the characterization of passing maneuvers during night conditions, in comparison with daytime. It can be divided into different specific objectives:

- Development of a methodology to collect accurate data of passing maneuvers under nocturnal lighting conditions, based on video data.
- Collection of data during daytime and nighttime from the same locations.
- Analysis of differences between day and night conditions: comparing passing frequency (macroscopic level) as well as individual passing behavior (microscopic level).

Traditionally, passing at night has been thought to be safer (*15*), because headlights of opposing vehicles anticipate their position. Perception of distances and speeds of objects at night is more difficult, though. This suggests a different hypothesis: if opposing vehicles are visible by the passing vehicle driver, passing decision could be different. Passing drivers would require longer passing gaps, and would pass in less time, in order to reduce risk.

In addition to this, when a passing maneuver is performed either with high traffic volumes or in long passing zones, an opposing vehicle is in most cases visible by passing drivers. The higher difficulty to pass accepting a gap limited by an opposing vehicle could decrease the passing frequency. Then, the traditional hypothesis would be only valid for sight-distance-limited passing opportunities.

METHODOLOGY

To collect data of passing maneuvers, two methodologies were developed. An additional data reduction work has been carried out in order to select the most significant variables.

Field study

Data collection has been based on video recording of passing maneuvers under naturalistic conditions, since influence of observers was minimized. Two methodologies have been used to record passing maneuvers. Observations were carried out at the same locations during day and night. Both methods are a further development of previous research work of authors (*5, 7*).

The first methodology (static) consisted in recording videos from external fixed positions of four passing zones along 2 km of a two-lane rural highway. The mobile traffic laboratory of the Universitat Politècnica de València (Spain) was parked next to the highway. This equipment is composed of six digital video cameras installed on the top of an elevator platform. Zoom and focus of cameras was adjusted on site via wireless network, to collect video images of the four passing zones (two in each direction of the road) with uniform quality. Infrared filters of cameras allowed night time recording.

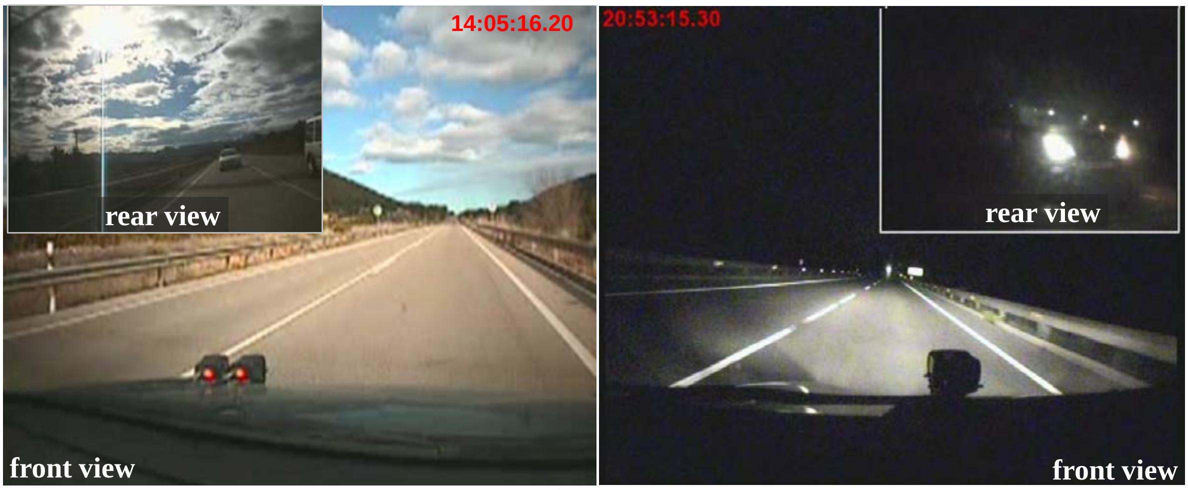
Position of cameras was fixed and daytime and nighttime recordings were carried out on the same day. Then, reference lines matching road marking were drawn in video frames during day, in order to facilitate data reduction during night (Figure 1).

The second methodology (dynamic) was based on an instrumented vehicle, which was driven along a road segment, which included passing zones observed with the first method. The objective was for other vehicles to pass the instrumented vehicle, collecting data of these maneuvers and the entire following process.

The instrumented vehicle was equipped with four 720x576 pixels resolution cameras, covering rear, left side and front of the vehicle, and connected to a Racelogic VBOX recording unit, as well as with a high definition mini-camera covering rear part. Two LTI True Sense S200 laser rangefinders were installed to measure headways between vehicles behind and in front of it. Accuracy of distance measurements is 4 cm. Measuring systems are very small and are installed inside the car (cameras and recording units) or in front and rear bumpers (rangefinders). No unexpected maneuvers of drivers who follow the instrumented vehicle were observed, like following without pass or with longer headways when there were passing zones and gaps very long enough.

Position and speed of the instrumented vehicle was provided by a 10 Hz GPS tracker connected to the VBOX unit too. Speed was fixed at 80 km/h. This estimation was made thanks to the observation of the static methodology, which had been previously carried out. This speed was the 15^{th} percentile of speed of impeding vehicles at this location (measured with the static methodology), neither too fast nor too slow.

(a) Observations from the fixed point



(b) Observations from the moving vehicle

FIGURE 1 Video images of day and night passing maneuvers: (a) static methodology, (b) dynamic methodology

During night, high beam was not used by the instrumented vehicle. Some studies (*16*) showed that percentage of high beam users is not general but quite moderate. Then, the effect of leader vehicle high beam use in perception of passing opportunities by the following driver has not been considered.

Headlights of following vehicle (before passing) and of the instrumented vehicle (after passing) allowed nocturnal video recording, and it was possible to observe accurately the starting and ending point of the maneuver (Figure 1).

Data collection was centered in a 15 km highway segment, located in highway N-225 in Valencia (Spain). Design speed, as well as posted speed limit is 100 km/h. Cross section along the entire segment has two lanes 3.5 m wide and paved shoulders of 1.5 m. The instrumented vehicle drove along this segment at constant speed of 80 km/h both during day and night. Passing zones recorded using the static methodology were located between stations 4.0 km and 6.0 km of this segment. Those four passing zones (two in each direction) have lengths between 265 m and 1,270 m. They are located in a tangent, and the no-passing zone between them is a crest vertical curve (Figure 2).

During the field study, two-way traffic volume was between 150 and 320 vph. During day it was between 230 and 320 vph and during night between 150 and 250 vph. Average percentage of heavy vehicles was 21%.

During the night period, road surrounding was completely dark, since no advertisement lighting or streetlamp are located in the studied road. Pavement was dry along all the data collection periods.

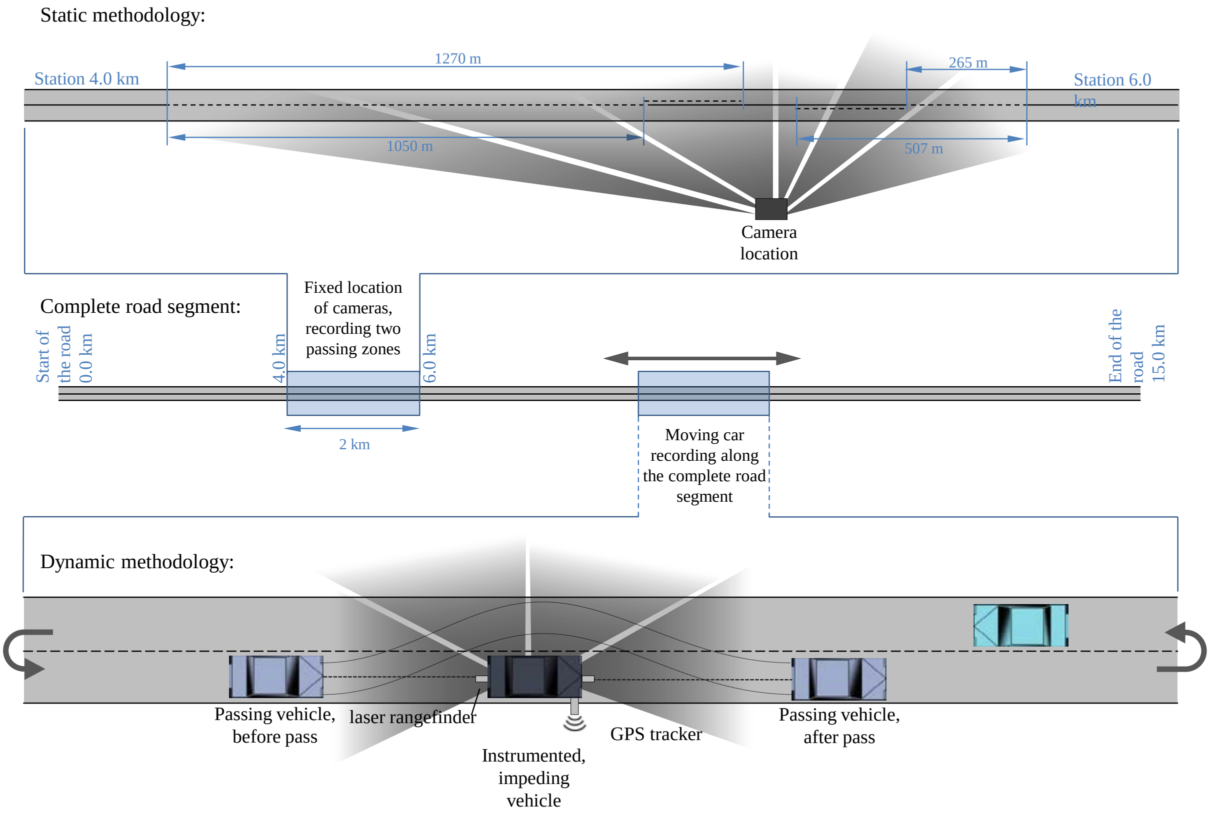


FIGURE 2 Field study design

Data reduction

This field study has provided data of a total of 291 passing maneuvers: 216 were observed using the static methodology during 28 hours of observation (7 hours per direction and passing zone). 75 vehicles passed the instrumented vehicle in 7 hours of recording. 81% of the total number of passing maneuvers was observed during day.

Static observations have been used to characterize passing frequency, measured in passes per hour. Hourly traffic volumes, as well as percent of followers were also registered during the whole time of the data collection. For this count, one vehicle was following a leader vehicle if headway between them was less than 3 s, according to the Highway Capacity Manual criterion (17).

From the total number of observations, only single maneuvers (one impeding vehicle) performed by passenger cars were considered for a day-night comparison. 349 passing gaps were studied (152 of them were accepted) and 128 passing maneuvers have been analyzed in detail. 60% of them were during day.

82 of those 128 maneuvers were recorded from static observations (45 during day and 37 during night). The following variables have been used to describe this sample (Figure 3):

- Lighting conditions: day/night
- Type of impeding vehicle: car/truck

- Visibility of opposing vehicle at start of maneuver: opposing-car-limited/sight-distance-limited
- Accepted or rejected passing gap (s) calculated as the difference between the end of gap t_4 and its start t_0
- Passing time – opposing lane occupation time t_3-t_1 (s) calculated as the difference between the ending point of maneuver t_3 and the starting point t_1
- Time to collision, TTC = t_4-t_3 (s) time between end of passing maneuver t_3 and crossing with next opposing vehicle t_4

From data provided by the instrumented vehicle, 46 maneuvers have been analyzed (38 during day and 8 during night). In all cases, the impeding vehicle was a passenger car. Following additional variables have been considered:

- Average speeds of impeding and passing vehicles during passing time V_i and V_p (km/h)
- Difference between average speeds of passing and impeding vehicles dV (km/h)
- Instant speeds of passing vehicle at starting and ending points of maneuver $V_p(t_1)$ and $V_p(t_3)$ (km/h)
- Headways between impeding and passing vehicles at starting and ending point of maneuver $h(t_1)$ and $h(t_3)$ (m)

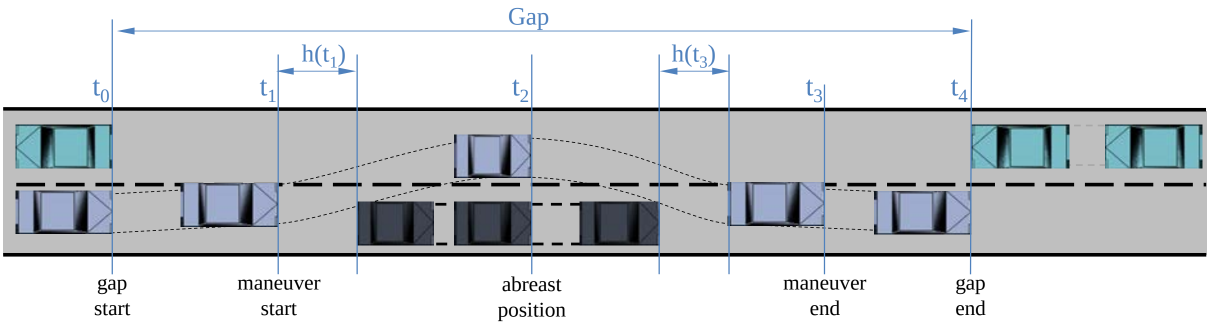


FIGURE 3 Variables of passing maneuver

Passing gaps, which can either be accepted or rejected, are calculated as difference between the ending time of a gap t_4 (crossing with an opposing vehicle) and the starting time of it t_0 (crossing with a previous opposing vehicle or entering in a passing zone). This can be applied to passing gaps limited by opposing vehicles, but in some cases, there is no opposing vehicle visible. Then, the real accepted or rejected gap matches the available sight distance from the location of the passing vehicle. To estimate the value of that gap (in time units), a virtual opposing vehicle is considered (*7*). It would drive at the posted speed limit and would appear at the moment the gap starts (t_0) from the point located at the end of the available sight distance.

Since passing gaps are calculated in time units, as $t_4 – t_0$, they could be divided in an initial perception and decision time (t_1- t_0), the passing time ($t_3 – t_1$) and the safety margin (t_4-t_3).

In addition to this, several variables describing the passing zone where a passing maneuver is performed have been considered. Passing zone length has been defined as the length where passing is allowed, between two no-passing zones. Available sight distance along each passing zone has been calculated combining video images, aerial photography and smoothed GPS longitudinal profiles. This has provided sight distances profiles for each direction of the road segment, which have been used to estimate passing gaps.

ANALYSIS

After data collection, an analysis has been carried out from a macroscopic point of view of the phenomenon to a behavioral approach of individual passing decisions.

Importance of passing during night

The effect of lighting conditions on this maneuver has been considered because of its potential influence on highway safety. Relative frequency of night passing maneuvers, compared with the total number of them, has been rarely estimated.

Detailed traffic data of year 2010 was available at location of the field study. It included daily and hourly traffic volumes for every day during the whole year. Sunset and sunrise were defined as start and end of night period. Taking into account the variations of those times during the year, the total volume of traffic was divided into daytime traffic and nighttime traffic. According to this calculation, 22% of vehicles drove during night along the segment.

On the other hand, an estimation of number of passing maneuvers was made. It has been centered on hourly passing frequency of the longer passing zone (in both directions) which was recorded using the static methodology. An ANOVA test was used to compare the passing frequency between day and night. Passing frequency adjusted adequately a normal distribution, according to a normal probability plot. The effect of lighting conditions was significant (F-Ratio=18.98, $p<0.05$), and average value were 0.0712 passes/hour/vehicle during day and 0.0516 passes/hour/vehicle during night. It means that the number of passing maneuvers per hour and vehicle is higher during day. Those values have been used to estimate that 17% of passing maneuvers at this location are under nighttime conditions.

Passing frequency

A deeper analysis of the influence of light conditions on passing frequency has been done. It is only centered in data provided by the static methodology, since it was obtained without any intervention in traffic which could affect normal passing frequencies. Apart from lighting conditions, passing zone length has been included in the analyses, due to its logical influence on the number of passing maneuvers performed.

Main variables, which have been chosen to characterize passing frequency in each direction of travel, were: number of passing maneuvers per hour and vehicle; and number of passing maneuvers (passing rate) per hour and vehicle following. A multifactor ANOVA was carried out to study those factors. Both number of passes and passing rate were normally distributed, according to a normal probability plot.

As shown in Table 1, the number of passing maneuvers in one hour in relation to traffic volume is lower during night than during day. However, number of passes per vehicle which was following a slower vehicle is not affected by lights conditions. These differences suggest that passing demand was lower at night (mean of 30% of vehicles were following during day and 23% night), but that drivers which really demand to pass did it. Besides, passing frequency is affected by passing zone length, increasing the number of passing maneuvers with it.

TABLE 1 Effect of light conditions and passing zone length

Variable	Factor	Level	Count	Mean	Significance
Number of passes $\left(\frac{passes}{vehicle \cdot hour}\right)$	Light conditions	daytime	168	0.071	Yes (F-ratio = 18.13)
		nighttime	56	0.052	
	Passing zone length (m)	265	56	0.035	Yes (F-ratio = 55.48)
		507		0.042	
		1,050		0.076	
		1,270		0.093	
	GRAND MEAN		224	0.061	
Passing rate $\left(\frac{passes}{follower \cdot hour}\right)$	Light conditions	daytime	168	0.24	No (F-ratio = 0.03)
		nighttime	56	0.25	
	Passing zone length (m)	265	56	0.14	Yes (F-ratio = 45.4)
		507		0.19	
		1,050		0.27	
		1,270		0.38	
	GRAND MEAN		224	0.25	

Passing gap acceptance

The number of passing maneuvers is the result of driver's passing decisions, among other factors. This process of decision making consists in accepting or rejecting the different passing gaps perceived during the time a driver desires to pass. A passing gap is an opportunity to pass a vehicle which is driving at a lower speed. As previously explained in data reduction section, two types of passing gaps can be found: sight-distance-limited gaps and opposing-vehicle-limited gaps. Estimation of time gaps for both cases makes possible their comparison, though.

According to most gap acceptance theories, each driver has a critical passing gap. Then, this driver will accept every gap longer than the critical, and will reject every gap shorter than it. Traditionally, several methods are used to estimate the value or distribution of critical gaps. Brilon et al. (*18*) compared different methods and established which ones can be applied to each conditions and objectives, including the maximum likelihood method described by Troutbeck (*18*).

In this method, only the accepted gap (a_i) and the maximum rejected gap (r_i) are considered. If there is no rejected gap, r_i is equal to zero. The maximum likelihood method calculates the probability of the critical gap t_c between a_i and r_i, assuming consistency between all drivers. Log-normal probability functions of critical gaps t_c are usually considered. The method consists in maximizing the likelihood function L* (Equation 1), characterizing critical gap distribution and calculating its mean and its standard deviation. One of the advantages of this methodology is that it does not depend on traffic volumes.

$$L^{*} = \sum_{i=1}^{n} \left(F_a(a_i) - F_r(r_i) \right) \quad (1)$$

where:

- a_i: accepted gap of driver i
- r_i: maximum rejected gap of driver i
- n: number of maneuvers
- F: Lognormal probability function
- L*: likelihood function

This method has been applied to data observed with the two methodologies. 349 passing gaps were initially considered, 152 of them being accepted. Parameters of log-normal critical gap distributions have been obtained according to Brilon et al. (*18*) by using an MS Excel function to maximize the Equation 1.

This estimation was separately carried out for day and night data. Slight differences have been found between both conditions, as seen in Figure 4. Mean critical passing gap is 1 s lower during day (9.9 s during day and 10.9 s night), while dispersion is higher during night (standard deviation of 3.7 s and 5.4 s, respectively). A higher dispersion under night conditions was also found by Farber (*14*) in several parameters.

Similitudes between day and night passing gap acceptance suggest that lighting conditions would not affect traffic operation. Passing process will be analyzed more accurately in following sections, though.

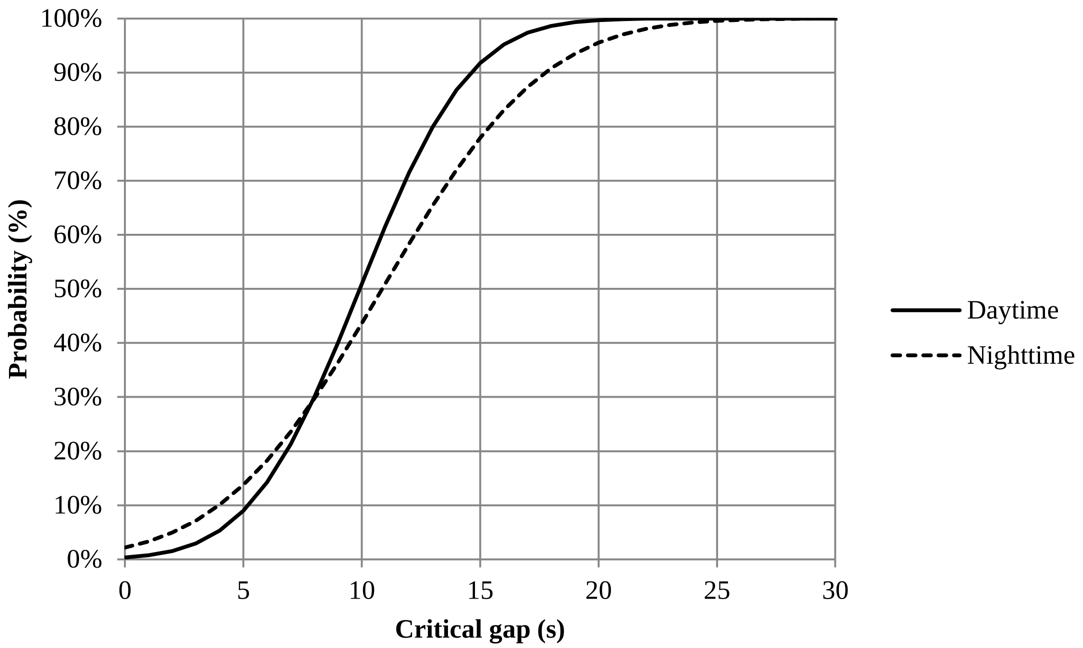


FIGURE 4 Estimated critical gap distribution under day and night conditions

Passing times

In order to compare passing process during day and night, different stages of passing maneuver were registered. Main variables of this analysis, as it was previously said in data reduction section, are:

- Passing gap duration: GAP (s)
- Left lane occupation time: t_3-t_1 (s)
- Remaining time to cross next opposing vehicle after a passing maneuver (time to collision): TTC (s)

A multifactor ANOVA analysis has been carried out, in order to analyze significance of effect on lighting conditions on these variables. In addition to this, influence of passing zone length and type of impeding vehicles has been considered. Data of 82 maneuvers obtained from static methodology has been used for this analysis. Average speed of impeding vehicles along the entire observed passing zones was compared. There were no significant differences between them during day and during night, with average values of 89 km/h and 93 km/h, respectively (F-Ratio=1.77, $p<0.05$).

Opposing-vehicle-limited and sight-distance-limited passing gaps have been considered in different groups, since there were strong, significant differences between them. This can be explained by the difference of driver's perception of gaps, either during day or during night.

Results of statistical analysis show differences between passing maneuvers limited by opposing vehicles or by sight distance restrictions. The effect of night conditions is different in each case.

TABLE 2 Effect of lighting conditions on passing gap, passing time and TTC

Type of passing gap	Lighting conditions	GAP	Passing time: t_3-t_1	Remaining TTC	Count
		Mean (s)	Mean (s)	Mean (s)	
Total	both	17.70	8.31		82
Opposing-vehicle-limited	day	**16.52**	**8.63**	**6.72**	18
	night	**20.15**	**7.21**	**10.12**	12
Forced opposing-vehicle-limited (Gap < 18 s)	day	**13.33**	7.61	4.77	8
	night	**16.39**	6.21	9.04	3
Sight distance-limited	day	25.14	8.76	-	27
	night	36.91	9.21	-	25
Forced sight-distance-limited (available gap < 18 s)	day	13.41	8.03	-	15
	night	14.12	9.02	-	13

statistically significant differences underlined ($p_{F\text{-statistic}} < 0.05$ if factor is significant)

During night, when an opposing vehicle was visible, drivers passed quicker than during day (t_3-t_1 was 1.4 s lower), even considering that mean accepted gaps and times to collision were longer during night. This means that drivers passed faster during night, although the gap available to do it was longer. The third of maneuvers which had a shorter accepted gap, designated as forced maneuvers, were analyzed separately. The threshold value was a gap of 18 s. As can be seen in Table 2, forced maneuvers show similar differences between day and night conditions, although passing times are smaller than in the whole sample.

Farber (*14*) observed the influence of gap size in passing time. However, no significant differences in passing times between daytime and nighttime situations were found.

On the other hand, when passing maneuvers were only limited by sight distance, passing maneuvers were faster during day (t_3-t_1 was 1.5 s lower). Therefore, the effect of nighttime conditions to opposing-car-limited situations is opposite to sight-distance-limited situations (Figure 5).

Apart from effect of lighting, other effects have been found in the analysis. Passing times between 1.5 s and 2.2 s higher have been measured when the impeding vehicle was a truck. This effect was statistically significant in most cases. Moreover, passing times are usually higher in longer passing zones.

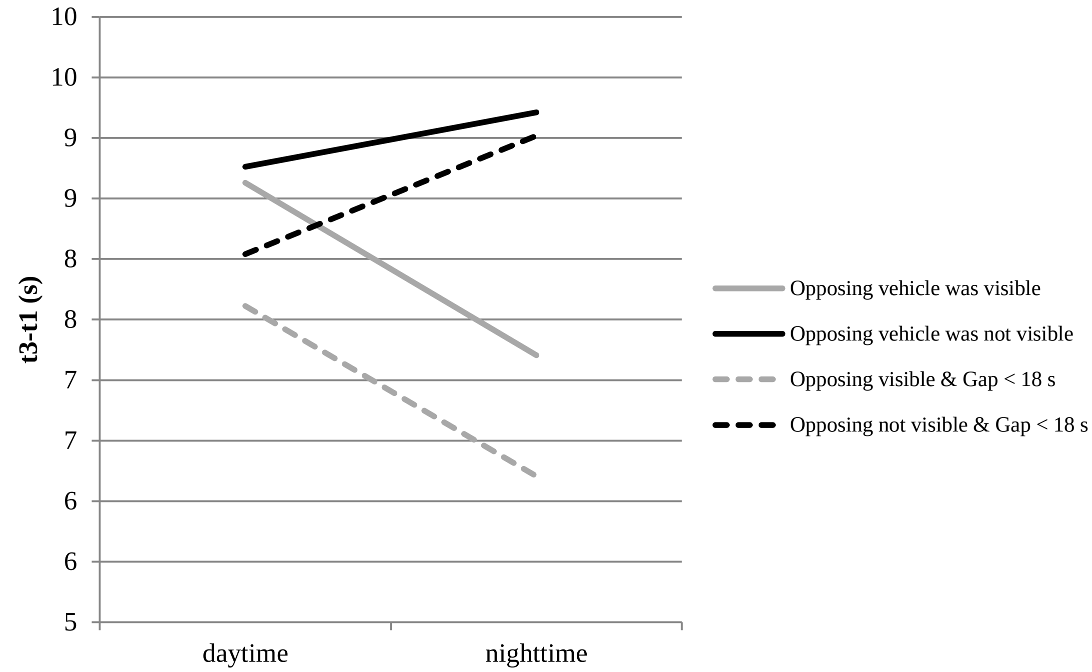


FIGURE 5 Differences in passing time between day and night maneuvers and presence or absence of an opposing vehicle

Passing speeds and headways

Passing maneuvers observed from the instrumented vehicle represent a smaller part of the sample of passing maneuvers (46 passes). However, level of detail of data acquisition is significantly higher, and additional variables have been analyzed. The following variables have been considered:

- Passing time t_3-t_1 (s)
- Headways between impeding and passing at start and end of passing maneuver $h(t_1)$ and $h(t_3)$ (m)
- Speeds of passing vehicle at start and end of passing maneuver $V_p(t_1)$ and $V_p(t_3)$ (km/h)
- Difference between average passing and impeding vehicle speeds during passing time dV (km/h)

In this case, in every passing maneuver the impeding vehicle was a passenger car. Lighting conditions, passing zone length and presence of opposing vehicles have been the considered effects. Since along the road segment 17 passing zones were located, they have been divided in three groups, according to their length.

Table 3 shows the effect of those variables in sight-distance-limited conditions, which represent the most frequent case in the sample.

Results obtained from instrumented vehicle data show similar tendencies for passing times if values are compared with previous analysis. In sight-distance-limited situations drivers passed in more time during night than during day. Differences between day and night were similar in the two data collection methods (around 1.5 s). Values from static methodology (Table 2) were higher, since they include passing maneuvers involving trucks, which required a longer passing time in most cases.

In addition to this, headways between impeding and passing vehicles, both before and after performing the pass, were higher during night, especially when returning to the right lane after passing (7 m longer during night).

In contrast, speed of passing vehicle was higher during night. Although mean initial speeds were very similar at the starting point of the maneuver, final speeds were 3 km/h higher during night. Consequently, average speed differences were also higher.

On the other hand, passing zone length had an effect on passing time, since gap sizes were highly related to available sight distance and, in consequence, to passing zone length. Long gap sizes may explain longer passing times. However, in relation to the other variables (headway and speed) no differences between zones were found.

TABLE 3 Effect of lighting conditions and passing zone length in instrumented vehicle recorded data

Lighting Conditions				
Variable		Level mean		Count
		day	night	
Passing time (s)	t_3-t_1	7.4	9.1	37
Initial headway (m)	$h(t_1)$	7.5	9.5	26
Final headway (m)	$h(t_3)$	19.7	26.7	26
Initial passing speed (km/h)	$V_p(t_1)$	85.6	85.1	26
Final passing speed (km/h)	$V_p(t_3)$	100.5	103.5	26
Average speed difference (km/h)	dV	18.3	21.5	37

Passing zone length					
Variable		Level mean			Count
		short	medium	long	
Passing time (s)	t_3-t_1	8.0	8.1	8.8	37
Initial headway (m)	$h(t_1)$	8.5	8.8	8.1	26
Final headway (m)	$h(t_3)$	22.7	23.1	23.8	26
Initial passing speed (km/h)	$V_p(t_1)$	87.6	84.0	84.5	26
Final passing speed (km/h)	$V_p(t_3)$	101.7	102.8	101.5	26
Average speed difference (km/h)	dV	20.0	19.9	21.0	37

DISCUSSION

Traditionally, a hypothesis assumed that passing during night would be safer, since headlights anticipate oncoming vehicles even before being seen. This hypothesis (*14*, *15*) would only be adequate for passing maneuvers without a visible opposing vehicle. On the other hand, previous research observed that it was more difficult to estimate distances to opposing vehicles during night. Therefore, the analysis of collected data was divided in opposing-vehicle-limited conditions and sight-distance-limited situations.

In the first case, opposing-vehicle-limited situations, statistically significant differences between passing times were found. During night, left lane occupation time was 1.4 s shorter, although the accepted gaps were longer. In spite of opposing vehicles being further, during night, drivers passed faster avoiding a potential conflict. The higher difficulty to estimate the distance and the speed of opposing vehicles may explain these differences.

On the other hand, when a vehicle passes without seeing an opposing vehicle, differences between night and day conditions are just the opposite. Passing times are 1.5 s longer during night, as well as headways between passing and impeding vehicles, either before or after passing. On one hand, traffic volumes at this location were slightly lower during night, and as a result, available gaps are longer, and probably passing maneuvers are less forced and drivers pass slower. However, since differences have been found also in those hypothetically forced maneuvers (sight-distance-limited gaps under 18 s) a second explanation would be related to the traditional hypothesis: headlights anticipate position of the opposing vehicle, so drivers are really accepting a longer gap than the measured one.

CONCLUSIONS

This research has carried out a field study on passing maneuvers under daytime and nighttime conditions. Two methodologies based on video recording were developed to collect naturalistic observations of up to 291 maneuvers. Detailed data of passing process has been obtained, and a comparison between both lighting conditions has been carried out.

Passing during night is not as frequent as during day, although it represents around 17% of total number of maneuvers at this location during the year. This proportion could be slightly different in other locations, but it justifies the importance of the phenomenon.

On the observed highway segment, passing frequency decreases slightly during night, because passing demand is also more reduced. However, average critical gaps are similar between both conditions, suggesting a similar operational effect of the maneuver.

Passing behavior is different if an individual characterization of maneuvers is done, though. Individual driver's behavior during night shows higher dispersion, if it is compared with daytime passing maneuvers. It depends strongly on the perception of opposing vehicles. On one hand, if an opposing vehicle is perceived, passing time decreases during night; on the other hand, if there is no opposing vehicle visible, passing time increases. Therefore, results could have an effect in traffic operation of two-lane rural highways. The consequence of higher traffic volumes during night is that a significant part of passing maneuvers is performed under opposing-vehicle-limited conditions. Since behavior is more conservative, number of passes could be reduced and quality of traffic flow would be affected.

The analysis of passing process during both day and night conditions could help to improve both operational analysis and microsimulation models, taking into account how almost that 20% of passing maneuvers are performed. Further work could be carried out to analyze the influence of impeding and opposing vehicle high beam usage on passing behavior during night.

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