DAYTIME AND NIGHTTIME FOLLOWING BEHAVIOR ON A MONITORED TWO-LANE RURAL ROAD

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ABSTRACT

This study investigates the effect of lighting conditions on speed, following and passing on two-lane rural roads. Nighttime driving, which represents around 20 percent of the total traffic volume, concentrates a significant number of crashes.

The present study analyzes speed, time headways and passing maneuvers on a 7 km road segment. Trajectories of 316 vehicles (200 daytime and 116 nighttime) were observed and characterized by 6 video surveillance cameras.

The analysis found that there were no significant differences in free flow speeds between both lightning conditions. Daytime headways between impeded vehicles decreased along the first 4.2 km no-passing zone. Up to 15 percent of followers had a headway under 1 s with the lead vehicle at the end of the no-passing zone. However, during night, this proportion was reduced to the half and the headways did not decrease significantly.

During daytime, two passing zones located in the last 2.8 km revealed an increase in time headways, showing the effect of passing maneuvers in the reduction of platoons. In contrast, nighttime headways decreased and percent of following vehicles increased. This result agrees with a lower passing frequency observed during night in the two passing zones.

These results indicated that headways between vehicles inside platoons may be higher during night, and passing decisions are more conservative. This result may be used for future operational and safety analyses.
INTRODUCTION

On two-lane rural roads, traffic volume is usually lower than on multilane roads. However, two lane roads concentrate a higher number of accidents and fatalities (1). Nighttime traffic represents around 20 percent of the total traffic volume in Spain (2) but crash and fatality rates are much higher during night (3,4). Despite the relative importance of nighttime driving, the higher risk and the safety problems that may be associated with this lighting condition, current geometric design guidelines and operational analyses do not usually consider nighttime driving conditions.

This paper focuses on the impact of lighting conditions on following behavior and operating speed on two-lane rural roads. The analysis consisted in a comparison between daytime and nighttime time headways and speeds along a 7 km road segment. Moreover, the influence of no-passing and passing zones was also evaluated.

PREVIOUS WORK

Field data on two-lane roads

Two lane rural roads represent the majority of road networks. On these roads, faster vehicles suffer delays and must pass slower vehicles occupying the opposing lane if they want to travel at their desired speed. This causes a strong interaction with opposing flow, and has important consequences on traffic operation and safety. Passing zones are designed where passing sight distance is enough to perform the maneuver safely. They contribute to reduce the formation of platoons. On the other hand, no-passing zones contribute to platooning and shortened headways.

Past authors collected data to analyze both traffic operation and road safety. Following behavior, passing maneuvers and speeds were considered. Time headways, combined with speed data, have been used as an indirect measure of safety (5, 6). These analyses used the Time to Collision (TTC) and Time Headway (TH) as conflict indicators to predict rear end collisions. Some authors considered time headways under 2 s as unsafe (5). However, traffic operation in rural highways is usually evaluated using the percent of vehicles traveling at headways shorter than 3 seconds, as surrogate measure of the percent-time-spent-following (7). Time headway and speed are easy to measure at different locations using traffic counters. Some authors focused the analysis of time headways in their probabilistic modeling (8,9,10). Most of them conclude that it was necessary to separate a following and a free flow state in order to predict the frequency of a certain headway given traffic conditions. Time headways around 5-7 s were selected as a threshold to distinguish followers and free-flow vehicles (11,12). The size of the headways indicated aggressive driving while the size of the platoons measured the grade of impedance of the traffic, after measuring the speed differences between platooned and free-flow vehicles. Others authors have analyzed the influence of external factors on time headways, such as weather. In some studies, observed time headways were shorter with rain (13) although other studies did not find differences (14).

Passing maneuvers reduce the number of vehicles trapped in platoons. Passing behavior is used to qualitatively describe traffic performance (7). Traffic counters provide data at certain points distributed in the road network but cannot identify passing maneuvers. Alternatively, some authors have analyzed passing behavior based on video recordings (15,16,17). Some of them (15,17) compared vehicle sequences at the
beginning and at the end of a road segment or passing zone and evaluated daytime passing
frequency and average speeds. It was found that balanced flows with two-way traffic
volumes between 600 and 700 veh/h optimized the number of passes (15). However, the
application of these methods is limited to short sections (15, 16) or do not provide
continuous data (17).

**Nighttime driving**

The number of vehicles driven at night represents around 20 percent of the total daily
traffic (2). Moreover, crashes and fatalities are more frequent during night (3,4).

Many of the nighttime traffic studies refer to crash rate analyses. Recent studies
focused on young drivers concluded that they had a significant higher crash risk during
night (3, 18). Lighting on roads was in general associated with lower risk levels (19).

Some authors analyzed the potential causes of the higher nighttime crash rates,
such as the estimation of distance and speeds of vehicles or other objects during night
(20). The judgment of these variables was more difficult, compared to daytime
conditions. Specifically, the estimation of distances to motorbikes or other narrow objects
was even more complex.

Based on driving simulators (21) or in instrumented vehicles (22), other authors
analyzed driver’s speed, acceleration and deceleration choices only in night conditions.
Daytime and nighttime results were not compared, though. Field studies of nighttime
operating speeds on two-way rural roads conclude that there were no differences (23)
between day and night speeds.

The observation of passing maneuvers and gap acceptance revealed differences
between day and night conditions (2,24). In absence of opposing vehicles, drivers passed
slower during night. In presence of opposing vehicle, drivers were more conservative
during night, and passed faster or simply decided not to pass. This would agree with the
difficulties in perception of distances to opposing vehicles. Furthermore, the potential
reduction of passing frequency may result in a reduction of capacity of two-lane road
segments (2).

Other problems related to nighttime driving and identified in the literature were
headlight glare (25) or sleepiness (26).

Even though the safety problems detected in the literature, the headway
distribution during nighttime, which may have both operational (either increase or
reduction on capacity or the level of service) and safety consequences (either increase or
reduction on the frequency of rear-end crashes), has not been studied in the field.
Moreover, there is a lack of knowledge on how the platoons are formed along a very long
no-passing zone during day and night.

**OBJECTIVES**

The aim of this study was to characterize and compare the trajectory of vehicles along a
two-lane road segment during day and night. This knowledge would be useful to analyze
traffic operation under different lighting conditions. Specific objectives were:

- Develop a methodology to observe the trajectories of vehicles on a long road
  segment, based on continuous video recordings in both daytime and nighttime
  conditions.
– Plot space-time diagram with the individual vehicle trajectories along this road segment.
– Analyze and compare daytime and nighttime speeds and headways.
– Analyze the effectiveness of passing zones on the platoon reduction, based on the variation of headways distribution and number of passing maneuvers.

HYPOTHESES
The following hypotheses were formulated:
– During night, time headways between platooned vehicles are longer, because of a different perception of distances and speeds as well as a different risk estimation. This may affect traffic operation, decreasing capacity in comparison with daytime.
– During night, the free-flow speed may be higher. This may be because traffic demand generally decreases and drivers would not expect entering in platoons or suffer delays, choosing higher desired speeds.
– During night, passing ratio may be lower, because the perception of distances to opposing vehicles is more difficult and drivers are more conservative even though they desire to pass. This would discourage drivers performing passing maneuvers, resulting in a capacity reduction. In contrast, opposing vehicle headlights anticipate its approach so the contrary could be observed as well.
– The number of short headways along the no-passing zone may increase, as the vehicles start being trapped on platoons. The effect will be higher during day.
– The number of short headways may decrease after the passing zone, as passing is allowed. The effect will be higher during the day, as passing frequency may be higher.

METHODOLOGY
A 7 km two-lane rural road segment of the CV-13 was selected for this analysis. This road is a two-lane main road in the province of Castellon (Spain) and can be classified as Class I highway (7). Annual Average Daily Traffic (AADT) was 7,133 vehicles/day in 2012 and the percent of heavy vehicles was 38.5 percent. The posted speed limit was 100 km/h for light vehicles, while heavy vehicles had 90 km/h speed limit, according to the Spanish highway code.

Grade along the road segment is between - 3.5 percent and + 1.4 percent in the analyzed direction. The cross section has 3.5 m width lanes, and paved shoulders at both sides. Passing was not allowed on the first 4.2 km in the direction of increasing stations, while passing was allowed on the opposite direction using a climbing lane. As one of the objectives was to evaluate the platoon formation, only one travel direction was considered. The percentage of no-passing zones in the analyzed direction was 69 percent.

As shown in Figure 1, there is no interaction with the opposing flow between stations 4+000 and 8+200, while there are two passing zones between stations 8+200 and 11+000.

The CV-13 is continuously monitored with help of 13 surveillance cameras (6 in the selected 7 km segment), which can register traffic performance along the entire length.
A video camera is installed on a vertical mast every 730-2,200 m. Cameras are placed on the top of the masts at a height between 15-20 m. Operators in the Traffic Management Center adjust focus and zoom of cameras to observe the desired part of the road.

The main purpose of this video surveillance system is traffic and emergency management. However, for this research, the highway authority provided 18 hours of video recordings on two different days in July 2011. Continuous recordings started at 3:00 PM and ended at 12:00 AM. The position of the cameras was fixed during the recording period.

The accurate position of cameras along the road was obtained thanks to field measurements and coordinated GPS and video data collected with an instrumented vehicle (2). Specifically, this provided the location of reference lines observed in video recordings, which were used latter to calculate the speeds.

The analysis of following behavior, speed and passing maneuvers was based on the construction of a space-time diagram with each vehicle traveling along the road. This process required the identification of vehicle sequences in each camera. For each vehicle passing by the first camera, time and vehicle type were registered. The same vehicles were identified in the following cameras so their trajectory was obtained. Timestamps corresponded to the instant at which the front bumper of vehicles (during day) or the headlights (during night) passed by the reference line. Each time stamp at each camera provided the time and space coordinates of every vehicle. The trajectory was obtained by
connecting the points corresponding to the same vehicle. This approximates the actual trajectory of the vehicle by a polygon. A sample space-time diagram is shown in Figure 2.

![Figure 2. Vehicle trajectory using space-time diagram](image)

Between cameras 4 and 8 passing is prohibited and the order of vehicles did not vary. This facilitated following the vehicles in the different cameras during day and night. Between cameras 8 and 9 passing maneuvers are allowed. During day, the same vehicles were identified by their physical characteristics (size, type or color). Comparing vehicle sequences in both cameras, the number of passing maneuvers was computed. During night, only light vehicles passing heavy vehicles were detected, by comparing the sequences of light and heavy vehicles. This assumed that heavy vehicles did not pass any other vehicle, which was actually verified in the daytime observations.

This procedure was used to construct the trajectories on a space-time diagram of up to 200 vehicles daytime (in a 70 min period) and 116 nighttime (in a 50 min period). Corresponding directional hourly traffic volumes were 176 vph during day and 140 vph during night.

Assuming that individual speeds at each camera came for normal distributions, the sample size was adequate to estimate the speed (Equation 1):

\[
n = \frac{Z_{0.95} \cdot s^2}{e^2}
\]

Where:
- \( n \): sample size.
- \( Z_{0.95} = 1.96 \): coefficient for the 95% confidence level.
- \( s^2 \): sample variance.
- \( e \) is the maximum error in the estimation of the mean.
Although some of the variables may not come from normal distributions, this test is less sensitive to non-normality. Using this equation, maximum errors e were lower than 5% of the mean, which justifies the selection of this sample size.

Once space-time diagram was completed, the following variables were obtained:

- Time Headway at camera \(i\) (\(TH_i\)), between front bumper of head vehicle and front bumper of subject vehicle.
- Head vehicle type (\(HeadType\)): light vehicle (L) (passenger car or van) or heavy vehicle (H) (truck).
- Subject vehicle type (\(Type\)): the same code as head vehicle type.
- Subject vehicle average speed between cameras \(i\) and \(i+1\) (\(V_{i,i+1}\)). It was calculated according to the following equation:

\[
V_{i,i+1} = \frac{Position\ (camera\ i + 1) - Position\ (camera\ i)}{Passing\ time\ (camera\ i + 1) - Passing\ time\ (camera\ i)}
\]

Where:

- \(Position\ (camera\ i)\): station of camera \(i\).
- \(Passing\ time\ (camera\ i)\): passing time of the considered vehicle by the reference line of camera \(i\).
- Lighting conditions (\(Lighting\)): daytime and nighttime.

In the analysis, free-flow and following conditions were compared. As there are many different criteria in the literature to determine if a vehicle belongs either to one state or to another, the analysis will compare different headway thresholds. According to this, an additional binary variable has been defined:

- Free flow conditions given the threshold \(X\) (\(FFX\)): yes, if headway > \(X\) and no otherwise.

**ANALYSIS**

The analysis of this study is a day-night comparison of the following variables: distributions of speeds, distributions of time headways and passing maneuvers.

**Speed**

Free flow speeds of light and heavy vehicles were compared between daytime and nighttime conditions. As previously said, the analysis distinguished following and non-following vehicles using different time headway thresholds. As there were no significant differences in the speed among cameras, they are included together in the following analysis.
Figure 3. Daytime and nighttime free-flow operating speeds (FF5 = true)

Figure 3 shows the Box-Whisker plot of the free flow operating speeds of light and heavy vehicles in all the locations of the CV-13. The criterion for selecting free-flow vehicles was a time gap longer than 5 s, although similar results were obtained for 10 and 15 s. This supports that vehicles driving with a headway higher than 5 s are travelling at their desired free-flow speed. Figure 3 shows that light vehicle free-flow speeds present a much higher variability and are, on average, over the 100 km/h posted speed limit. Heavy vehicles speed is lower and concentrated around their 90 km/h speed limit.

Nighttime speeds are slightly higher than the equivalent daytime values. These speeds were compared using non-parametric tests, since data did not come, from normal distributions at the 95 percent confidence level (Chi-square test p-values over 0.05 in most cases). The Kolmogorov-Smirnov test compares the distributions of the two samples (daytime and nighttime). This test is performed by computing the maximum distance between the cumulative distributions of the speeds during both lighting conditions. At the 95 percent confidence level, there were no differences in the speed of light vehicles (p-value = 0.340), and a statistically significant but very small difference between speeds of heavy vehicles (p-value = 0.000). The same results were found when following criterion was 10 and 15 s.

Alternatively, the Mann-Whitney W-test is the nonparametric equivalent to the independent samples single-factor analysis of variance. The test is sensitive to the differences in location (mean or median) between two populations. The median is located at the notch of each box in the graphic. This test is constructed by combining the two samples, sorting the data from smallest to largest, and comparing the average ranks of the
two samples in the combined data. According to this, during night, the median of the heavy vehicles speed was 2 km/h higher than during the day (p-value = 0.000) while there were no differences in the case of light vehicles (p-value = 0.278).

Traveling speeds between camera 4 and 8 (no-passing zone) were also calculated. The variable considered all the vehicles, regardless their type (light or heavy) and the following conditions. The comparison between daytime and nighttime showed that there were no statistically significant differences (W test p-value = 0.650) between both periods (Figure 4). Median of average travel speed was around 91 km/h, both during day and during night. Daytime speeds showed a higher dispersion.

**Figure 4. Daytime and nighttime travel speed**

The results agree with previous work, where no differences between day and night speeds were detected (21).

**Following behavior on the no-passing zone**

The objective of this section is to analyze the differences in time headway between consecutive vehicles during daytime and nighttime on the no-passing zone, where platoons are formed due to the inability to pass. This required dividing the observations between following and non-following conditions. Several headway criteria were considered and the results were similar among them. The 5-second headway criterion is used.

The variable was non-normally distributed (Chi-square test p-values over 0.05 in most cases), so non-parametric test must be used. The Kruskal-Wallis test was used to compare the differences on the median value, and it is identical to the Mann-Whitney W test for comparing more than two populations.

Firstly, Figure 5 shows the differences between daytime and nighttime in following time headway along the road segment from camera 4 to 8 (no-passing zone). Time headways are shorter during day, as the median of time headway (represented by the notch in Box-Whisker plots) was around half second lower than during night. On the other hand, the effect of the no-passing zone was different during day than night. During daytime, the headway distribution was more concentrated as the no-passing zone length increased and the headway mean size decreased 0.5 s. Consequently, the percentage of vehicle trapped in platoons increased and the drivers maintained shorter headways inside the platoons (Kruskal-Wallis test among cameras, p-value = 0.000). Reversely, the
headway distribution during night was similar among the cameras, and the dispersion was higher on the last cameras (Kruskal-Wallis test among cameras, p-value = 0.070), which could indicate that not all the drivers adopted shorter headways as the no-passing zone length increased. Time headways did not decrease so clearly as during the day, which indicate that the nighttime following behavior was more conservative than daytime following behavior.

Figure 5. Daytime (a) and nighttime (b) time headways at cameras 4 to 8 (FF5 = false)

In addition to this, the percentage of following vehicles (using the same 5 s criterion) increased at a different rate. During day, it started at 27 percent of followers (at camera 4) and reached 51 percent (at camera 8). During night, it started at 28 percent and only reached 38 percent, showing a slower platoon formation.
Figure 6. Percentage of headways shorter than 1 s and 2 s over the time headways at each camera (FF5 = false)

Figure 6 shows the percentage of headways under 2 s, described as unsafe headways \((5, 27)\), from the total number of following vehicles. The percentage of headways under 1 or 2 seconds was significantly higher during the day. Assuming the same values of deceleration and reaction times in both daytime and nighttime conditions, a higher safety level would be expected during nighttime. Similarly to Figure 5, the proportion of vehicles that approach the lead vehicle and reduce the time headway along the no-passing zone increased significantly during daytime. This was not observed during night.

On the other hand, differences in time headways depending on the type of the follower and leader vehicle were detected. Figure 7 shows the Box-Whisker plot for each one of the four combinations of light and heavy vehicles as follower and leader vehicle. Only time headways under 5 s were included in this analysis. In general, time headways were longer during night. Non-parametric Mann-Whitney W-test was used to verify the existence of these differences at the 95 percent confidence level. Only when both follower and leader vehicle were light vehicles, the lighting conditions were statistically significant.
On the other hand, the time headway increased significantly if the following vehicle was a heavy vehicle, regardless the leader vehicle type. This might be related either to the lower passing demand of heavy vehicles or to their higher stopping distance requirements.

Besides, if the following vehicle was a light vehicle, the time headway did not vary significantly between lead light and lead heavy vehicles, both in daytime and nighttime conditions. The consequence of this was that time gaps (measured between rear bumper of lead vehicle and front bumper of following vehicle) are shorter between light and heavy vehicles. Time gaps were estimated from time headways assuming mean lengths of lead vehicles (4.5 m light vehicle length and 16.5 m heavy vehicle length) and their actual speed. This resulted in daytime mean time gaps of 0.92 s following a light vehicle and 0.84 s following a heavy vehicle (nighttime values of 1.72 s and 0.64 s respectively).

### Following behavior on the passing zone

As previously said, the analysis scenario is a no-passing zone located between cameras 4 and 8, followed by a two passing zones between cameras 8 and 9. The differences between the headway distribution before and after the passing zones were obtained to quantify the effectiveness of the passing zones in the platoon reduction.

As shown in Figure 8, there is a different time headway variation between cameras 8 and 9, depending on lighting conditions. During day, the median of headways after the two passing zones increased (W test p-value = 0.000), while during night it decreased, being statistically not significant (W test p-value = 0.933). The reason may be that the passing zone effect during day on the reduction of platoons was higher, as drivers performed more passing maneuvers. During night, the effectiveness of passing zone was lower, though. Following vehicles kept on approaching the lead vehicles.
The variation in time headways was also correlated with changes in percent of following vehicles. During day, it decreased from 51 percent (at camera 8) to 36 percent (at camera 9). During night, it increased from 38 percent to 39 percent.

![Daytime and Nighttime Time Headways at Cameras 8 and 9](image)

Figure 8. Daytime (a) and nighttime (b) time headways at cameras 8 and 9 (FF5 = false)

Lastly, the number of passing maneuvers is also related to the effectiveness of passing zones, as they reduce the number of vehicles trapped in platoons. So, the number of passing maneuvers was compared during daytime and nighttime. Due to the limitations of the nighttime analysis, passing maneuvers between light vehicles could not be identified. The results of this comparison showed that nighttime heavy vehicle passing frequency (as number of passes per vehicle) decreased from 23 percent to 14 percent compared to daytime. The same tendency was measured in the passing ratio (as number of passes only per follower vehicle), decreasing from 67 percent to 50 percent. This result explains that the reason of a lower passing frequency is not only the reduction on passing demand, but also that during nighttime more drivers decided not to pass. The results agree with the headway distributions as well as with the variation in percentage of following vehicles. Previous research (2) found a reduction in passing frequency during night too.

CONCLUSIONS
This study observed the trajectory of vehicles along a 7 km two-lane rural road segment. Data obtained by existing video surveillance cameras provided the space-time diagram of 316 vehicles travelling along this road under daytime and nighttime conditions.

This analysis involved the development of a new methodology of data collection and processing. It improved in some aspects existing techniques to evaluate traffic operation on two-lane rural roads. Compared to traffic counters, observed road segment
was much longer and individual trajectories along the entire segment length could be analyzed by identifying the same vehicles by different cameras. Compared to previous video recording to analyze passing maneuver, the new methodology increased also the analyzed length and could be used during night.

The main findings of the analysis are:

1. No differences in free flow speed of light vehicles between daytime and nighttime. In the case of heavy vehicles, this difference was statistically significant, although speeds were only 2 km/h higher during night.
2. In the observed traffic conditions, there is no difference in average travel speeds between daytime and nighttime.
3. Time headways between platooned vehicles are shorter during daytime as the median of time headways were 0.5 s higher in almost all locations during nighttime. During daytime, headways inside platoons tend to decrease with the distance travelled along a no-passing zone. This effect was not observed during night.
4. The proportion of unsafe headways (under 2 s) increased significantly from 15 percent to 35 percent of platooned vehicles along the no-passing zone during day. The magnitude of this effect was much lower during night and the proportion of headways under 2 s was 60 percent of the observed during day. This result contrasts with the general hypothesis of less safe nighttime driving. However, this suggests that, in the analyzed area, the cause of these unsafe nighttime driving would not be related to shorter following headways and, consequently, rear-end crashes.
5. The most significant differences in time headway between daytime and nighttime affected light vehicles following light vehicles.
6. Time gap between light vehicles following heavy vehicles was shorter than time gap between light vehicles following light vehicles, both in daytime and nighttime conditions.
7. The effect of the passing zones was higher during day than night. The headway distribution was more disperse during night, which could indicate that passing behavior was also more disperse and not all the following vehicles carried out a passing maneuver. The number of passing maneuvers involving a heavy impeding vehicle was lower during night, as well as the passing ratio.

These findings suggest important consequences on traffic operation of two-lane rural roads during night. Although freeflow and average speeds seem to be the same during day and night, there were differences in following and passing behavior. During night, more difficult distance estimation, longer reaction and a more conservative behavior may cause longer time headways between platooned vehicles. This agrees with the observed lower passing frequency. As a result, with increasing traffic volumes, capacity and level of service of roads would be affected during night.

Very little research has been carried out in this field and it is not clear whether the guidelines, which are mostly developed for daytime conditions, are also valid during nighttime conditions. The paper explores the differences on free flow speed, platooning and headway distribution during day and nighttime conditions, and it improves the
existing methodologies to evaluate traffic performance during night. We understand that the conclusions of the study are not ready for practitioners and more data should be collected to fully support a modification of the current guidelines, however we consider that the findings of the study are enough to support a review of the guidelines, such as the Highway Safety Manual and Highway Capacity Manual. These results may be also used for additional operational and safety analyses: specific crash causation studies either for daytime or nighttime, or calibration of microsimulation models under different lighting conditions.

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